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Microwave Journal

www.mwjournal.com

European Microwave Week 2007

Munich, Germany

Conference and Exhibition Preview

European Special Report

Training of Young Engineers: A European Overview

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EUROPEAN MICROWAVE WEEK 2007

GUEST EDITORIAL

SPECIAL REPORTS

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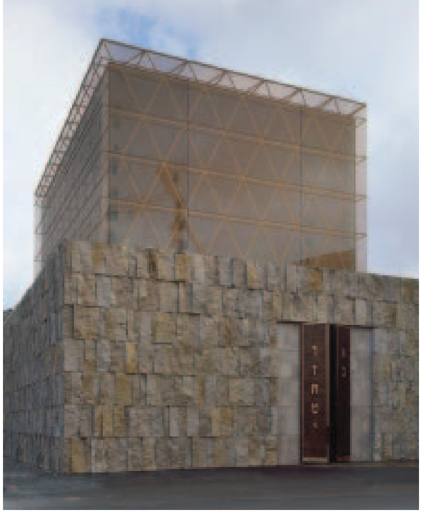
FEATURES

NOTE FROM THE EDITOR

SPECIAL REPORT

TECHNICAL FEATURES

TUTORIALS



FEATURES

PRODUCT FEATURES

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Webinars

RF Fundamentals – *Graphical Design Techniques and the Smith Chart*

Presented by **Besser Associates** and *Microwave Journal*

Live webcast: 9/18/2007, 11:00 AM (EST)

Executive Interviews

Agilent EEsof and **Applied Wave Research** (AWR) each announce new product releases targeting added capability in their circuit EM co-simulation technologies. *Microwave Journal* technical editor, David Vye, talks individually with Agilent EEsof's general manager, Todd Cutler, and AWR's VP of marketing, Sherry Hess, to get a sense of each company's perspective on the circuit/EM co-design market.

Events

WiMAX World, Sept. 25–27
Microwave Journal provides a wrap-up of news, information and product announcements at this year's WiMAX World held in Chicago, IL.

European Microwave Week 2007
Oct. 8–12

EuMW 2007
Munich, Germany

On-line Show Daily: Pre-show coverage featuring product and company news, show reports and interviews begins October 1st.

On-Line Technical Papers

"How a SiP-based Approach to RF Design Will Change the SMT Landscape"
Jim Stratigos, CEO and President, Jacket Micro Devices Inc.

"New Techniques Aid 802.11n and MIMO Testing"
Jim Taber, Product Planner, Real-Time Spectrum Analyzer Group, Tektronix Inc.

"Modern RFID Readers"
Stevan Preradovic and Nemai C. Karmakar, Electrical & Computer Systems Engineering, Monash University

"Ensuring Successful Operation of RFID Tags in Aerospace Asset Tracking"
Emerson & Cuming Microwave Products

Expert Advice

featuring Ask Harlan

Industry expert Harlan Howe has worked in the global microwave industry for over 50 years. To help build an on-line community dedicated to peer-to-peer communication and the exchange of technical information, Harlan monitors the responses and chooses the best answer to the on-line featured microwave-related question of the month. All of the responses to the featured question will be posted on our web site. Now exclusively on-line.

This Month's Question:

Turki Aommran asks–

"I have designed microwave filters with Agilent ADS and the simulation results were perfect, but I have run into a problem with the measured results, which displayed huge differences…"

MICROWAVE INFORMATION IN THE NEXT HALF-CENTURY

DAVID VYE, *Microwave Journal* Editor

As the majority of baby boomers approach 50, perhaps it's time to re-label the term "mid-life crisis." The "crisis" in turning 50 often refers to the looming realization that our existence is finite and the time has come to second-guess some of our choices. However, this generation in particular has a stronger sense of what they want and a willingness to break with tradition. They run marathons, hike, kayak, ski backcountry, mountain bike, travel the globe and start new careers. I personally enjoy that other familiar image of middle age: the silver-templed man or woman driving down the highway in a luxury sports car—top down, wind blowing through their hair (a truly enviable image for us balding boomers).

So what does this have to do with *Microwave Journal*? Well, next year, your beloved *Journal* turns 50 and we intend to celebrate with all the enthusiasm of a vigorous baby boomer. Our magazine will take a look back at where we (the microwave industry) have been and where we are headed (from the perspective of numerous special guest editorials). But before we start this celebration, we have been putting the pedal to the metal of what may be the media equivalent of a fast luxury sports car—the Internet.

In September, the *Microwave Journal* web site will launch a host of new features that will tap into the interactive capabilities of this medium. To start, the *Journal* is partnering with Besser Associates to provide a free webinar series focused on RF/microwave topics. Besser Associates has been providing professional training for decades and is the recognized leader in teaching microwave concepts. This month the instructors discuss RF fundamentals in a 45-minute presentation and 15-minute question and answer session. We look forward to this series of active and informative webinars, along with additional webinars from leading microwave component, software and service providers.

Other new web features include monthly interviews with executives and company technologists, more product highlights, and an expansion of the content and functionality of our resources section, including the Buyer's Guide and Vendor Views. To kick-off the interview series, we talk individually to the executives of two leading RF circuit design companies, both of whom have an eye toward enhancing the state of EM/circuit co-design as summarized in their product features running in this month's magazine. Our on-line interviews compliment these articles with added depth and executive perspective.

Starting this month, we expand the number of featured exclusive technical articles and white papers posted on-line. The increase reflects the growing quantity of high-quality technical material that is being submitted to the *Journal*'s editorial board. The web allows us to deliver more content than ever before. In the coming months, our web team will launch a new web-exclusive technical article library archive with excellent search and article referral capabilities. Many of our more observant readers will notice the "Ask Harlan" feature to be missing from this month's magazine. Our Expert Advice column is now exclusive to our web site. In the near future, look for this feature to expand in a way that only an on-line community could.

Finally, the *Microwave Journal* web site will cover the 2007 European Microwave Week (EuMW) with its On-line News Service. In the run up to EuMW the On-line News Service Web Page will offer a guide to Europe's premier microwave, RF, wireless and radar event. It will contain essential information on the four conferences, the European Microwave Exhibition and organized social events, together with a visitors guide to Munich. Through *Exhibitor Perspectives* exhibitors will share their views on EuMW and the microwave industry in general. Exclusive interviews with the conference chairpersons are also highlighted. During the week of the show (October 7th to 13th) the editorial team will provide daily updates from the show floor, including up-to-the-minute news, new product announcements, promotions, etc. After the show concludes the whole Week will be reviewed, highlighting key events, major product announcements and follow up on ongoing stories.

The *Microwave Journal* web site is an invaluable resource for microwave professionals who prefer the convenience and 24/7 readiness of the Internet. As our staff prepares for our 50th year in publication, we are leveraging the capabilities of electronic media to extend our delivery of microwave-centric content beyond what is possible through print alone. While the web cannot fully replace the thrill and practicality that comes with receiving your monthly print edition of *Microwave Journal*, we are confident that our readers will come to rely on the *Journal*'s web site for additional insight into and interaction with the microwave community. Through a combination of print (monthly and special edition supplements), electronic media (web site and e-Newsletters) and live events (industry trade shows and sponsored workshops), *Microwave Journal* is ready to keep you informed for the next 50 years and beyond. Welcome to our mid-life renaissance. ■

CALL FOR PAPERS

IEEE MTT-S International Microwave Symposium 2008
by December 7, 2007

SEPTEMBER

IEEE International Conference on Ultra-WideBand (ICUWB 2007)
September 24–26, 2007 • Singapore
www.icuwb2007.org

WiMAX World USA 2007
September 25–27, 2007 • Chicago, IL
www.wimaxworld.com

Antenna Systems and Short-range Wireless 2007
September 26–27, 2007 • Denver, CO
www.antennasonline.com

OCTOBER

COMSOL Conference 2007
October 4–6, 2007 • Newton, MA
http://comsol.com/conference2007/

European Microwave Week (EuMW 2007)
October 8–12, 2007 • Munich, Germany
www.eumweek.com

AOC International Symposium and Convention
October 28–November 1, 2007 • Orlando, FL
www.crows.org

Military Communications Conference (MILCOM 2007)
October 29–31, 2007 • Orlando, FL
www.milcom.org

NOVEMBER

Antenna Measurement Techniques Association (AMTA 2007)
November 4–9, 2007 • St. Louis, MO
www.amta2007.com

2nd European Conference on Antennas and Propagation (EuCAP 2007)
November 11–16, 2007 • Edinburgh, UK
www.eucap2007.org

ARFTG 70th Microwave Measurement Symposium
November 27–30, 2007 • Tempe, AZ
www.arftg.org

DECEMBER

Asia-Pacific Microwave Conference (APMC 2007)
December 11–14, 2007 • Bangkok, Thailand
www.apmc2007.org

JANUARY

IEEE MEMS 2008 Conference
January 13–17, 2008 • Tucson, AZ
www.mems2008.org

IEEE Radio and Wireless Symposium (incorporating WAMICON)
January 22–24, 2008 • Orlando, FL
www.radiowireless.org

WCA International Symposium and Business Expo
January 29–February 1, 2008 • San Jose, CA
www.wcai.com

FEBRUARY

International Solid-state Circuits Conference
February 3–8, 2008 • San Francisco, CA
www.isscc.org

Satellite 2008 Conference and Exhibition
February 25–28, 2008 • Washington, DC
www.satellite2008.com

JUNE

IEEE MTT-S International Microwave Symposium and Exhibition (IMS 2008)
June 15–20, 2008 • Atlanta, GA
www.ims2008.org

Workshops & Courses

'First-pass System Success' Application Workshops

■ **Topics:** Ansoft's 'First-pass System Success' application workshops for high performance design will provide a platform for leading technology companies and Ansoft's technical staff to collaborate and discuss the latest simulation techniques and design methodologies to help engineers achieve first-pass system success when designing electronic systems.
■ **Sites:** Asia, North America and Europe
■ **Dates:** September 11–November 15, 2007
■ **Contact:** For more information, visit www.ansoft.com/firstpass/.

OPERA-3d Software: Introductory Training Course

■ **Topics:** The OPERA-3d three-day course provides the user with structured guidance in 3D design, including the analysis programs TOSCA, ELEKTRA, SCALA, CARMEN and TEMPO. Theoretical aspects are covered in sufficient depth to allow accurate use of the programs for the users' own designs, while "hands on" example models illustrate the rich variety of model creation tools and their efficient use.
■ **Site:** Oxford, UK
■ **Dates:** October 8–10, 2007
■ **Contact:** For more information, visit www.vectorfields.com.

Far-field, Anechoic Chamber, Compact and Near-field Antenna Measurements

■ **Topics:** This course presents the state-of-the-art in antenna measurements, including far-field, anechoic chamber, compact and near-field measurements. The course also includes range evaluation, compensation techniques and microwave holography. For more information, visit www.pe.gatech.edu.
■ **Site:** Atlanta, GA
■ **Dates:** October 22–26, 2007
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

2007 Power Seminars

■ **Topics:** Fairchild is The Power Franchise® and its power experts will provide the latest in design techniques for optimizing system power with analog, discrete and optoelectronic solutions at these one-day events. The 2007 Power Seminar technical sessions include: low cost, isolated current source for LED strings, design considerations of LLC resonant converters and application review and comparative evaluation of low side MOSFET drivers. For more information, visit www.fairchildsemi.com/powerseminar07/.
■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** Fairchild Semiconductor Corp., 82 Running Hill Road, South Portland, ME 04106 (207) 775-8100, www.fairchildsemi.com.

The Entrepreneurial Engineer

■ **Topics:** This short course is an efficient and memorable introduction to the personal, interpersonal, business and organizational skills necessary to help engineers of applied science and mathematics perform at high levels in today's increasingly opportunistic organizations and enterprises. For more information, visit http://online.engr.uiuc.edu/shortcourses/tee/index.html.
■ **Site:** Archived on-line course.
■ **Dates:** Archived on-line for anytime viewing.
■ **Contact:** University of Illinois at Urbana-Champaign, 117 Transportation Bldg., 104 S. Mathews Avenue, Urbana, IL 61801 (217) 333-0897 or e-mail: deg@uiuc.edu.

PCB Design Techniques for EMC and Signal Integrity

■ **Topics:** This course will assist practicing engineers who are responsible for PCB designs and system-level products. Disciplines include PCB layout, logic design, regulatory compliance and EMC. For more information, visit http://epdwww.engr.wisc.edu.
■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** University of Wisconsin, Department of Engineering Professional Development, 432 North Lake Street, Madison, WI 53706 (800) 462-0876.

Welcome to European Microwave Week 2007

Willkommen in München, for the 10th European Microwave Week. Join us at the city's ICM Congress Centre from 8 to 12 October to celebrate both EuMW's first decade and the RF and microwave industry's endeavours and achievements. The city that hosts the world famous Oktoberfest knows how to organise an event and so do the European Microwave Association (EuMA) and Horizon House Publications Inc., as witnessed by the fact that EuMW continues to grow in content and stature. The four conferences are focussed and challenging, while the ever-growing European Microwave Exhibition offers valuable access to and interaction with an international line-up of key players in the industry.

Europe's premier RF and microwave event is benefiting from the globalisation of the RF and microwave industry with the US, Asia and Eastern European states having an increasingly significant presence and influence on both the conference content and the exhibition. In particular, EuMA sets great store in its newly established cooperation with the Asia-Pacific Microwave Conference.

Not only has the geographical reach of EuMW expanded since Munich last played host in 2003, but so too have the conferences. Since the addition of EuRAD in 2004 there are now four distinct, yet complementary conferences: the 37th European Microwave Conference (EuMC), the European Microwave Integrated Circuits Conference (EuMIC), the 10th European Conference on Wireless Technology (ECWT) and the European Radar Conference (EuRAD). Papers on the latest innovations, panel sessions and addresses by invited speakers have been carefully selected to stimulate interest and debate.

As the scientific programme has strengthened so too has the realisation that new technologies and developments must be commercially viable and have true value in the real world. At EuMW this is acknowledged through the increase in the number of papers submitted and accepted from the industrial sector, which is reinforced by the industry's continued and strong support of the three-day European Microwave Exhibition.

As the largest trade show dedicated to RF and microwaves in Europe, EuMW acts as an interactive forum for microwave companies, large and not so large, to showcase and discuss the latest technical developments. The exhibition has attracted key players worldwide who will spotlight their latest ranges, provide demonstrations and dispense technical advice.

Wolfgang Heinrich
General Chairman, EuMW 2007
Ivar Bazzy
Horizon House Publications Inc.

It has also established itself as the stage that manufacturers target for launching new products.

The exhibition continues to increase its international reputation and attract significant numbers from the US, together with the rapidly growing Asian market. For those wanting to get hands-on experience and guidance direct from the experts there are also workshops and short courses on various subjects. New in 2007 are tutorial seminars for young engineers aimed at stimulating and encouraging the next generation.

All ages are encouraged to mix business and pleasure through the rich calendar of social events that have been organised throughout the week. Highlights include the EuMW Welcome Reception that has now become synonymous with the event as it encourages interaction between academia and industry. There is also an invited reception by the Bavarian State Government at the Munich Residenz. Alongside, there are other social and tourist events throughout the week including the chance to sample the unique atmosphere of Oktoberfest.

From cyber cafés to conference sessions and exhibition stands to excursions every effort has been made to offer the best possible event. On behalf of the Local Organising Committee we would like to thank the four international Technical Programme Committees and the reviewers who worked tirelessly to shape the conference programmes. We would like to acknowledge the EuMA Board for its continued advice and guidance and we wish to thank Horizon House personnel assigned to EuMW for their invaluable support in organising this major international event, as well as their contribution to the staging of a world-class exhibition. Last but not least, we acknowledge the financial and in-kind sponsorship of many industrial enterprises and other organisations.

Thanks to their efforts the 10th European Microwave Week promises to commemorate and celebrate the past, while looking forward and heralding the future. Join us to discover just how far EuMW and the RF and microwave industry have advanced over the last decade and its intentions for the next 10 years. ■

ATTENDING EUROPEAN MICROWAVE WEEK 2007

Munich is central to the European RF and microwave industry geographically, as it is within easy reach of all major European markets, and commercially, as the city and surrounding region is a hub for companies active in the industry. For one week in October (Monday 8 to Friday 12) it will also take centre stage as the Munich International Congress Centre (ICM) plays host to the *10th European Microwave Week*.

To mark its first decade Europe's premier RF and microwave event intends to celebrate the industry's camaraderie, endeavour and achievements, while focussing on the efforts needed to further technological and commercial development and take the industry forward. As testament to how far the event has progressed over the last decade, this year, for the third year running, there were more than 1000 paper submissions, enabling the Technical Program Committees (TPC) to fashion a high level program, with 464 oral papers and 155 poster presentations, complemented by a wide range of workshops and short courses.

In all aspects the aim of EuMW is to provide high quality to the 4000 plus attendees—comprising delegates, exhibitors and visitors—that are expected to attend. As an international showcase for leading manufacturers in the RF, microwave, integrated circuit, wireless and radar industries, the week provides an invaluable platform for the presentation and introduction of the latest technological developments and a forum for discussing the latest trends and exchanging scientific and technical information.

That is particularly true of the *European Microwave Exhibition*, which has made its presence felt over recent years and established itself as the premier RF and microwave trade show in Europe. This year has seen continued expansion with the exhibition attracting more than 270 exhibitors from around the world, including North America, a significant Asian contingent and increased participation from Eastern Europe. Over the three days—9 to 11 October—visitors will be able to discover products launched onto the international stage for the very first time, discuss specific areas of interest with development engineers and find the right products for their particular needs.

The official European Microwave Week opening ceremony on Tuesday morning is open to all conference delegates, while the *EuMW Welcome Reception* (see Social Events), later that evening, continues to be a highlight of the week, providing good food, drink and the opportunity for academia and industry to network, debate and socialise.

This mix of conferences and trade exhibition, academic and industrial, offers attendees opportunities for networking, exchanging ideas and, of course, for doing business. However, EuMW is not all work and social events have been organised to enable visitors to savour and experience the sights of Munich.

To help you to plan your visit the following quick reference guide is designed to complement the Conference Programme and Exhibition Catalogue, where you will find more detailed information.

THE CONFERENCES

The four conferences and associated workshops and short courses run on specific days throughout the week and are scheduled as follows:

RICHARD MUMFORD
Microwave Journal *European Editor*

- The 37th European Microwave Conference (EuMC 2007) runs from Monday 8 through to Friday 12 October
- The European Conference on Wireless Technology (ECWT) takes place on Monday 8 through to Wednesday 10 October
- The 2nd European Microwave Integrated Circuits Conference (EuMIC) runs from Monday 8 through to Wednesday 10 October
- The European Radar Conference (EuRAD 2007) ends the week from Wednesday 10 to Friday 12 October

Registration is sponsored by Rohde & Schwarz and begins on site on Sunday 7 October (16.00 to 19.00), then commences at 07.30 each morning from Monday 8 to Friday 12. The registration area and delegate bag collection are located in the Main Foyer of ICM.

Delegates should register for one, two, three or all four of the conferences. Those who wish to register for two or more conferences will receive a discount on these registrations. A new introduction this year is the *One Day Conference Ticket*, which offers the flexibility of paying one fee for the ability to attend all conferences on that specified day.

THE EUROPEAN MICROWAVE CONFERENCE

There were a high number of submissions received from all over the world, but this year, through critical selection, there will be fewer sessions than in previous conferences, while maintaining the delivery of a high quality and comprehensive technical programme.

The conference is dedicated to a broad range of high frequency related topics, from materials and technologies to integrated circuits, systems and applications. It is the perfect platform for keeping up to date with recent achievements in the RF, microwave and millimetre-wave domain, and an exciting forum for the presentation and discussion of the most recent advances in the microwave arena. This year large numbers of papers were submitted, particularly on the topics of filters, antennas, power amplifiers and linearisers, microwave measurement/characterisation techniques, metamaterials/photonic bandgap structures and devices, tuneable RF components and reconfigurable systems as well as RF MEMS.

The EuMC will consist of three poster sessions and 66 regular oral sessions, where 22 of them are joint sessions with the associated conferences, EuMIC, ECWT and EuRAD. This large number was a particular aim, in accordance with the EuMW concept of integrating the four conferences and uniting their respective communities. In addition, there are various workshops designed to encourage technical exchanges on specific topics in the microwave arena.

PRIZES AND AWARDS

The €5000 *EuMC Microwave Prize* will be given in recognition of the best contributed paper, while the EADS sponsored *Young Engineer Prize* of €4000 will be awarded to the young engineer judged to have submitted and presented an outstanding paper at the conference.

EUMIC

This conference is the successor to the well-known GAAS® symposium, which was renamed last year and is held under the umbrella of both the European Microwave Association and the GAAS® Association. The 2007 technical program includes more than 100 technical papers and is made up of contributions from all over the world. In particular the large number of papers submitted from the Far East demonstrates the global importance of this European event.

The papers are distributed over more than 20 sessions all scheduled for Monday and Tuesday of European Microwave Week. A significant number of sessions are planned as joint sessions with the European Microwave Conference and the European Conference on Wireless Technology, demonstrating the strong link between these conferences and allowing participants to get a flavour of the topics presented throughout the week. The program will be completed by two invited talks in the plenary session, several workshops and short courses.

PRIZES AND AWARDS

To acknowledge the high quality of papers presented at EuMIC, a Best Paper Prize and a Best Student Paper prize will be awarded. In addition, the GAAS® Association will be presenting these winners with a plaque commemorating their achievements and will also provide three additional student fellowships.

ECWT 2007

As the premier European forum for wireless technology the conference encompasses all aspects of technology for wireless systems, including applications and standards, systems and signal processing, antennas and propagation, and key technologies and subsystems for base stations and terminals.

Co-sponsored by EuMA and the IEEE MTT Society, ECWT is primarily focused on wireless technology, which was once synonymous with mobile phone systems but has developed much further in recent years, with advances in technology being the enabling force behind many innovations in communications using microwave and mm-wave signals.

This year's conference has grown to accommodate these new concepts and the TPC has produced a top class technical program. Joint sessions with the European Microwave Conference and the European Microwave Integrated Circuits Conference give delegates an intensive update on all of the new developments in this industry.

EUROPEAN RADAR CONFERENCE

Now in its 4th year, EuRAD presents a selection of peer reviewed technical papers as well as focussed sessions with invited papers on highly relevant technical topics. From 110 submitted papers the TPC has put together a conference programme of excellent quality and general interest. A total of 18 sessions, including two invited sessions and four joint sessions, which are organised in cooperation with the European Microwave Conference, will give a wide overview of the most recent advances in the radar field.

The conference programme consists of 65 oral presentations and 17 poster papers. Contributions have been received from authors from around the world, covering a wide scope of topics from broadband radar, sophisticated radar signal and data processing, including STAP to SAR interferometry and imaging, both from a scientific as well as from an application-related perspective. A special attraction is the focussed sessions, which are on the topics of millimetre-wave imaging, communication by radar, broadband radar and short-range automotive sensing. Also, five invited papers on subjects of current interest will be highlights of the opening and closing sessions.

PRIZES AND AWARDS

Two EuMA Radar Awards sponsored by Raytheon will be presented. The *Radar Prize* of €3000 is awarded to the paper that best advances the state-of-the-art in radar and the *Young Engineer Prize* of €2000 goes to a young engineer or researcher who has presented an outstanding paper at the conference.

THE EXHIBITION

This free to enter exhibition is the largest trade show dedicated to RF and microwaves in Europe. It is central to EuMW in terms of content and timing, as it spans the middle three days of EuMW—9 to 11 October. For those three days the exhibition, located in the Foyer and Hall B0 of the ICM, becomes the hub of the event, housing the conference coffee breaks, poster sessions and hosting the ever popular and invaluable Cyber Café sponsored by CST.

The exhibition is a vibrant shop window for companies large and small, established and developing from Europe, North America, Asia and beyond, to showcase their products and expertise. To find out just who these companies are see the latest exhibitor list, starting on page 58. The exhibition is established as an essential stage for manufacturers to launch new products and this year is no exception with leading players specifically targeting the show to make important product announcements.

Promoting the strength and development of regional clusters, specific focussed sectors include a German Pavilion and a French Pavilion. Alongside, the largest number of workshops ever offered at the event will provide the opportunity for visitors to gain hands-on experience.

This year too, for the first time ever, there is a significant new innovation with the introduction of *Tutorial Seminars for Young Engineers*, which are structured to provide vital educational input to the next generation. Planned to continue at EuMW in the coming years, the seminars are an investment in the RF and microwave industry's future and aim to help young engineers along their chosen career paths.

Exhibition Hours

Tuesday 9 October: 09.30 to 17.30 (followed by the Welcome Reception)
Wednesday 10 October: 09.30 to 17.30
Thursday 11 October: 09.30 to 16.30

GETTING TO THE ICM

The conference and exhibition centre is located to the east of Munich and has excellent road, rail and underground (U-Bahn) links. It is conveniently located near Munich Airport, being approximately 30 km away. By public transport, the journey is firstly on the urban railway (S-Bahn) lines S1 and S8, changing onto line U2, which will take you directly to the ICM at exit 'Messestadt West'.

From the airport, trains depart for downtown Munich every 10 minutes. Taking one of the city's 3500 taxis is a convenient way to travel from the airport to the ICM. The one-way trip takes approximately 45 minutes, depending on traffic, and costs around €70. For more information regarding public transport in Munich, visit: www.mvv-muenchen.de/en/.

SIGHTSEEING

Beautiful downtown Munich, which preserves much of the medieval character of the city, while combining it with elegant modern stores, is only 20 minutes from the ICM by the underground route U2. Therefore, it is convenient to book a hotel in the centre of Munich, but be aware that the Oktoberfest only ends on the Sunday (7 October) before European Microwave Week.

Theatres, museums and galleries as well as many other places of general interest including the Philharmonic Hall, the National Theatre, the Munich Residence and the remarkable Deutsches Museum are close to the city centre and many other points of interest, such as fountains, churches and traditional restaurants are within walking distance. Other sites such as the Nymphenburg Castle are conveniently accessible using the public transportation system.

HOTEL RESERVATIONS

If you require hotel accommodations during your stay in Munich, the Hotelzon Resotel hotel-booking agency makes reservations at reduced rates in various 2, 3, 4 and 5 star hotels, free of charge. For more information contact either Hotelzon Resotel: Tel: +44 (0) 1962 834464 or check out the EuMW2007 web site: www.eumweek.com under accommodation.

SOCIAL EVENTS

The *EuMW 2007 Welcome Reception*, on Tuesday 9 October, has become more than just a social event and is where academia and industry are offered the unique opportunity to network and interact. All registered conference delegates from all four conferences, as well as representatives from the companies participating in the exhibition are invited to this Agilent Technologies, EuMA and Horizon House Publications sponsored event.

The evening will begin with a champagne drinks reception at 18.00 in the first floor foyer of the ICM, followed at 19.00 by an address by Platinum sponsor Agilent Technologies and announcement of the winners of the Grand Prize Draw. The reception continues with an Italian-Bavarian buffet and the chance to combine good food, drink and conversation.

The following evening, Wednesday 10 October, there is a reception by invitation of the Bavarian State Government at the Munich Residenz. The 'Kaisersaal' of this magnificent building in the centre of the city will play host to the guests from 19.00.

During the week excursions have been organised to enable visitors to sample the sights that Munich and the surrounding area have to offer, including the chance to sample the unique atmosphere of the Oktoberfest on Sunday 7 October.

GENERAL INFORMATION

In advance, take time to familiarise yourself with the event and plan your visit by logging onto the show web site: www.eumweek.com. ■

MUNICH: EMBRACING THE ANCIENT AND MODERN

Munich is renowned for being both traditional and forward thinking and blending the age-old Bavarian style of life with modern high-tech, making this metropolis at the edge of the Alps an intriguing area to visit. For RF and microwave engineers the city and surrounding region is a major contributor to their industry, with excellent universities and numerous high-tech companies such as Siemens, Infineon, EADS, BMW and, of course, Rohde & Schwarz, that are continuously redefining the limits of technology.

The local belief in progress paired with a sense of tradition is expressed in Munich's image and lifestyle. To give you a flavour of the city I will endeavour to showcase the sights and experiences that Munich has to offer beyond the usual tourist spots. Much has changed since the city last hosted European Microwave Week (EuMW) in 2003. Therefore, I will focus on some exciting new projects, culinary musts and exclusive shopping opportunities that have dramatically changed the city over the last few years, as the love for tradition has been matched by the quest for progress.

However, there is one thing you should never forget: no matter how progressive Munich may be, time-honoured and age-old customs such as the city's numerous beer gardens are waiting around every corner. If you allow yourself to get caught up in the atmosphere you will find yourself swept away by the magic of the city on the Isar.

THE OUTSKIRTS OF MUNICH

Most EuMW visitors will arrive at the airport and the easiest means of transport to the town centre is the S-Bahn (local train). If you take a taxi from the airport you will soon see an architectural highlight of modern Munich. Directly off an interchange on the A9 highway is the *Allianz Arena*, which looks like an oversized, illuminated rubber boat with a honeycomb-like facade of giant air pillows. Since 2005, this ultramodern stadium has been the home of the two local soccer teams, FC Bay-

PATRIZIA MÜHLBAUER
Rohde & Schwarz
Munich, Germany

ern and TSV 1860, and more famously was the venue for the opening game of the FIFA 2006 World Cup. The three stands of the stadium can hold more than 69,000 spectators.

Further towards the city, you will come to the *Münchner Tor* (Munich Gate), which marks the end of the interstate between Berlin and Munich. It is the site of a brand-new city district named *Parkstadt Schwabing* that has been created over the past few years. It features office buildings, apartments and parks, and renowned companies have already established themselves there. The dominant sight is HighLight Towers, two slim towers designed by the famous architect, Helmut Jahn.

Even though it says so in the name, not quite so new is the Munich International Congress Centre (ICM) of the New Trade Fair in Riem, where EuMW 2007 is being held. Located on the premises of the former Munich Riem Airport—where busy air traffic was the order of the day until 1992—an ecology-oriented municipal construction concept was brought to life recently. This concept includes the new park, *Landschaftspark Riem*, which was created for the National Garden Show in 2005. It features linear and geometric shapes with groves, hedges, individual trees, natural meadows and a man-made lake for swimming. It is just the place to relax between conference sessions.

AFTER HOURS

After a busy day at European Microwave Week, everyone deserves some relaxation time and the first stop should be the Old Town or Altstadt, which is only 20 minutes from the ICM on the subway. *Marienplatz* is the traditional heart of the city, featuring the main historic sites: the Mariensäule, a column with a statue of the Virgin Mary, the Altes and Neues Rathaus, the old and new city halls, the world-famous Glockenspiel, with its clockwork chimes and dancing statues, the Frauenkirche, a late-gothic Cathedral of Our Lady, with its unmistakable double towers, and Peterskirche or St. Peter's Church, which is Munich's oldest church, recognisable by its characteristic clock tower.

Theatinerkirche/Odeonsplatz (photographer: Christl Reiter, TAM MUC).

Only a block or so away, there is the *Viktualienmarkt*, a rare smorgasbord of stalls and shops offering fresh fruit and vegetables, sausage, cheese, baked goods, and other local and international specialties. Nearby, the contrast between the old and new is nowhere more evident and intense than in the *Schrannenhalle*.

Built in the mid-1800s as a wrought-iron trading centre for grain, it was gradually dismantled between 1914 and 1932. It has now been rebuilt from original materials and architecturally expanded—as a modern structure, of course, and reopened in 2005. Inside are a number of eateries as well as bars and clubs, making it an ideal location for an enjoyable evening after a hard day's work.

The building at the front entrance of the Schrannenhalle is home to *Der Pschorr*, a restaurant specializing in Bavarian dishes. It is especially known for its old-style draught Bavarian beer, served directly from a wooden keg that has been cooled on slabs of ice.

Another attraction that has become a cultural institution downtown is the new Jewish Centre on St. Jakobsplatz. It was opened in 2006 and is a complex of buildings that includes one of the largest new synagogues in Europe, the Jewish Community Centre and the Jewish Museum. Featuring outstanding architecture, the Centre is located in the heart of the city between the Viktualienmarkt and

Technology Centre of Rohde & Schwarz.

Sendlinger Straße. The various exhibitions at the museum include a permanent exhibition on Jewish history and culture in Munich.

Just a couple of blocks away, Munich's nightlife district is centred around *Gärtnerplatz* and the *Glockenbachviertel*. This area is full of bars, pubs, cafés and restaurants renowned for their innovation. A good example is Essneun on Hans-Sachs-Straße, a restaurant with a cool design that serves a constantly changing menu of unusual dishes such as mustard miso kangaroo on bean cream. During the day, the area is well worth a visit too for a stroll up and down the streets to see the numerous small boutiques and designer businesses with their eye-catching products on display.

For elegant shopping, the place to go is *Maximiliansstraße*, where one shop after the other carries the name of a world-famous fashion designer. The *Maximilianshöfe*, completed in 2003, closed a once-gaping hole in the luxury shopping mile located behind the National Theatre. In addition to exclusive shopping, this 'courtyard' offers excellent dining. The *Brenner Operngrill* is housed in a historic portico that serves as the foundation of a cubic, glass-panelled building. The Mediterranean dishes are prepared on an open grill centred beneath the portico arches.

River Isar near Flaucher (photographer: Josef Wildgruber, TAM MUC).

Frauenkirche and skyscraper (photographer: Heinz Gebhardt, TAM MUC).

One of the most elegant shopping arcades in Munich is *Fünf Höfe*, which was created by radically redesigning an entire old-town block along Theatinerstraße. This prize-winning complex consists of five interconnected courts, each with its own character. Vines hanging from the sky like suspended gardens and tunnel-like, mosaic-decorated passageways imbue the complex with a charm of its own. Among the numerous smart shops there is one branch of the Japanese lifestyle chain Muji, known for its minimalistic design. The *HypoKunsthalle* is an art centre in the complex that regularly stages changing retrospectives and exhibitions of works by important artists.

The contrast between historic and modern construction could hardly be more apparent than in the *Alter Hof*, the recently renovated site of the former imperial residence of Ludwig of Bavaria and the exact spot where the origins of Munich once lay. A castle complex, dating from the 12th century, originally stood here. The only structures remaining are the gate

New synagogue (photographer: Roland Halbe).

Allianz Arena (photo: Allianz Arena München Stadion GmbH).

tower of the former imperial residence and the gothic oriel, also known as the ‘monkey turret’. Legend has it that a court monkey once held the little Ludwig captive on the spire of the turret. This structure is joined by new residential and business buildings, which were opened in 2006.

The Alter Hof is also home to a branch of *Manufactum*, which offers a wide range of household goods, furnishings, cosmetics, groceries and much more. The company slogan proudly states: “The good things in life still exist.” At *Vinorant* next door, you can enjoy creative local cooking and Bavarian wines from the Franconian region.

Beyond the Old Town, you will find Olympiapark (subway station: Olympiazentrum), the architectural masterpiece that was home to the 1972 Summer Olympics. Right next door is BMW Welt (BMW World), where the curved facade of the new Delivery Centre and Event Forum complements the distinctive silhouette of the company’s headquarters that was built in the 1970s in the shape of a four-cylinder engine. However, it is not scheduled to open until the end of October, so it may be a sight to see the next time EuMW comes to Munich.

GETTING AROUND

The best way to discover Munich is by foot or by the extensive public transport system, which is zone-based, and most places of interest are within the inner city zone. Tickets come in short-trip, daily and weekly varieties, and are valid for the S-Bahn, U-Bahn, trams and buses; just stamp your ticket as you enter the station and hop aboard. You can buy tickets from vending machines at stations, bus stops and newspaper kiosks.

If you like to exercise while sightseeing then Munich is one of the ‘bike friendliest’ cities in Europe with more than 700 km of cycle paths. If you want you can join a guided tour of the inner city. Visit www.spurwechsel-munich.de for more information.

FIND OUT MORE

If you are interested in visiting any of the sights, restaurants, bars and shops you have just read about, here is a list of contact details, either web links or addresses and telephone numbers. Following that is a selection of restaurants, beer gardens, cafés, bars and clubs to whet your appetite as to what Munich has to offer. Addresses and phone numbers are given, but if calling from outside Germany use the International Dialling Code: +49 and omit the first zero. In Munich the city code 089 is not required.

Allianz Arena

www.allianz-arena.de
Schrannenhalle
Tel: 089-5181818
www.schrannenhalle.de

Der Pschorr

Viktualienmarkt 15
Tel: 089-518185-00
www.derpschorr.de

Jewish Museum

St. Jakobs-Platz 16
Tel: 089-23396096
www.juedisches-museum.muenchen.de

Hans-Sachs-Straße

Tel: 089-23230935
www.essneun.com

Brenner Operngrill

Maximiliansstr. 15
Tel: 089-4522880
www.brennergrill.de

Muji

Tel: 089-224412
www.muji.de

HypoKunsthalle

Theatinerstraße 8
Tel: 089-224412
www.hypo-kunsthalle.de

Alter Hof

Tel: 089-24243733
www.alter-hof-muenchen.de

Manufactum

Dienerstr. 12
Tel: 089-23545900
www.manufactum.de

RESTAURANTS

UPPER CLASS

Nektar

It is a mecca for colourful personalities looking for inspiration as to the latest trends in kitchen, art, fashion and music.

Stubenvollstr. 1
Tel: 089-45911311

Schuhbeck in den Südtiroler Stuben

In this castle-like atmosphere replete with stucco, woodwork, comfortable chairs and beautiful fabrics, master chef Alfons Schuhbeck serves seasonal Bavarian cuisine for gourmets.

Platzl
Tel: 089-2166900

Acquarello

First class Italian food.

Mühlbaurstr. 36
Tel: 089-4704848

MIDDLE CLASS

Zerwirk

Being vegan is made easy at Munich's most famous vegetarian restaurant, which also doubles as a club. It's full of history, being one of the oldest buildings in the city.

Ledererstrasse 3
Tel: 089-23239195

Sushi Duke

The sushi masters here conjure up dishes to individual tastes and in the true spirit of Asian courtesy; the guest is treated like a king.

Platzl 3
Tel: 089-22807500

Weinhaus Neuner

In Munich's oldest wine-house guests can enjoy culinary delicacies and exquisite wines.

Herzogspitalstr.
Tel: 089-2603954

MUNICH CLASS

Franziskaner

A traditional restaurant with fine Bavarian cuisine and its own freshly brewed beer.

Perusastr. 5
Tel: 089-2318120

Hofer – der Stadtwirt

Situated in Munich's oldest townhouse (1551/1552) right in the centre of the city.

Burgstr. 5
Tel: 089-24210444

Beer Gardens

These traditional open-air eateries are open not only in summer, but also on nice autumn afternoons.

Hirschgarten

Munich's oldest and largest beer garden is situated near Nymphenburg palace right next to a deer-enclosure.

Hirschgarten 1
Tel: 089-172591

Chinesischer Turm

Enjoy a cool beer while listening to kettledrums and trumpets. This multicultural rendezvous is located in the heart of the English Garden.

Englischer Garten 3 • Tel: 089-38387320

Café

Tambosi

A traditional café situated directly at the Hofgarten. If you can snare one of the many coveted tables in the sun, you can while away the afternoon enjoying the view. Inside, you will find an excellent mixture of old and new plush sofas.

Odeonsplatz 18 • Tel: 089-298322

Bars

Anna-Bar

With its coffee bar and stylish restaurant, the attractive Anna hotel provides lots of space not only for its hotel guests, but for the general public too.

Schützenstr. 1 • Tel: 089-5236249

Schumann's Bar am Hofgarten

An historic place famous for drinks and cocktails.

Odeonsplatz 6+7 • Tel: 089-229060

Round the Gärtnerplatzviertel

Funky and cool. Here you will find many stylish, comfortable, hip bars, restaurants and pubs.

Clubs and Nightlife

P1

Getting past the doorkeepers at Munich's legendary club can be difficult, particularly on weekends, but if you do get in you might spot a VIP.

Prinzregentenstr. 1 • Tel: 089-294252

8-seasons

Enjoy the view, savour the good food and drink, and hear the music.

Maximilianstr. 2 • Tel: 0176-23232323

Optimolwerke

With its many clubs and bars you will find party people everywhere here in Munich's Party Zone and also in the neighbouring Kultfabrik, which is Europe's biggest party area.

Friedenstrasse 10 near Ostbahnhof

HELPFUL WEB SITES

www.muenchen.de
www.munich-info.de

Training of Young Engineers: A European Overview

European Microwave Week (EuMW) features the latest developments in the RF and microwave industry and identifies future initiatives. The future does not just depend on academic and commercial development, however, but also relies on the selection, nurturing and progression of the next generation of engineers who will take our industry forward. EuMW 2007 is inaugurating Tutorial Seminars for Young Engineers, aimed at stimulating the next generation. This article examines the present state of training of young engineers in Europe, areas that need to be addressed, new initiatives and investment in the future.

Europe is a varied continent made up of diverse and disparate countries, each with its own education system and provision for technical training. The RF and microwave industry transcends national borders and regardless of their geographical location, academic institutes, research labs and manufacturing companies must encourage and invest in young engineers to ensure commercial success and the future health and prosperity of the industry as a whole.

Where do we stand in 2007? Currently Europe is in a similar position to California 10 years ago with native students being less interested in 'hard science' and more attracted to higher profile careers in fields such as biology/medicine, law and business. This has resulted in a high number of electrical and electronic engineering students coming from far afield such as the likes of India (especially for the UK), Asia (including China) and Africa, with Eastern Europe also increasing its presence.

BARRIERS AND CHALLENGES

Such diversity is not a problem, perhaps with the exception of the defence sector where security clearance may be an issue. A more practical barrier is the language barrier. English is the language of technology, but students expert in electronics and physics often do not have the same facility for learning languages.

Furthermore, students from outside Europe face the double challenge of learning the local language plus English. Inside Europe the attainment of the right level in English can be an issue too—not so much in the Nordic countries and Holland, but more in France, Germany and Spain.

Some steps are being taken to address the situation. For example, in France, the plan for the future definition of master of science degree calls for all students to take a test in English to a predefined level. However, only 20 percent would currently be at that level.

Even without the selection criteria being too strict, recruitment is often difficult and not helped by the bad press that the electrical and

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electronics industry has had in recent years. Ideally placed for employment are the small number who have been educated to the RF and microwave curriculum. However, employers are looking for the complete package—those that not only have the technical knowledge, but who also possess 'soft skills' such as creativeness, flexibility and the ability to work in a team. Finding such rounded candidates may be easier said than done, but once recruited he/she will need to further his/her technical skills.

In particular, there are two simple processes that need to be grasped: design and verification. Historically, particularly at conferences, there has been a good deal of emphasis placed on how to design RF and microwave circuits, systems and subsystems, but not so on verification. And how do you verify your device? Through test and measurement.

THE REMEDY

In medicine, diagnostics is seen as a vital and important skill. That is not generally the case in our industry but should be, with engineers being encouraged to develop diagnostic skills associated with test and measurement. The verification of a design depends on the ability of engineers to properly diagnose what is going well, what is going wrong and what should be changed. Just like a doctor having the appropriate tools and knowledge and the skills to use them correctly is paramount.

Medical students get plenty of opportunities to develop their diagnostic skills, but electrical and electronic engineering students often do not. Ask an electronics engineer how much of his/her studies were spent using an oscilloscope or spectrum analyser and the answer is likely to be one hour or maybe 10. It is unlikely to be longer. This lack of provision for using real instruments sufficiently is often a question of cost as creating labs in the education system is a major investment for technical schools and universities.

It is easier and cheaper to bypass the lab and use a PC—to inhabit the virtual world that is so familiar to young students whose own lives are surrounded by computers and games. Now in their studies too they spend a significant amount of time in the virtual world of simulation. This is necessary, but it has to be balanced with working on real devices, real circuits, real functions and real systems.

ONGOING DEVELOPMENT

Training and more broadly technical/educational development is an ongoing process that should continue throughout a person's career and employment. The ideal is a combination of self-learning and formal training within a company or educational institution.

Self-learning—an individual's personal desire and willingness to improve their own worth and prospects—is potent, but is allied to self-motivation, which is often difficult. After all, we accept that we need to keep fit, but frequently find an excuse not to due to time constraints, etc. However, those who can balance self-learning with more structured training have a distinct advantage.

Whatever the training medium used, companies need to invest time, effort and resources into developing the technical skills of all employees, from the top to the bottom, both for the good of the individual and the organisation. In larger companies employee development and training can be mandatory, which is a good thing so long as the training offered is not just provided for the sake of it and is structured and focussed on the practical. Some big companies provide e-training with tools provided on the intranet and with a pre-defined curriculum.

Less formally the Internet offers a wonderful opportunity for learning, as it holds a vast amount of technical information. It is a medium that is especially attractive to the young, is an environment they are happy to inhabit and satisfies their natural curiosity. I say to students that instead of spending one hour a day on chat lines and music why not spend half of that time learning on the Internet?

THE REAL WORLD

As has been mentioned, the virtual world may be all well and good for the 'entertainment' element of the Internet, but the challenge, particularly for the test and measurement engineer, is to be able to differentiate between the real and virtual world, namely simulation and measurement, specifically the necessity to manage the paradox of achieving the objective of accuracy while recognising the uncertainty of the measurements being carried out.

Instruments, simulations and computers give results, but it is up to the engineer to decide their validity. Thus, teaching about uncertainty of measurement and how to evaluate and understand specifications are crucial. Manufacturers provide specifications, typical values, etc., but engineers still need to ask, "What is the uncertainty of my measurement under the prevalent conditions?" They also have to acquire the practical skills to enable them to arrive at an answer.

Such questions are a lot easier to answer when working within strongly defined standards, where there is a consensus. In particular, the telecom industry is creating standards that are

well defined. This enables students to understand better the uncertainty and assess the expected accuracy. In other domains the situation can be a lot fuzzier.

The same dilemmas arise in design and the use of simulation software. Design tools like EDA use real world models, but are not perfect and must be used within the prescribed parameters. This sounds obvious, but I have seen software used for simulating 40 GHz circuits where the documentation states that the models are not valid above 20 GHz. What is worse is that the results are treated as the 'truth'. We must be equipping engineers with the confidence and capability to question the results of simulation and measurement, and furnish them with the skills to judge the accuracy correctly.

INCREASING VISIBILITY

Looking forward a key question in Europe is, "How do we ensure that the RF and microwave industry attracts and retains the required calibre of engineer?" One answer is to raise the visibility of the electronics industry, to celebrate its achievements and recognise its contribution to society and modern life. After all, the mobile phone is very visible, especially to the young, and its components are RF and microwave electronics.

We need to publicise the work of those developing such technology rather than just the applications they enable. Ironically, in this regard, the industry can be its own worst enemy in terms of its own research objectives. For instance, one of the aims of 4G is to make technology easier to use and so less visible, which means that we do not demonstrate the value of working in electronics.

THE FUTURE

There are various ways that the visibility can be increased and that young engineers can be encouraged to learn and progress their careers, including specific content focussing on future engineers from high technology companies and electronics media, together with the promotion of the value of electronics through technology TV shows. Relevant and focussed conferences such as European Microwave Week are ideal platforms for young engineers to be exposed to and experience the breadth and depth of current technological development, participate in tutorial sessions, and network with their peers and counterparts.

The delivery of training should be a high priority for individual European countries, the continent as a whole and the companies that operate in it. Investment in young engineers is the only way for our industry to move forward and have a bright and productive future. ■

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Honeywell Selected to Provide R&D Expertise for Air Force JPALS

Honeywell announced that it has been selected to provide research and development expertise for the US Air Force land-based Joint Precision Approach and Landing System (JPALS). Honeywell will help the Air Force develop concept and architecture solutions for precision approach and landing system technologies under a $5.2 M research and development contract. Honeywell's team will test key elements, perform software development studies and conduct program analysis for a land-based differential global positioning system (DGPS) aimed at achieving Category II and III approach performance levels. DGPS enables precision aircraft landing by enhancing the accuracy of GPS signals. "Adverse weather and visibility conditions make aitcraft landings complex and often difficult," said Scott Starrett, vice president, Military Aircraft, Honeywell Defense and Space. "Our research and development expertise will reinforce Air Force efforts to develop a system that allows military aircraft to land in adverse weather conditions using a common approach and landing system." Honeywell's JPALS team, which includes Sierra Nevada and Boeing, was recently bolstered by the addition of QinetiQ, a leading aerospace and defense technology research company. The team received a $4.2 M contract in March to support the Navy's sea-based JPALS program. The JPALS program will develop differential GPS-based systems that provide rapidly deployable, mobile, day-night, all weather precision approach and landing capability for military aircraft. It will replace various legacy approach and landing systems with a single system that will be used by all branches of the US military. The system is also interoperable with Honeywell's civil Ground Based Augmentation System (GBAS) currently slated for 2008 Federal Aviation Administration (FAA) category I approval. "We are working to develop and certify this innovative technology to help the FAA and Department of Defense ensure timely deployment of this valuable, lifesaving technology," said Starrett. "JPAL and GBAS are critical components of both the Joint Strike Fighter and CVN-21 aircraft carrier programs as well as new civil aircraft programs including the Boeing 787 and Airbus A-380."

Northrop Grumman Teams with USAF and FAA to Study Pilot Response to Lasers

The US Air Force and the Federal Aviation Administration (FAA) led a team that included Northrop Grumman Corp. and its partners, Taboada Research Instruments and Cherokee CRC, to design, build and integrate a one-of-a-kind laser positioning system in a Boeing 737 flight simulator to study flight performance while aircrews are exposed to lasers. The Northrop Grumman's Information Technology (IT) sector team assisted the Air Force and FAA in creating this technology capability, which will help define how pilots respond to lasers when pointed at aircraft during flight. The researchers integrated eye-safe lasers in the flight simulator to monitor pilots' reactions so that new flight safety measures can be developed to counter the threat. "The team's technological contribution to the flight simulator will lead to improvements in cockpit procedures so commercial and military pilots can concentrate on safely flying their aircraft should a laser be pointed at them," said Jim Barry, vice president of Technology Integration & Applications for Northrop Grumman IT's Defense Group. "We look forward to continued development of technological enhancements with the Air Force and the FAA to create new defensive mechanisms against lasers threats." Work on the contract was conducted at Brooks City Base, San Antonio, TX, and at the FAA's Mike Monroney Aeronautical Center in Oklahoma City, OK.

Raytheon Awarded Contract to Evolve the DCGS Integration Backbone to the USAF

Raytheon Co. has been awarded a US Air Force contract to develop the next generation of the Distributed Common Ground System (DCGS) Integration Backbone (DIB). The DIB is an architecture through which military analysts and the intelligence communities can collaborate globally, regardless of their military service affiliation, enabling joint interoperability. The architecture connects disparate locations and allows users with the appropriate security clearance to access a host of intelligence sources. Raytheon first developed the DIB under the DCGS 10.2 contract for the Air Force and has delivered more than 110 units of the software to integrate into their existing and emerging systems. The DIB has been delivered to the military services and intelligence community and will soon be fielded at all Air Force DCGS sites. The DIB 1.2 updates will extend the baseline architecture to address new requirements for more widespread sharing of data across enterprise firewalls. The updates will provide expanded event delivery and notification capabilities using mechanisms such as real simple syndication, or RSS, and e-mail, with additional enhancements for data retrieval and presentation of results to the user. Raytheon designed and developed the DIB roadmap process to increase the latest enhancement for the DIB 1.2 product. The DIB roadmap provides a plan for regular enhancement cycles to stay attuned to the latest technologies and to provide new features and services to the user community. Raytheon will work closely with the DIB Management Office to ensure that the company addresses the latest inputs from the user community. "This next version of the DIB will deliver significant advantages to military analysts to perform their mission flawlessly," said Anthony DiFurio, director of Multi-Intelligence Systems for Raytheon's Intelligence and Information Systems. "The DIB is an essential architecture for discovering and sharing information in the ISR (Intelligence, Surveillance and Reconnaissance) community, which was a shortfall cited by the 9/11 Commission."

Lockheed Martin Receives $33 M for Paveway II Guided Systems

Lockheed Martin has been awarded a $33 M contract to deliver paveway II Laser Guided Bomb (LGB) GBU-12 kits to the Air Force. Delivery to the US Air Force is scheduled to begin in the first quarter of 2008. This contract reflects the US Air Force's continuous need for paveway II LGBs and highlights Lockheed Martin's commitment to delivering the most cost-effective precision-guided weapon system. "Lockheed Martin's paveway II Laser Guided Bombs set the benchmark for affordability in the precision guided weapon market," said Daniel Heller, general manager of Lockheed Martin Missiles and Fire Control in Archbald, PA. "The ongoing split-share competition supports the critical industrial base while maintaining the value we brought to the paveway acquisition process. By providing the entire family of paveway II Laser Guided Bombs, Dual Mode Laser Guided Bomb tactical weapons and live-fire trainers, our products are addressing the warfighters' need for mission readiness and precision engagement." Lockheed Martin is qualified to produce and support all three variants of the paveway II MK-80 series LGBs and has delivered more than 40,000 kits to the Air Force, US Navy and international customers. GBU-12 kits are used on 500-pound bombs, while GBU-16 kits are used on 2000- and 1000-pound bombs, respectively. Lockheed Martin kits can be used by all Air Force, Navy and international aircraft currently authorized to carry and release LGBs. These kits have been used successfully in operation Iraqi Freedom and the global war against terrorism. ■

PULLNANO Consortium Reports Breakthrough

PULLNANO, a project sponsored by the European Commission within the 6th Framework Program (FP6), has reported several important results related to the future-generation 32 nm and 22 nm CMOS technology platforms, including the realization of a functional CMOS Static Random Access Memory (SRAM) demonstrator built using 32 nm design rules.

PULLNANO is a collective effort of 38 European partner organizations, including leading chip manufacturers, industry-orientated research institutions, universities and SMEs. Its aim is to develop advanced knowledge that will enable European chip manufacturers to maintain their strong presence in the worldwide microelectronics industry from 2010, when the 32 nm generation of CMOS technology is expected to be commercially available.

SRAM is required in most of the complex System-on-Chip devices that are built with leading-edge CMOS technologies and the demonstration of a functional SRAM is an important milestone. Significantly, the PULLNANO consortium has fabricated a functional SRAM using innovative MOS transistors whose device architecture differs significantly from that of the transistors used in the 45 nm technology node.

The transistors are built using a low power consumption approach based on Fully Depleted Silicon On Insulator (FDSOI) coupled with a gate stack composed of a high-k gate dielectric and a single metal electrode stack. This is believed to be the first time that such a compact SRAM cell has been fabricated using FDSOI, high-k dielectric and metal gate together. PULLNANO is ahead of schedule in reaching this first milestone and also expects to demonstrate an even smaller cell before the end of 2007.

ST and Nokia Expand 3G Collaboration

Nokia and STMicroelectronics have announced their intention to deepen their collaboration on the licensing and supply of integrated circuit designs and modem technologies for 3G and its evolution. The two companies are also negotiating a plan relating to transferring a part of Nokia's Integrated Circuit operations to STMicroelectronics. The multi-faceted agreement will enable ST to design and manufacture 3G chipsets based on Nokia's modem technologies, energy management and RF technology, and deliver complete solutions to Nokia and the open market.

At the same time, the two companies are negotiating Nokia's IC operations transfer plan and accordingly, in order to reorganize and effect the planned competence transfer, Nokia will start the personnel consultation process required by local regulations with its personnel representatives. The transfer is anticipated to concern approximately 200 Nokia employees in Finland and the UK, and it is estimated to take place during the fourth quarter of 2007.

The collaboration is in line with the renewal of Nokia's chipset strategy, whereby the company will continue to develop its leading-edge modem technology, which includes protocol software and related digital design for WCDMA/GSM and its evolution. This modem technology will then be licensed to chipset manufacturers who will develop and produce chipsets for Nokia. These manufacturers will also be able to produce and sell to the open market chipsets based on this modem technology.

Laird Opens Research Lab in India

Laird Technologies, designers and suppliers of customized performance-critical products for wireless and other advanced electronics applications, have established a Corporate Research Laboratory in Bangalore, India. The focus of the new laboratory will be in the development of novel materials for use in electronic components and systems.

The facility is located in the International Technology Park and shares Bangalore as a home along with many major technology companies and will serve as the technical hub for the company as it expands in India. A broad range of technical specialists, including physicists, chemists and material scientists are being recruited to staff the laboratory. These technical specialists will augment the company's global engineering and technology staff of over 400.

Rick Rothenberger, technology vice president of Laird Technologies, commented, "Our new Corporate Research Laboratory will focus on longer-term research in materials and products that will enable step-change improvements in our current and future products, as well as develop products that are multi-functional in nature."

NTT DoCoMo Begins Super 3G Experiment

NTT DoCoMo Inc. is testing an experimental Super 3G system for mobile communications, the aim of which is to achieve a downlink transmission rate of 300 Mbps over a high speed wireless network.

The project has begun with an indoor experiment to test transmission speed using one transmitting and one receiving antenna. The company will then expand the experiment to examine downlink transmission by employing up to four MIMO antennas for both the base station (transmission side) and mobile station (receiving side), with the goal being to achieve a downlink transmission speed of 300 Mbps. Also to be examined is the 'handover function,' the switching of the connection between two base stations.

DoCoMo will also examine the functionality of applications for voice and image transmission, games, etc., key capabilities impacting the Super 3G system's marketability. The company is also aiming to achieve sustainable, efficient use of 3G spectrum resources, is leading the discussion over LTE and believes Super 3G will allow it to make a smooth transition to 4G in the future.

Surrey and ITA Partner on Carbon Nanotube Research

ITA, the advanced technologies research institute in Trapani, Sicily, and the UK's Surrey NanoSystems are working closely to research carbon nanotube-based nanocomposites and mechanical sensors, for aerospace and medical applications. In August Surrey NanoSystems delivered its innovative carbon nanotube growth tool to ITA and the two companies have also entered into a partnership agreement.

ITA selected the NanoGrowth tool for its ability to repeatably grow defined carbon nanotube configurations, and to grow materials at low temperatures. The tool configuration chosen includes a large range of materials processing modules, to support ITA's diverse research programs. In addition to the NanoGrowth tool's core chemical vapour deposition (CVD) and plasma-enhanced CVD (PECVD) nanomaterial growth capabilities, Surrey NanoSystems will fit modules for catalyst delivery, ion etching and thin film deposition. This wide-ranging capability will allow ITA researchers to grow precision single and multi-walled nanotube structures and silicon nanowires, as well as being able to dope, etch and deposit silicon.

The two organizations have signed a three-year development partnership to share intellectual property. Surrey NanoSystems is developing advanced processing templates to support the fabrication of carbon nanotube and silicon nanowire structures for commercial manufacture of semiconductor devices and related electronics applications. Under the agreement ITA will receive these recipes in advance of launch, in return for beta testing. ■

IEEE Modifies Balloting Procedures in IEEE 802.20™

The non-conflicted IEEE 802 Executive Committee (NC-EC) has adopted a motion to immediately change the voting approach within the 802.20 Working Group on Mobile Broadband Wireless Access (MBWA). The new approach requires that all votes and ballots in the working group be cast on the basis of entity affiliation, with a single vote allowed for each entity. After adopting the new procedure, the Working Group voted to accept the new IEEE 802.20 draft standard and forward it to a Working Group letter ballot. The IEEE working group is creating an air-interface standard to deliver voice, video and data services to portable computers and other mobile devices at levels comparable to those of wired broadband systems. The standard, IEEE P802.20,™ "Standard Air Interface for Mobile Broadband Access Systems Supporting Vehicular Mobility—Physical and Media Access Control Layer Specification," will boost real-time data transmission rates in wireless metropolitan area networks to 1 Mbps or more. It will do so at a range of at least 15 km from a base station for users traveling up to 250 Km/hr. "The atmosphere and level of cooperation within IEEE 802.20 has been steadily improving. The implementation of the entity/affiliation voting approach provided further momentum in this direction, with the motion to forward the Working Group draft Letter Ballot approved unanimously by all those who voted in the Working Group," said Arnie Greenspan, IEEE 802.20 Working Group chair. The latest NC-EC actions are among several the IEEE has taken over the past year after conducting an investigation into a lack of transparency, possible dominance and other irregularities in the MBWA working group. "This group has made significant progress after being reorganized in September 2006 to ensure a clearly neutral leadership," said Paul Nikolich, IEEE 802® committee chair. "Concerns about dominance have continued, however. While work on the standard has continued to move forward since the reorganization, this change in voting approach will put the IEEE 802.20 Working Group in a better position to move forward quickly in a fair, open and consistent manner."

Bluetooth Market Continues Growth, but Rate is Slowing

Bluetooth had another successful year in 2006 and it will have continued success in 2007, led by its increasing penetration into mobile phones, reports In-Stat. However, market growth for Bluetooth products is beginning to slow and it will see some complications arising from integration trends and new Bluetooth standards hitting the market, the high-tech market research says. The market for Bluetooth chips is also in flux. "The Bluetooth silicon market is beginning to see some consolidation, as larger silicon vendors add new capabilities, such as Wi-Fi and GPS to their chip portfolios, either by internal development or acquisition," says Brian O'Rourke, In-Stat analyst. "The goal is to create combined radio silicon that is being demanded by mobile phone vendors."

Recent research by In-Stat found the following:

- Growth of Bluetooth devices will increase by 34 percent in 2007, slowing from the recent past.
- Wireless chip companies are seeking to offer integrated radio chips with Bluetooth, Wi-Fi, GPS and FM.
- New low power and data rate Bluetooth standards will emerge over the next two years.
- According to recently conducted In-Stat surveys, France, Germany and the UK have the highest percentage of those extremely or very familiar with Bluetooth. Korea and Japan had the lowest percentages, while the US was in the middle.

Substrate Demand Will Continue to Increase Through 2011

The latest Strategy Analytics analysis on the semi-insulating (SI) GaAs bulk substrate market reveals that demand for SI GaAs bulk substrate increased by 29 percent year-on-year in 2006. "Markets for Semi-insulating GaAs Substrates: 2006–2011" forecasts that the overall SI GaAs substrate market will grow at a compound annual average growth rate of 6 percent through 2011. Volume growth for SI GaAs bulk substrates will be driven primarily by increasing GaAs content in cellular handsets and Wi-Fi radios with millimeter-wave, CATV, DBS and fiber-optic markets also adding demand. However, while substrate demand will continue to increase, rising material costs will place pressure on bulk substrate supplier profitability and process technology trends will impact overall growth. "With major GaAs fabrication running at full capacity throughout the industry, the GaAs bulk substrate suppliers were in a strong position in 2006," notes Asif Anwar, director of the GaAs service. "However, the strong demand has also increased raw material costs. We estimate that gallium costs have risen by almost 120 percent over the past two years." "Overall demand will be counterbalanced by process technology trends toward integration and smaller die sizes, which at first glance, is a negative for bulk substrate suppliers," observes Stephen Entwistle, vice president of the Strategy Analytics Strategic Technology Practice. "Ultimately, however, these trends will ensure that GaAs device manufacturers offer added value to their end-customers, securing future demand for GaAs substrates."

Mobile Business Data Services to Generate Over $100 B by 2012

Mobile e-mail, sales force automation tools, mapping applications and Internet access—these are all mobile data applications and services that make business customers more efficient and improve their work quality. According to a new report by ABI Research, mobile data applications and services used by business customers will generate over $100 B in worldwide revenue by 2012. Principal analyst Dan Shey comments," The industry is at the cusp of some phenomenal growth for data applications and services delivered to the handset. Although voice will still generate the bulk of revenue from business customers, mobile data service revenue will become 26 percent of ARPUs by 2012, a 29 percent compound annual growth rate." Business applications and services for the handset include communications, information access, computing, integrated information access/computing and business process solutions. The communications category includes real-time communications and messaging. Combined revenues from all mobile business categories (including voice service) will grow from $242 B in 2007 to $389 B by 2012. Information access/computing and business process solutions are relatively new categories of mobile applications and services for the business customer. These categories will experience the highest growth rates of all because they address needs specific to a business, an industry sector or a functional area. According to Shey, "Business functions and processes require different amounts of communications, computing and information access. Value chain players that participate in creating products with the right mix of these capabilities will be riding a wave of growth for mobile solutions having CAGRs of between 80 and 90 percent." ABI Research's study, "Mobile Business Applications and Services," provides a comprehensive view of the global market for business customer mobile applications and services. It describes and outlines the enablers for all mobile applications and services including voice, video and data applications. Complementing the discussion is a review of value chain players, market activity and relevant statistics. Finally, market forecasts are provided, segmented by revenues, and ARPUs by mobile application and service category, and by region. The report forms part of the firm's Business Mobility Research Service, which includes Research Reports, Research Briefs, Market Data, On-line Databases, ABI Insights, the ABI Vendor Matrix and analysis inquiry support. ■

INDUSTRY NEWS

■ **CommScope Inc.** and **Andrew Corp.** announced that the companies have entered into a definitive agreement, unanimously approved by their respective Boards of Directors, under which CommScope will acquire all of the outstanding shares of Andrew for $15.00 per share, at least 90 percent in cash, creating a global leader in infrastructure solutions for communications networks. The transaction, which is valued at approximately $2.6 B, is expected to be accretive to CommScope's cash earnings per share, excluding special items, in the first full year after closing.

■ **EMS Technologies Inc.** announced that it signed a definitive agreement to acquire **DSpace**, Adelaide, Australia, for (US) $5.7 M. The acquisition will enable EMS to build on the strength of its SATCOM business, which grew approximately 40 percent last year, and to exploit rising demand for Inmarsat's BGAN services in new markets.

■ **Ansoft Corp.** announced a strategic partnership with **ZTE Corp.**, China's largest listed telecommunications equipment provider of customized network solutions for telecom carriers worldwide. Using Ansoft signal and power integrity analysis software, ZTE engineers are now able to predict radiated emissions and induced interference from printed circuit boards (PCB) and to examine multiple PCBs within a cabinet to determine trends for system-level emission. The new design methodology has allowed ZTE to eliminate expensive build-test-repeat iterations in its design cycle.

■ **Agilent Technologies Inc.** and **GCT Semiconductor Inc.** announced plans to jointly implement a WiMAX manufacturing test system for GCT's WiMAX chipsets, which will accelerate manufacturing throughput and allow mass production deployment. Agilent will support GCT chipsets with its E6651A Mobile WiMAX Test Set and MXZ-1000 WiMAX Manufacturing Test System. The initial GCT chipset supported will be for 2.3 GHz wave 1 mobile WiMAX products, consisting of GCT's GDM7201S baseband chip and the GRF7201 RF chip, and will be followed by mass deployment of 2.5 GHz wave 2 mobile WiMAX chipsets.

■ **Tektronix Inc.**, a worldwide provider of test, measurement and monitoring instrumentation, announced a partnership with the **China Electronics Standardization Institution** (CESI) to set up a joint lab for advanced research and assessment of digital RF and digital TV standards in China, key drivers of the New Digital World. The new lab will be a key research facility for the development of China's new DTV and digital RF standards. Tektronix will provide the newly established joint lab with its latest enhanced video and RF test instruments including the PQA500 picture quality analyzer, WVR7120 waveform rasterizers and RSA6100A Real-time Spectrum Analyzers.

■ **Cree Inc.**, a market leader in silicon carbide (SiC) power semiconductors, announced an agreement under which **Nihon Inter Electronics Corp.** (NIEC) will introduce a line of SiC-based Schottky power rectifier diodes in Japan with die manufactured by Cree Inc.

■ **Keithley Instruments Inc.** and **CEA Leti** have entered into a Joint Development Partnership (JDP) centered on semiconductor device material testing technology. The JDP calls for Keithley and CEA Leti, one of the world's most sophisticated semiconductor development laboratories, to research methods for characterizing advanced semiconductor materials and devices that support DC, high frequency, and RF-level signals on both micro and nano-level structures.

■ **RF Micro Devices Inc.** (RFMD) announced a major expansion at its Beijing, China facility. The expansion includes increased assembly capacity and the addition of new advanced capabilities. The expansion is expected to support RFMD's POLARIS™ 3 RF solution, which is currently scheduled to ramp production in the current quarter.

■ **ANADIGICS Inc.** ceremonially broke ground for construction of a new state-of-the-art 6" gallium arsenide (GaAs) integrated circuit (IC) wafer fabrication facility (fab) in the Kunshan New and Hi-Tech Industrial Development Zone (KSND) as part of a city wide celebration in the city of Kunshan in the Jiangsu Province in China. Driven by wireless and wireline broadband markets, in order to support ANADIGICS anticipated growth beyond its primary wafer fabrication located in Warren, NJ, the company and KSND plan to complete construction of the new facility in the first half of 2008, and to bring the fab operational in the latter part of the year.

■ **Sypris Test & Measurement Inc.**, a subsidiary of Sypris Solutions Inc., relocated its Burlington, MA Testing Laboratory to an existing site in Billerica, MA. The relocation allows Sypris to bring additional value to its customers by offering testing and calibration services in one convenient lab, a central location for pick up and delivery, a comprehensive suite of testing services including electromagnetic compliance and an improved infrastructure for customer support. The lab's new address is 7 Sterling Road, North Billerica, MA 01862. The new phone number is (978) 663-2137 and the fax number is (978) 663-6275.

CONTRACTS

■ **Anaren Inc.** has received a contract valued in excess of $11 M from **Northrop Grumman Corp.**, Baltimore, MD, for integrated ferrite assemblies used in the S-band radar, which is part of the Mission Equipment for the Cobra Judy Replacement Program. The Cobra Judy Replacement Program is for long-loiter foreign ballistic missile data collection in support of international treaty verification. Northrop Grumman is a subcontractor to Raytheon Integrated Defense Systems, the prime contractor for the Cobra Judy Replacement Mission Equipment Program. The contract calls for the first full-rate production and deliveries starting in November of 2007 expanding over a 15-month period.

■ **Akon Inc.**, San Jose, CA, has received contracts totaling over $2 M from the Government of India's research organizations DARE and DLRL, for microwave integrated subsystems and assemblies such as 0.5 to 18 GHz synthesizers, 6 to 18 GHz downconverters and LO assemblies, and 0.5 to 40 GHz receiver front-ends and amplifiers. These awards are to support developmental EW programs underway in India.

■ **Auriga Measurement Systems LLC** announced it has been awarded a research and development contract entitled "Solid-State High-Efficiency Radar Transmit Module" by the Naval Air Warfare Center. Auriga will lead the project with its partner, Raytheon, on this Small Business Innovation Research Award. After successful completion of this project, Auriga will be eligible to win an already identified follow-on award that would include final development, production and commercialization of the transmit module to governmental and non-government customers.

■ **TRAK Microwave Corp.** was selected as a key supplier for **BAE**'s AN\ALR-56M Radar Warning Receiver Program. This program will provide a new fleet of US Air Force and US Marine Corps C-130J radar warning receiver systems. TRAK will supply high performance frequency sources used in the microwave subsystem payload.

FINANCIAL NEWS

■ **Credence Systems Corp.** reports sales of $121.1 M for the second quarter of fiscal 2007 ended May 5, 2007, compared to $129.9 M for the same period in 2006. Net loss for the quarter was $3.5 M ($0.03/per share), compared to a net loss of $14.2 M (0.14/per share) for the second quarter of last year.

■ **TriQuint Semiconductor Inc.** reports sales of $113.8 M for the second quarter ended June 30, 2007, compared to $96.3 M for the same period in 2006. Net income for the quarter was $1.4 M ($0.01/per diluted share), compared to $5.6 M ($0.04/per diluted share) for the second quarter of last year.

■ **RF Monolithics Inc.** reports sales of $13.4 M for the third quarter of fiscal 2008 ended May 31, 2007, compared to $14.7 M for the same period in 2007. Net loss for the quarter was $1.4 M ($0.15/per diluted share), compared to a net income of $413,000 ($0.05/per diluted share) for the third quarter of last year.

■ **RF Industries Ltd.** reports sales of $3.4 M for the second quarter of fiscal 2007 ended April 30, 2007, compared to $3.8 M for the same period in 2006. Net income for the quarter was $178,000 ($0.05/per diluted share), compared to a net income of $395,000 ($0.11/per diluted share) for the second quarter of last year.

NEW MARKET ENTRIES

■ **White Mountain Labs**, a leader in test and characterization of advanced technologies, announced the addition of its new Automated Test Equipment (ATE) business segment, **ClearTest ATE Services**. Offering an experienced, test-engineering staff, along with expert development systems, ClearTest ATE Services will provide semiconductor manufacturers with complete test engineering solutions.

■ **MtronPTI**, a producer of frequency control and filter products, has expanded its already broad product portfolio to include ceramic filters. The ceramic filter line will feature products with frequencies from 300 MHz to 6 GHz with a 1 to 40 percent bandwidth. Products are tailored to the customers' needs and offered in custom packages with RoHS compliance. The ceramic filter products are often used in applications that are already supported by MtronPTI's broad product portfolio.

■ **SPINNER**, a leader in the development and manufacturing of state-of-the-art passive RF components, announced the installation of a newly developed jumper cable assembly line in its Norcross, GA manufacturing location.

PERSONNEL

▲ *Jack Cowper*

■ Rohde & Schwarz announced that **Jack Cowper**, currently vice president of Rohde & Schwarz Inc., has been appointed president of Rohde & Schwarz Canada Inc. He will continue to hold his current position as well, and reports directly to Wolfgang Schmittseifer, chief executive officer of Rohde & Schwarz Inc. Cowper replaces Peter Foulger, who is retiring but will continue to serve as a member of the Rohde & Schwarz Canada Board of Directors and will pursue special projects for the company. Cowper has more than 15 years of experience in the test and measurement industry. He joined Rohde & Schwarz in 2000, and has served as marketing manager, director of marketing and currently as vice president.

■ Inphi® Corp. announced that industry veteran **Young K. Sohn** has been named CEO. Sohn will lend his expertise to drive Inphi's strategic direction and growth to deliver the industry's broadest and highest performing portfolio of integrated circuits for processing high speed data. Most recently, he was president of Agilent Technologies' Semiconductor Group (now known as Avago Technologies) where he led the successful turnaround of the semiconductor operation. Prior to that time he served as chairman and CEO of Oak Technology, a digital media semiconductor company providing solutions for the consumer electronics markets.

■ Sirific Wireless announced the appointment of **Russell K. Johnsen** as chairman and chief executive officer. Johnsen has served as an independent director on Sirific's board for the past three years and will now focus his attention to leading the company's strategic short- and long-term business strategies. Previously, Johnsen managed the cellular wireless and high speed broadband wireline communications businesses at Analog Devices, where he held the titles vice president and general manager of the Communications Product Division, as well as vice president of corporate development. Prior to Analog Devices, he was the general manager of the wide area networks division for National Semiconductor and co-founded its wireless communications and PLL synthesizer product line.

■ AMI Semiconductor announced the appointment of **Joseph J. Passarello** to senior vice president and chief financial officer. Passarello was chief financial officer of Therma-Wave Inc. from June 2005 to May 2007. Therma-Wave develops, manufactures, markets and services process control metrology systems used in the manufacture of semiconductors, and recently became a KLA-Tencor family of companies.


▲ *Paul A. Magill*

■ Nextreme, a manufacturer of advanced thin film thermoelectric components designed and produced to address the thermal management and power generation needs of the electronics, photonics, bio-tech and defense/aerospace industries, has recently appointed **Paul A. Magill** as vice president of marketing and business development. Magill has more than 20 years of experience in the electronics and optoelectronics industry with expertise in sensors and laser diode applications as well as electronics and MEMS packaging and manufacturing.


▲ *Ray Crampton*

■ Nitronex, a developer and manufacturer of high performance RF power transistors for the commercial and broadband wireless infrastructure markets, has named **Ray Crampton** as the new director of marketing. Crampton brings more than 10 years of industry experience spanning RF IC amplifier design, technical and marketing management to Nitronex. Before joining Nitronex, Crampton served as a strategic marketing and systems engineering manager for Texas Instruments' Linear Regulators product line. Prior to that, Crampton held various positions at Sirenza Microdevices including product line manager, engineering manager and senior RF IC design engineer.


▲ *James Rowland*

■ **James Rowland** has been named director, customer service, at MI Technologies. As director, customer service, Rowland is responsible for managing MI Technologies' global field service network, training and certification programs, warranty and post warranty services, calibration and repair services, equipment refurbishment and customer range verification services. Prior to joining MI Technologies, Rowland was president of Ultra Electronics, EMS Development Corp., Yaphank, NY, where he had overall responsibility for the company's strategy, operations and business growth.

■ Quantum Leap Packaging Inc. (QLP), a provider of high performance semiconductor packaging, announced the appointment of **Roger Kuroda** as senior vice president of manufacturing. Kuroda brings to QLP years of experience in the semiconductor packaging industry as well as other advanced technologies. He has held senior positions in manufacturing, engineering and R&D where he had responsibility for design, assembly and packaging. Prior to QLP, Kuroda was vice president of engineering at XCOM Wireless, responsible for designing RF MEMS devices, foundry management, project management, and developing and qualifying new assembly and packaging.

▲ Robert G. Schumacher, Jr.

■ Pole/Zero Corp., a provider of cosite mitigation products, announced that **Robert G. Schumacher, Jr.** received the Ernst & Young Entrepreneur Of The Year® 2007 Award in the technology category for South Central Ohio and Kentucky. According to Ernst & Young, the award recognizes outstanding entrepreneurs who are building and leading dynamic, growing businesses. Schumacher was selected by an independent panel of judges and the award was presented at an Ernst & Young Entrepreneur Of The Year gala event at the Cincinnati Duke Energy Center on June 28, 2007.

REP APPOINTMENTS

■ **EADS North America Defense Test and Services** and **Tabor Electronics** announced that, effective immediately, EADS North America Defense Test and Services is the exclusive distributor of Tabor-branded products in the United States.

■ **Aethercomm**, a provider of high power RF amplifiers, is pleased to announce their partnership with **Component Distributors Inc.** (CDI). This distribution arrangement will allow Aethercomm and CDI to quickly address the military RF market. Under terms of the agreement, a wide selection of standard products will be stocked by CDI.

■ **G.T. Microwave Inc.**, Randolph, NJ, announced the company's appointment of domestic representative, **Reese Associates Inc.**, to cover Arkansas, Louisiana, Oklahoma and Texas. Reese Associates' headquarters is stationed at 612 Twilight Trail, Richardson, TX 75080 and its web site is www.jayreese.com.

■ **I.F. Engineering Corp.**, a manufacturer of high performance RF and microwave components and distribution systems, announced the appointment of **YGITECH Microwave** as its exclusive representative in France. Contact information: YGITECH Microwave, 3ter rue du Pot Francois Mitterand, Longjumeau, France 91160 ph: 01.64.48.45.57; fax: 01.64.48.65.77, www.ygitech.com or e-mail: contact@ygitech.com. In related news, **Cross-Point Technologies Inc.**, a manufacturer of high performance RF and microwave components and distribution systems, announced the appointment of YGITECH Microwave as its exclusive representative in France.

MICROWAVES IN EUROPE: PAST CHALLENGES, FUTURE PROSPECTS

How have the events of the last decade impacted on the European microwave industry? How has it emerged from the market downturn of the early 2000s, accommodated the expansion of the European Union and embraced the globalisation of the marketplace? And what technologies are driving its future?

European Microwave Week (EuMW) celebrates its first decade in October and the intervening 10 years have been eventful and consequential for the European RF and microwaves industry. Back in 1997 confidence was fairly high after what was seen as recovery from the recession that had hit the microwave community quite hard in the early '90s.

This was before the unprecedented 'boom' at the end of the late '90s, but even then the statistics for the growth in mobile communications were impressive, not only for the suppliers but also for the pull-through that had been gained at the components, systems and backbone levels. Digital technologies, particularly the Global System for Mobile (GSM) communication, were reaping the benefits of the growth in demand and capitalising on the deregulation of the communications community.

Conversely, the defence and military markets were static in comparison and a number of microwave companies changed emphasis and boarded the communications gravy train. For many that ride proved to be hazardous and some companies did not survive the journey as the market's subsequent downturn in the early 2000s claimed significant casualties. The telecommunications industry bore the brunt, but the knock-on effect that it had on associated markets in the RF and microwave sector has been far reaching.

Hard and painful lessons have been learned, but the European RF and microwaves industry has survived. In fact, as will be illustrated, the industry has evolved and transformed to such a degree that the 1997 scenario is largely unrecognisable now.

Similarly, Europe's political and economic complexion is very different too. The expansion of the European Union has seen Eastern Europe gain prominence as a contributor to the overall economy, both as a growing consumer market and a competitor to traditional, established companies worldwide.

The global market is also a different entity. In particular it is being influenced by the phenomenon of Far East markets where internal economic growth, in China, other Asian countries and emerging economies such as India, allied to their infiltration of markets worldwide through mass produced, relatively cheap offerings is significant.

Europe cannot compete on the basis of cheap labour and therefore its main strategy has to be to raise productivity, make use of its highly skilled research and development capability and produce added value products and services. The RF and microwaves industry can play a key role in this objective and capitalise on the political, economic and industrial drivers that

RICHARD MUMFORD
Microwave Journal *European Editor*

are now in place. Through structured initiatives the European Union strives for an inclusive, collaborative approach to technological and market development.

Such initiatives include the European Networks of Excellence (NoE) Programmes, many of which have targeted the RF and microwaves sector. This will continue and is set to expand its scope, reach and impact with the new seven year 7th Framework Programme (FP), which was introduced at the beginning of 2007.

The technology driving these programmes will be featured at European Microwave Week in Munich and be the subject of papers in the four individual conferences: the European Microwave Conference (EuMC), the European Conference on Wireless Technology (ECWT), the European Microwave Integrated Circuits Conference (EuMIC) and the European Radar Conference (EuRAD). In advance, *Microwave Journal* has capitalised on its unique access to the conference chairmen, academic contributors and key industrial players to evaluate current activities in the European microwaves and RF market and identify the trends shaping its future.

In this report, the individual conference chairmen each present an overview of their market sectors and executives whose companies play a key role in determining the direction and prosperity of the European microwave industry provide a commercial perspective in the 'company survey'. To reflect the worldwide nature of the industry the author has canvassed companies across the globe actively participating in the European microwave market to provide an 'international perspective'.

In order to provide a context for these opinions let's first consider the political, commercial and technological environment in which the European microwave industry is operating 10 years after the first EuMW.

EUROPEAN PERSPECTIVE

The dynamic of the European RF and microwaves industry has changed considerably in recent years with a degree of polarisation between West and East. Western Europe harbours considerable research and development expertise and is making every effort to effectively harness this rich technical and academic resource. Industry has adapted, for instance, many vertically integrated companies, formerly responsible for both product development and manufacturing have restructured their operations to allow them to concentrate on their core competencies. Companies are also opting to partner with like-minded and complementary companies/organisations worldwide for mutual benefit.

Due to growth in production networks and direct foreign investments, allied to relatively cheap labour costs Eastern Europe is emerging as a global hub for the electronics manufacturing industry and is now estimated to account for more than half of the overall European electronics market. Of course the region can't compete on price with the likes of China and other Asian countries, but it can offer the West relatively low labour rates and potential savings in reduced time to market and freight costs.

The establishment of production facilities has significantly bolstered the economies of countries such as the Czech Republic, Hungary and Poland, and further eastward expansion of the EU is likely to see countries that joined the EU in 2007, Bulgaria and Romania, follow suit. They are also potential markets for new business and investment.

It is sometimes overlooked, but Eastern Europe possesses a large pool of skilled labour with a high level of education and in particular Russia's qualified technical labour force is relatively untapped. The presence of quality labour, catering to growth markets like telecommunications, makes such countries ideal for electronics manufacturing.

For industry to progress requires technological innovation and development. Research in Europe takes place at a national level, but there is also a strong cooperative research ethos developed over many years of EU Framework Programmes. The 6th FP supported many large microwave-related activities, including Networks of Excellence in the field of power amplifiers (TARGET), RF MEMS (AMICOM), and antennas (ACE).

On 29 October 2006, the European Parliament adopted a Competitiveness and Innovation framework Programme (CIP) for the period 2007–2013, with a final budget of €3.62 B. This 7th Framework Programme is conceived to become the backbone for the construction of a European knowledge economy. Spanning a period of seven years for the first time, the 7th FP will largely build on the themes of the 6th FP with the addition of security research and space, to reflect the growing importance the EU is attaching to this sector. Within each theme, there is sufficient flexibility to accommodate new emerging topics of scientific, industrial or policy interest.

From the technical content of FP7, wireless communications and technology is well represented, both in terms of basic technologies and applications. Moreover, many projects will be focused on micro/nano-systems, which will boost microwave technology. In addition, there are currently more than 30 European Technology Platforms addressing strategic technological challenges, some of which are related to RF/microwave technology.

Importantly, in order to address Europe's weakness in commercialising the results of research and to identify the market potential of new technology, the 7th FP is specifically tailored to meet industry's needs. Where industrially relevant, the definition of work programmes will draw on the strategic research agendas developed by industry-led technology platforms. These agendas, presenting the European dimension of research challenges, also influence national research programmes. Industry is being encouraged to participate in funding and to actively contribute to the Networks of Excellence.

Also, with the support of national agencies and the European Space Agency (ESA), the pan-European development of the Galileo global navigation infrastructure system is moving towards its goal of being fully operational in 2012.

RF and Microwaves

The RF and microwaves industry is a complex web of interdependencies between highly specialist components manufacturers, subsystem manufacturers and large scale equipment contractors. Across the entire spectrum European companies and research institutes, aided by national governments, pan-European agencies and the European Union strive to drive innovation forward and improve Europe's global competitiveness. In recent years the mobile and wireless communications sector has emerged from the doldrums of the communications downturn and is now at the forefront of innovation and implementation.

The endeavour of Europe's wireless equipment suppliers, mobile phone companies and content producers, along with the EU's initiative to provide 'always on' connectivity for European citizens, has delivered the success of GSM and 3G systems. GSM/UMTS is evolving to an advanced 4G system and the development of mobile broadband wireless access is reaching a significant stage, while cognitive radio is edging further along the developmental path.

Away from the telecommunications market, important technology is being developed, such as RF/microwave high power amplifiers, including linearization techniques and signal sources. While wide band-gap semiconductors open up undreamed of possibilities for microwave power generation per unit device size, there is also an increasing interest in exploiting mm-wave frequencies from 60 GHz upwards. In the past, the advantages of lack of spectral congestion, large bandwidths and small antenna size have been negated by high component cost, including packaging. However, this is now being addressed by the rapid progress in the high frequency behaviour of deep sub-micron silicon-on-insulator technologies.

Another area of activity in Europe is the RF MEMS field, which is the subject of two ongoing 6th Framework Programme projects, AMICOM and INTEGRAMplus, which focuses on silicon-based MEMS components. A specific challenge is the integration of RF MEMS with modules and ICs with the ultimate goal being the single chip transceiver. With components on the market, in development and on their way to full production—cavity resonators and tunable capacitors are expected to reach this stage in 2008—RF MEMS is set to take off.

The high end automotive industry is a high profile contributor to the European economy and one that is prompting technological development in the RF and microwaves sector. Heightened concerns over traffic congestion, road safety and pollution are prompting the development of technology such as automotive radar systems at 77 GHz to provide driver assistance and the adoption of advanced traffic management systems.

Finally, a sector of the market that is doing better than it has for years is the satellite communication industry. With the support of national agencies and ESA satellite companies are addressing the fact that remote broadband, HDTV and increased wireless backhaul require more satellite bandwidth at a time when supply is more constrained.

Wireless Technologies

When attempting to identify future trends, the wireless sector is probably the most unpredictable and where markets and are not always easy to interpret. For instance, the bare facts say that mobile phone subscriptions continue to grow. According to Informa the total number of mobile subscriptions has reached three billion worldwide but calculates that the actual number of users of mobile services is fewer than 2.3 billion. The truth is that the subscription growth being driven by the expansion of networks is coming from developing markets such as China, India and Eastern Europe, while growth in mature markets like Western Europe is being driven by multiple subscriptions.

The reality in Western Europe is that despite having achieved more than 100 per cent mobile penetration not many carriers have attained reasonable return on investment after spending billions of Euros in acquiring 3G spectrum and rolling out related networks. So, while in developing markets the fundamental requirement is for mobile to fulfill the basic need for voice and text based communications, in Western Europe the prevailing saturated voice market and various alternatives such as voice over Internet protocol (VoIP) are necessitating the search for new mobile applications and revenue streams that will generate greater income and sustain profitability.

Various next-generation mobile broadband technologies are in different stages of development and implementation, including emerging mobile radio techniques such as HSPA, 3GPP long-term Evolution (LTE), MIMO LTE and MIMO WiMAX. With many at a fairly embryonic stage it remains to be seen which will come to the fore and which might fall by the wayside.

Certainly, in the parts of Europe that are currently served by DSL or cable services WiMAX has the potential to extend the reach of high speed Internet access outside urban areas. As it allows roaming among base stations and has the capability to support fixed wireless applications mobile WiMAX, in particular, saw a flurry of activity towards the end of 2006 and into 2007. However, the cost of mobile WiMAX base stations and the number that will need to be deployed for extensive coverage are key considerations if it is to compete with existing networks such as 3G.

Wireless technologies are also gaining importance in the automotive industry where they are being deployed for safety and core vehicle telematics and infotainment. In Europe Bluetooth® is the established standard for wireless voice applications, but vehicle manufacturers are investigating other technologies. BMW has announced the likely introduction of WiFi technology into its premier models in 2008, Ultra Wideband (UWB) is also being considered, while the low power requirements of ZigBee make that an attractive option too.

ICs & Semiconductors

According to the spring 2007 forecast of the World Semiconductor Trade Statistics (WSTS), the global semiconductor market is expected to grow 2.3 percent on an annualized basis to $253.5 B in 2007. The figures are not remarkable, but the fact that European chipmakers are contributing significantly to this growth is. IC Insights' August update to the 1H07 top 20 semiconductor supplier ranking has two European chip makers, STMicroelectronics and NXP (formerly Philips Semiconductor), in the top ten with Infineon Technologies just outside in twelfth.

That was not the case 10 years ago at the first EuMW. By that time many of the large number of European semiconductor manufacturers had folded due to inefficiency, overstaffing and, in some cases, lack of foresight. In fact, at one time there was the distinct possibility that Europe would abandon the high risk, high cost semiconductor industry altogether.

It did not, but instead has restructured and consolidated by focussing on its core competencies, concentrating on high end chips and developing integrated system-on-chip products that primarily went beyond computers into the telecommunications, automotive and digital electronics markets. An important role in the survival of the European semiconductor industry has been played by European Union activities such as MEDEA+ and the EU Framework Programmes as well as forward-looking industry initiatives such as the European Nanoelectronics Initiative Advisory Council (ENIAC).

Collaboration has been important too. It has been vital for European companies to form alliances with key players in the global market to share the costs and risks of designing new manufacturing processes. Also, as a large proportion of the $253.5 B global semiconductor market is outside of Europe, it has been essential to forge research and production partnerships and have a local presence in key developing markets such as China.

As for the technologies, in the compound semiconductor devices and ICs for microwave and mm-wave sector, GaAs is being challenged by Si-based and emerging high power technologies. Si-based technologies are coming to the fore in the automotive sector and in UWB development, III-V compound semiconductors are prominent in the defence domain, while gallium nitride is being developed for power applications.

However, while such technical innovations are creating new business opportunities, the reality is that continuous price pressure remains the dominating factor and market driver for microwave and mm-wave components and ICs.

Defence

One of the fundamental roles of government is to ensure the security of its citizens. And while individual governments address national and border security, on a European scale that responsibility falls to the European Union. In a constantly changing world it is only by co-operating and coordinating efforts on a Europe-wide scale that the EU can identify, understand and respond to threats.

Making Europe more secure for its citizens while increasing its industrial competitiveness is the goal of European Security Research and in response to increasing concerns, security research is now an integral part of the 7th RTD Framework Programme, with an average annual budget of €200 M.

The objective of the security theme is: to develop the technologies and knowledge for building capabilities needed to ensure the security of citizens from threats while respecting fundamental human rights; to ensure optimal and concerted use of available and evolving technologies to the benefit of civil European security; to stimulate the co-operation of providers and users for civil security solutions; to improve the competitiveness of the European security industry and to deliver mission-oriented results to reduce security gaps.

The European Security Research Advisory Board (ESRAB) advises the European Commission on how FP7 research should contribute efficiently to citizen's security, particularly through the development and demonstration of new technologies. With its expertise and experience the microwave industry has a key role to play in the development and provision of such technology.

For instance, the increased interest in network-centric warfare (NCW) is likely to result in the growth of the European land-based Intelligence, Surveillance, Target Acquisition, Reconnaissance (ISTAR) market with greater focus on the development of radar and sensor systems to provide network friendly solutions.

Indicators are that weapons locating radar (WLR) will remain key with remotely deployed and networked unattended ground sensors (UGS) systems gaining importance as part of larger networks of sensors. Alongside, WLR and battlefield surveillance radar (BFSR) are likely to be the main beneficiaries of the latest NATO Response Force (NRF) and the European Union's Battle Group (EUBG) initiatives.

The command and control (C2) market is interesting too. Although dominated by the large European military spenders such as France and the UK, with smaller but significant programmes in Germany, Netherlands, Spain, Italy and Greece, new Eastern European NATO allies have moderate C2 programmes. As these countries often have limited technical expertise lucrative opportunities could arise for Western European companies through partnering with local defence contractors.

OVERVIEWS AND SURVEYS

Political, economic and commercial influences all impact on the performance and development of the microwave industry. These are fluid and the European Perspective can only hope to be a barometer of the current conditions. To gain a focused insight the author has sought the views of the academic and industrial and taken European Microwave Week as its platform. The EuMW chairman offers a sector wide overview while the chairmen of the four individual conferences concentrate specifically on their market sectors. They consider how technology is developing and the long-term impact it is likely to have, while giving a perspective of how the sector fits into the overall microwave picture.

Complementary to that is the commercial and industrial view given by the company executives canvassed for the 'company survey'. Representing a cross-section of the European microwave industry in terms of size of operation and product focus they offer an insight into current market conditions and technological development. The format is generally a brief overview of the company's microwave activity, followed by comments on technological and market initiatives.

Reflecting the global nature of the industry this report offers a 'wider' perspective. International players spanning the geographical and technological development spectrum proffer opinions on the practicalities, barriers and benefits of competing in the European Microwave market, in the 'international perspective'.

INDUSTRY-WIDE PERSPECTIVE

Microwave industry overview by EuMW General Chairman, Heinrich Wolfgang

RF and microwave engineers in universities, research organizations and industry continually endeavour to implement new initiatives and develop technology. Annually, in Europe, there is the opportunity to gauge the strength and depth of those efforts when European Microwave Week showcases the very latest activities in both the academic and the industrial world.

For three years now the number of paper submissions to EuMW has exceeded the 1000 mark, with a wide international representation. This year, after the host country, Germany, the most paper submissions are from France, closely followed by South Korea and the US, with the UK, Italy and Japan making significant contributions as well. This broad distribution demonstrates the globalisation of our field and the importance of embracing new ideas, technological development and market innovation from all quarters. As well as quantity there must be excellence and EuMW 2007 has striven to offer high quality and stimulating papers, covering the complete field of wireless technology, microwaves, and radar, with a good balance between academic and industrial contributions. The conferences always give an indication of which are the popular areas of research as well as which are the burning issues in industry, while the interest in the European Microwave Exhibition is a measure of the economic situation. This year it has attracted more exhibitors and takes up more square metreage than ever before, which supports the observation that the European microwave industry has continued to consolidate and is now on a stable economical upturn.

So, what are the key factors that are fuelling this upturn? The individual conference chairmen will provide in-depth answers with regard to the activity in their specific field later in this report. However, I shall briefly identify the main industry-wide trends. What is clear is that the hot topics in research in Europe mirror those worldwide. Interestingly, power amplifiers and the corresponding linearization techniques continue to be most popular in terms of paper submissions. Besides this, work on silicon-based circuits, particularly CMOS, continues to grow. Finally, tunable components and multi-band devices should be mentioned, which are being developed for different fields of application, particularly with regards to the need for reconfigurable components, which enable multi-standard and multi-band wireless systems.

RF AND MICROWAVES

Sector overview by EuMC Chairman, Professor Rolf Jakoby

The RF and microwave sector is currently developing strongly worldwide and in Europe, driven by both commercial and security/defence applications, where mobile and wireless communications are the key drivers. Europe is at the forefront of the mobile and wireless communications sector, boasting many of the world's largest equipment suppliers, mobile phone companies and mobile content producers. This is no accident, but the result of a coordinated European Union effort by the European Commission, national governments and industry as well as the result of the EU's future vision of 'ambient intelligence' featuring 'always-on' connectivity for European citizens.

The basis for Europe's success is GSM and 3G systems such as UMTS, where enhanced UMTS-TDD competes directly with WiMAX (long range system) and WiFi (shorter range system). Both aim to offer DSL-class Internet access in addition to phone services. GSM/UMTS is evolving to an advanced 4G system, the 3GPP LTE effort is aiming for high bandwidth, low latency, all-IP networks with voice services built on top. In addition, Mobile Broadband Wireless Access technology is being developed for operations from 120 to 350 km/h. All this will ensure Europe's global competitiveness, boosting economic growth and ensuring sustainable prosperity.

Europe is also well placed in satellite communication systems, where it is home to three of the five largest operators in the world. These provide global telecommunications, television broadcasting, data and mobile services. Satellite technology has been strongly supported through national agencies and the European Space Agency. Perhaps the best known program is Galileo, the global navigation infrastructure system.

Of key strategic importance to Europe's economy is the high end automotive sector. There is continuing interest in automotive radar systems at 77

GHz. At much higher frequencies, there are intriguing signs that the upper mm-wave and THz region, long unexploited, is beginning to open up entirely new markets and opportunities.

European industry is also the world leader in micro-systems and related advanced technologies, with nano-system development another key target. So too are distributed wireless sensors integrating many novel sensor technologies and addressing various applications ranging from RFID, climate monitoring, security and biomedical systems.

Challenges facing the industry include coping with the competing demands of linearity, power and spectrum efficiency in emerging radio systems. Also tunability and reconfigurability, so natural at the digital level, will be required in future at the level of the RF transceiver (front end), in order to achieve cost-effective frequency-agile, multi-band, multi-access radios, RF-beamforming antenna configurations, RF sensors or RFIDs in the microwave and mm-wave region. Another future goal is 'cognitive radio' that can sense its environment and intelligently adapt itself to meet user needs optimally.

A sticking point is the availability of 'compact' tunable or switchable microwave components that have high performance at a cost that is attractive for low and high volume production. Besides RF MEMS or semiconductor devices such as varactors or CMOS silicon-on-sapphire RF switches, emerging tunable passives based on ferroelectric thin and thick films or liquid crystal cavities might play a part in the future.

Overall, I believe the RF and microwave sector is exciting, growing and has mainstream strategic importance with excellent future prospects.

COMPANY SURVEYS

Credowan

As a long established manufacturer of waveguide technology-based products the company's main activities can be split into three distinct areas. The first is the manufacture of lightweight high performance waveguide assemblies for the payload satellite industry. These products are configured from ultra thin-wall aluminum; silver plated, and are qualified and tested to achieve excellent microwave and passive intermodulations (PIM) performance.

Second come high power multichannel rotary joints, primarily for use in the naval and ATC radar markets. Having acquired the intellectual property as part of an acquisition from EEV in 1999, the manufacturing and design processes and features have now been modernised to represent state-of-the-art rotary joint manufacture.

The third product area is the company's traditional business of waveguide-based components, ranging from basic hardware such as waveguide bends, straights, flexible waveguides, etc., through to high power waveguide loads, couplers, transitions and subsystems.

Each of these three product groups is developing new technology. The rotary joint's dominant new technology is the use of fibre optic brush block slip ring assemblies for the transmission of relatively high power data traffic to support active phased-array radar customers.

The main development in the microwave components group is the increasing of power handling and frequency coverage of high power loads using new technologies such as silicon carbide and rubber fillers, allowing ever increasing high temperature operations. Another exciting opportunity in this area is the low cost rubber-based load elements, which can be successfully moulded and sold into the small boat radar and high volume microwave radio markets.

Asked to identify key changes influential in the industry, Nigel Bowes, sales and marketing director, commented, "The biggest change in the marketplace over the last 10 years has unquestionably been the desire of customers to have more depth in their supply of hardware products. The major prime contractors have recognised the need for long-term partnership arrangements, particularly in the military area, where the long-term through-life support is a key success measure for their prime contractorship.

"Therefore there is an obvious logic to collect together a number of products purchased from three of four different suppliers into a single supplier, in order that the placing of continuing business is collective. Credowan recognised this back in the 1990s and joined the Cobham Group precisely to offer a wide range of technologies and products to the ever decreasing number of European prime contractors."

While the company's prime business still remains the UK's domestic space and defence market it has expanded its horizons and over the last year has secured contracts in Canada, Spain, France, Germany and Sweden. Generally speaking Europe remains the company's prime target, while consolidation of its primacy in its chosen market areas remains a priority.

Bowes considers the major driving force in the defence industry to unquestionably be the sustainability of current platforms and through-life support. He explains, "Our major prime contractors are certainly very focused on long-term supplier relationships and an open partnership policy. The communications market is now maturing fast, with I believe, an increasing acceptance that the Far East will offer the prime manufacturing base for most microwave radio and RF communication platforms."

Credowan is focused on supporting the radar market, both defence and ATC—at original manufacturing level and supporting direct end users such as services, shipyards and airports. Bowes proffers, "It is my personal belief that the increasing use of precise and versatile sensor systems throughout the radar industry will sustain that sector of our microwave industry for the foreseeable future."

As far as the future is concerned Bowes believes that the development of long-term relationships more than technologies will drive the industry. He elaborates, "Small has been beautiful over the last decade, where price and speed of response were key, small companies have thrived. The prime contractors however have now recognised the need for long-term sustainable relationships. They are looking less at short-term performance and more at long-term stability; both technological and financial.

"I believe that this is an era for consolidation in the component industry, which will mirror the consolidation in the prime contractor industry over the last 10 to 15 years.

The microwave companies that will be successful in the future will be those who listen closely to their customer's needs, stay closely in touch with technological changes and are flexible enough to meet those needs time after time."

Radiall

From its early beginnings as a manufacturer of coaxial plugs for television in the early 1950s the company has continuously broadened its range of coaxial products. Its core competency is the manufacture of coaxial parts using technologies such as machining and metal stamping, while its other activities in the RF and microwave field are cable assemblies, PTFE-wrapped cable, mechanical switches, passive components and military antennas.

Currently the company is focusing its R&D on several technologies to meet short-term applications demanded by the market. These include the metal stamping of coaxial connectors to meet the needs of the automotive industry in terms of production capacity and yield, reliability and price. In particular the company has developed a system for fully stamped coaxial connectors whereby the machine crimps both the centre conductor and the braid of the coaxial cable on the connector in one single operation, thus enabling very high production capacity.

Plating is another technology in which Radiall is investing. The company is looking into alternative plating to reduce the cost of plating for telecom applications where price reduction is a driving factor. It is also investigating the corrosion resistance of RoHS-compliant plating to replace non-RoHS plating with chrome or cadmium on coaxial connectors used in military applications, which poses a difficult challenge.

For coaxial connectors, the impact of the increase in raw material prices is a major factor, especially for brass. In order to become less affected by price fluctuations, plastic overmoulding technology is being used to replace brass in connectors with non- conductive parts. There is also a focus on products such as lightweight coaxial cable and connectors and smaller dimension antennas for vehicular applications.

The company sees emerging technologies and trends in the aeronautical field as being significant. In civil aeronautics engine manufacturers are developing new engines with less pollution and lower fuel per mileage ratio, so the RF and microwave industry has to follow suit and develop lightweight products. Such products include lightweight Teflon wrapped armoured coaxial cables and lightweight coaxial connectors using aluminum and composite. In wireless communications, fibre optics is playing a role, particularly in the base station, where 'RF type' fibre optic connectors with two or four fibres assembled into a RF N-connector body are significant.

Radiall is well established in Europe. Eighty percent of its sales are made outside its native France and it needs to balance its industrial presence in all continents because of the strong Euro. The acquisition of Applied Engineering Products Inc. in 2005 was significant in the company's expansion in North America and in order to increase its competitiveness the company is looking to expand its production capacity in Mexico.

The company also continues to grow market share in Asia with the help of its manufacturing units in Shanghai, China and Bangalore, India. However, it has two specific issues as far as Asia is concerned. First, the booming economy means that it is difficult for the company to retain highly skilled employees once it has trained them. The second is related to intellectual property protection and the lack of political action with regards to the flouting of connector patents.

Radiall sees defence (including military aircraft) and security as the most demanding market segments for product development. Military radio communications and jamming equipment against improvised explosive devices (IED) are fuelling the demand for new connectors, cable assemblies and antennas. So do array antennas for small high frequency, high density coaxial connectors.

Also, telecom wireless is still strong in underdeveloped countries like India where BTS installation programs are scheduled to run for several years, prompting RF and microwave companies like Radiall, serving this sector to invest in the country.

SUSS MicroTec

The company is primarily a supplier of wafer-level test systems (probers), RF/microwave probes and wafer-level RF/microwave calibration software. In addition, it also provides consultation services, assisting customers in choosing and configuring the wafer-level test systems that suit their application. This also includes working with measurement equipment manufacturers to make sure that the test engineer gets a complete solution.

Currently the company is developing new |Z| Probes (RF wafer probes) for higher frequencies and power as well as expanding the functionality of the SussCal calibration software. As its customers design and produce RF semiconductor devices that use higher frequencies and power, the company endeavours to satisfy their demands to be able to test these advanced devices on-wafer for model verification and improvement. Furthermore, more customers are using RF techniques for traditionally DC measurements such as C-V. They need simple tools that allow them to calibrate their measurement system simply and accurately.

As consumers demand more advanced and less power-hungry devices and the ability to be connected just about anywhere, the company sees differential and multiport device designs becoming more commonplace. The company's marketing group manager, Joshua Preston, explains, "Several years ago, most people would never have thought about using an eight-port measurement system but as world phones, more energy efficient wireless devices and new services like WiMAX and 4G become established, the need for such test equipment and software is becoming acuter."

SUSS is based in Europe but through its network of sales and service centres it aims to be a local company regardless of the customers' geographical location. However, it is working hard to gain a higher profile, especially in Asia, which is strategically important as a growing market with significant potential. To address this, the company opened an Applications and Measurement Centre in Singapore earlier this year.

With regards to influences on technology, Preston states, "We think that the consumer is taking a greater role in driving the industry to new technologies. As consumers, we all want to be more connected with the world and to have more information at our fingertips. And as more of the developing world gets access to these technologies, we will certainly see the consumer taking over the driver's seat."

He also sees new wireless technologies and interconnectivity coming to the fore and explains, "As consumers demand richer and more content, faster performance and more efficiency, the RF and microwave industry will have to respond with newer, more efficient designs that use higher bandwidths. Interconnectivity, that is, the ability of different devices to 'speak' to each other, will also fuel growth. We have already witnessed the power of interconnectivity through the Internet, and that concept will in time transfer to new devices that have wireless connectivity so that they are connected to one another in ways that we wouldn't think of today."

WIRELESS TECHNOLOGIES

Sector overview by ECWT Chairman, Robert Weigel

Wireless technology was once synonymous with mobile phone systems but has developed much further in recent years, as the 2007 European Conference of Wireless Technology (ECWT) testifies. Advances in technology for the phone industry are the enabling force behind many innovations in communications using microwave and mm-wave signals, but applications in the local positioning sector or promising emerging wireless transmission techniques such as UWB are also driving innovation.

Submission to the ECWT technical programme committee closely mirrors industrial and academic research and development efforts in the wireless technology arena, including emerging mobile radio techniques and technologies such as HSPA, 3GPP LTE, MIMO LTE and MIMO WiMAX. In the future we will have to cover up to 25 frequency bands with a mixture of narrow and wide bandwidths. Thus, highly flexible and reconfigurable hardware architectures are greatly needed, both in the baseband, where the research trends are moving from ASICS towards superprogrammable baseband processors (SBP), and in the RF front end, where frequency agile (tunable, switchable) solutions are becoming indispensable.

Besides reconfigurability of architectures and circuit blocks, higher modulation formats such as 64/128 QAM have to be implemented on the system level. At the signal path level, the growing trade-off between selectivity and sensitivity (linearity) has to be addressed. Here, high dynamic range RF signal processing incorporating mixed-signal systems and calibration loops is needed.

At the technology level, new RF and analogue circuit architectures fabricated from 65 and 45 nm CMOS technologies and RF capable CMOS and Si-based integrated technologies are required for the terminal side. With regards to base stations, RF power and its transmission is the main topic. Here, the research trends are towards new power amplifier semiconductor technologies such as GaN for Class S PAs and new smart passive technologies based on functional materials such as metamaterials, ferroelectrics and piezoelectrics.

The whole range of wireless communication is in the ECWT's focus, from the antenna and reconfigurable front-end devices, through signal processing architectures for wireless applications, to modelling or coding techniques. As has been mentioned UWB is

a major topic. Another big subject area relates to antennas, UWB antennas, patch antennas, beam steering concepts, size reduction and special design and construction technologies.

Systems-on-chip, radio architectures and channel investigations are subjects of development, while other growing areas of interest include indoor and outdoor positioning technologies and cognitive or software defined radio.

COMPANY SURVEYS

Farran Technology

Now fully integrated as part of Smiths Group, Farran Technology has over 25 years experience in millimetre-wave and submillimetre-wave technologies. The company can design, prototype and manufacture MMIC-based multi-chip modules for 10 to 320 GHz to customer requirements. It is established in Europe and the US and is intent on growing its business in Asia, where there is significant R&D activity at mm-wave frequencies, including plasma and medical applications.

David Gibbons, managing director at Farran, forecasts wireless technologies as the sector where much attention will be focussed going forward. In particular, he predicts that cellular telephony and data link infrastructure in addition to terrestrial satellite communication systems and mm-wave ground-based communications will see significant growth for mm-wave systems.

Since mobile connectivity is a technology driver, this will see a need for higher bandwidth to extend beyond 100 GHz. This is a prerequisite for video and high definition TV availability via combined broadband access and Gibbons states that the company is well placed to provide products for these new applications.

He also notes that the emerging demand for passive imaging technologies in the security market is driving new developments at the 150 GHz frequency and beyond. Farran has developed low cost advanced amplifier designs and arrays that result in superior resolution for a given aperture size specifically for this market segment.

Gibbons sees that concomitant demand for power will drive increased developments in new semiconductor technology areas such as gallium nitride, while demand for miniaturised devices and more efficient packaging will encourage the use of mm-wave MEMS.

Emerging spectroscopic applications will require sensitive THz-based systems, and thus developments in new quantum sources and detectors will become important. As imaging sensors lower in cost, the deployment of electronically scanned systems in security, satellite systems and a host of civil applications will increase.

Achieving higher frequencies and greater bandwidth will be future goals according to Farran, particularly, very high bandwidth (> 60 GHz) for media data distribution and components in the 150 GHz region for security imaging technologies with higher response speeds and resolution for stand off applications.

IMST GmbH

Founded in 1992, IMST is an independent and private research and development company. Its main activities are the design and development of wireless radio communication components, subsystems and complete systems, which are based on integrated circuits on silicon, SiGe, III-V or IV-VI compound semiconductors. Microwave and mm-wave modules are integrated and packaged using hybrid and LTCC technologies, where LTCC offers the possibility to integrate antennas and their feed networks in various constructions and a three-dimensional technique into the circuit design.

The company develops antennas for wireless communications, multi-band and wideband antennas for mobile terminals, planar antennas for sensors and radar applications, active phased arrays and electronic beam steering antennas for satellite communications. Its development work spans all current wireless communication standards from GSM to HSxPA, WiMAX, 802.11x (a,g,n,p), UWB, GPS/GALILEO, ZigBee and Bluetooth.

This broad area of expertise means that IMST is developing technologies for various applications, including emerging technologies for wireless indoor communication and the application of MIMO concepts in particular. Also under investigation is the application of wireless technologies in car-to-car communication, automotive security and driver assistance systems incorporating intelligent radar sensors at millimetre-wave frequencies.

Other areas of interest include smart antenna solutions for local multimedia data stream distribution, new concepts for electronically steerable antennas for satellite communication and the development of wireless sensor networks, especially for industrial automation, where broadband (UWB) solutions are being considered

As cellular networks continue to evolve from WCDMA/UMTS towards HSxPA and LTE, IMST sees interest growing in WiMAX, which while still under development is being stimulated by the current roll out of backhaul components. The company also sees WLAN technology evolving from 802.11a/b/g towards high data rate systems such as 802.11n, as well as towards high dynamic networking protocols for vehicular communications like in 802.11p, with standards exceeding the current frequency bands and exploring the 60 GHz band for indoor or intra-vehicular communications.

Although IMST is active in almost all relevant worldwide markets such as Japan, China, India, USA and Canada, the major portion of its business is in Europe, where there is demand for novel and innovative solutions for future wireless radio applications to keep Europe at the leading-edge in technology deployment and utilization. Outside Europe, India and China are seen as growth markets, which the company is targeting for expansion through partnerships with companies and institutions.

Standardization has a very important role in communication, according to IMST. For example, the worldwide regulation for 802.11x and WiMAX has fuelled the potential growth of these technologies. Considering not only today's frequencies at 2.7 GHz and 3.5 GHz, but also those above 10 GHz, the standardization of WiMAX could become the key factor for deployment not only as a simple DSL-like access technology but also for standardizing the backhaul of cellular networks. Standardization, of course, leads to more competition, making access cheaper and more widely available.

As for the future, IMST believes that a major factor that will fuel the wireless industry is the trend for more individualism, more media sovereignty (on TV, video, audio broadcasting and internet) and unified access capabilities, which will all require larger transmission rates and more efficient frequency bandwidth utilization. The desire for increased mobile content means that current cellular phone systems must be developed to higher transmission data rates, higher frequencies and be user friendly. This can be achieved through the long-term evolution of the available networks, with the progression of software defined radio techniques and other new developments on the physical layer being urgently needed.

Also, IMST envisages mobile satellite communication changing from a niche market to a high penetration market offering data and voice services inside planes, ships, trains and cars, which will push the production of satellite terminals to much higher volumes.

ICS & SEMICONDUCTORS

Sector overview by EuMIC Chairman, Klaus Beilenhoff

Compound semiconductor devices and ICs are building the core of today's microwave and mm-wave subsystems. Whereas in the past GaAs was viewed as the workhorse for many applications ranging from telecommunication to defence, Si-based and new emerging high power technologies are gaining ground and attempting to take market share. However, this statement needs to be quantified for the individual microwave and mm-wave markets.

The GaAs semiconductor industry remains the main supplier of active components and ICs for the wireless telecommunications market. However, business conditions are tough and the industry is still suffering from a volatile market after the telecom crisis in 2000/2001. Consolidations (for example, Nokia/Siemens, Alcatel/Lucent) driven by cost reduction plans are demonstrating the continuous price pressure faced by the market. The component and MMIC manufacturers are also in a difficult situation since the worldwide capacity for manufacturing III-V compound semiconductors is higher than the demand, creating additional price pressures.

It is not only price that is driving the telecom market. Technical innovations have led to new challenges too. Mark Murphy from NXP, one of the keynote speakers in this year's EuMIC, mentions in his presentation abstract: "The cellular wireless (base station) industry is at a key phase in its evolution path from today's third-generation systems towards next generation (4G) systems. New technologies are required to achieve data throughputs in excess of 100 Mbps." Ultra Wideband technology is another area of technical innovation. Although invented in 1950 it is still on its way to becoming a standard but more and more component and IC designs for this market are appearing, mainly based on Si-based technologies.

The market for III-V compound semiconductors in the defence domain is increasing following the start of real volume production of modern active phased-array radar technology in Europe. However, the price pressure seen by the telecom market is also appearing in the defence domain and, thus, there is a trend towards the use of commercially available products and technologies (COTS). Nevertheless, the speed of innovation exhibited by commercial markets is often a stumbling block for utilising such products in long-term defence programmes.

There is also a strong market increase in the automotive sector. The 77 GHz radars used for adaptive cruise control are still important, but the emerging 24 GHz short-range radar applications have taken the lead. This can mainly be attributed to the fact that new safety features can be introduced leading to better market acceptance. Due to the high number of microwave systems forecast and the good history of Si-based components and ICs, the Si-based technologies (SiGe, CMOS, BiCMOS, etc.) are constantly attempting to enter these emerging 24 and 77 GHz markets. However, GaAs can still compete and is the benchmark in terms of performance.

As was mentioned, the typical GaAs market is facing competition in the low frequency and low power domain from Si-based components and ICs. The rising star for power applications is gallium nitride. Many semiconductor manufacturers are working on this new wide band gap material and aiming to get the first products to market, while research labs are still working on some fundamental questions. The pressure felt from the base station and defence markets is significant since gallium nitride makes it possible to achieve higher output powers over a wider frequency range at excellent power-added efficiency (PAE).

We are also seeing an increasing demand for packaging of monolithic microwave and mm-wave ICs (MMIC), in order to reduce module manufacturing costs by implementing SMD technologies for frequencies up to 30 to 40 GHz. Even beyond this limit, packaging becomes more and more important since the module manufacturing costs (die pick and place, soldering/gluing, bond wiring, module sealing) are tremendous especially for price sensitive markets.

COMPANY SURVEYS

OMMIC

The main activities of the company are the design and manufacture of GaAs PHEMT and InP HBT-based MMICs and associated fabrication and services (measurement, packaging, qualification, engineering, etc.) of MMICs, as well the supply of epitaxial wafers to the merchant market.

Current developments include enhancement mode 100 nm, 150 GHz MHEMT technology for next generation intelligent antennas that exhibit lower noise, lower power consumption, smaller size RF functions and higher density lower power consumption digital functions. Add to that 300 GHz, 70 nm MHEMT technology for security type applications (passive imaging) at high millimetre-wave frequencies and fully integrated RF MEMS for phased-array antennas, adaptive matching and redundancy switching.

OMMIC has a well established customer base in Europe and, for a number of years, has been developing its presence in Asia and India where the company has a number of important customers and contracts. Asia, in particular, is a large and dynamic market susceptible to value added technologies.

In general the III-V business has been driven by the military or handset requirements giving rise to two very different types of suppliers. However, OMMIC has been able to span both markets, maintain a customer base spread over the communications, space, security and defence markets, and developed products that cross these boundaries.

Being in the foundry business and a manufacturer of semiconductors means that environmental issues are very important to the company, not only from a legislative viewpoint but there is also a growing customer requirement to respect the environment. This is viewed as positive, leading to better operation of the Fab, the use of fewer materials and the reduction of energy consumption.

Looking forward the belief is that each application will drive or be driven by its own unique set of technologies and standards. For example, GaN will be important for the defence industry, but its role in other applications will depend on new standards with higher frequencies. Otherwise LDMOS will maintain its dominance in these markets.

Also, OMMIC foresees that the growth of the security market will foster the development of advanced short gate length high In content HEMT technologies, such as the 70 nm MHEMT process where the combination of a robust technology, high performance and high yield opens up a much wider market for passive imaging systems.

Reinhardt Microtech

As one of the largest independent thin film manufacturers in the world, the leading one in Europe and a key supplier to the US market, the company manufactures customized thin film substrates and passive MEMS for RF, opto-electronic, medical and microelectronic applications.

Currently, technological development is concentrated on thermal heat sinking, high density packaging and assembly, which focus on the miniaturization of microelectronics components. Emerging technologies that impact on this market are design to assembly and testing, together with packaging and stacking technologies.

In its field Reinhardt identifies the key players as the military (radars), security (sensors) and telecommunication. It does not see the situation changing dramatically except that it expects telecommunications to take a more prominent position driven by a fairly stable world economic situation.

The company believes that globalisation will lead more and more to standardization, running in parallel with the harmonization between the fields of application. It accepts that this will create additional work, but will result in greater interchangeability. Conversely, Reinhardt sees other issues as being detrimental to market development, for example, the US ITAR restrictions, which it believes is closing most of the US military markets to European companies.

As for the future, the company identifies three distinct areas as driving the markets in the thin film business—multimedia applications demanding larger bandwidths in the telecommunications sector, mm-wave-based sensor technology for security industries and adapted phased-array radar technology for the military sector.

RADAR

Sector overview by EuRAD Chairman, Jürgen Detlefsen

The European Radar Conference was established in 2004. Since then it has established itself towards the top of the hierarchy of international radar conferences and as such offers an insight into the breadth and depth of current developments in the field of radar and a barometer of the most recent advances. Within the context of European Microwave Week, EuRAD is particularly useful for evaluating the latest developments within the context of all the other activities in the microwave community.

Looking at this year's conference, it is no surprise to discover that common trends such as UWB, MIMO, and Dual Use are impacting on the world of radar applications. They demonstrate, together with the ability to take advantage of low cost microwave components and to design low power, solid state radar sensors, the convergence of communications techniques, and technologies and radar. On a system level this trend is emphasized within the conference by a focussed session on *Communication by Radar*.

The conference contributions reflect the current trends and activities within the industry and cover a wide range of topics from broadband radar, passive radar to sophisticated radar signal and data processing, including STAP. Significant too are SAR techniques, SAR interferometry and imaging, both from a scientific as well as from an applications related viewpoint. The origin of contributions demonstrates a thriving European radar community, with contributions from the Newly Independent States being particularly significant.

At the high frequency end of the spectrum there is increasing interest in exploiting mm-wave frequencies from 60 GHz upwards, helped by significant progress in the high frequency behaviour of deep sub-micron silicon-on-insulator technologies. The development and adoption of automotive radar systems at 77 GHz are impacting on the high-end automotive sector. It is of key strategic importance to Europe's economy and there is continuing interest in automotive radar systems. The aim is to provide further driver assistance functions which are capable of reducing road injuries and fatalities.

A rapidly growing area of research and development is related to imaging for security, using active and passive millimetre-wave techniques. The efforts of the European Union within the Seventh Framework Programme, which devotes a complete topic to security, will also advance the application of radar sensors. Increasing the security of citizens, of infrastructures and utilities, realising intelligent surveillance and enhancing border security are fields where radar can be successfully applied. Even at much higher frequencies, there are intriguing signs in Europe that the application of terahertz technologies is beginning to open up new markets and opportunities.

Also, the concern about the environment has led to significant research into radar remote sensing of the atmosphere from space, airborne and land-based platforms. An important milestone was the launch of TerraSAR-X in June 2007, a new German high resolution radar satellite with an X-band SAR sensor that can be operated in different modes (resolutions) and polarizations. The mission objective is the provision of high quality, multi-mode X-band SAR data for scientific and commercial applications. A future extension will be the TanDEM-X mission, which will comprise two fully active SAR satellites operating in X-band. The primary goal of this mission is the derivation of a high precision global Digital Elevation Model (DEM).

With the launch of TerraSAR-X, 2 SAR-Lupe satellites, Cosmo-Skymed by the Italian Space Agency and the start of the development of Sentinel-1 by the European Space Agency, Europe is entering into a new era with several high resolution SAR satellites and therefore, expanding its leading role in the technologies and applications of radar remote sensing for earth observation.

COMPANY SURVEYS

AFT Microwave

With radar applications being a specific focus the company has expertise in the design and production of passive RF components such as waveguides, circulators, loads, isolators, couplers, phase shifters, thin film substrates and hybrids. The areas of application range from milliwatts for the thin film technology up to kilowatts or even megawatts for coaxial or waveguide applications. Nowadays, both these approaches have a role to play in radar applications as distributed low power RF systems or high power sources can be distributed to the radiating elements.

To achieve a high integration and light weight, thin film becomes a part of the housing itself. Therefore, the company has been working to develop technologies that achieve hermetically sealed housings with integrated circuitry serving as package and carrier for the active components. It is also striving to address the growing demand for low loss drop in circulators/isolators in order to improve output power and noise figure of the Rx/Tx systems.

In the field of scientific particle acceleration AFT Microwave serves the worldwide market for high power circulators and isolators. This expertise in high power RF components (up to 65 MW peak or 1.3 MW CW) serves the growing demands from radar applications, mainly driven by solid state components.

The company identifies the defence and security sectors as being major driving forces. It sees the growing market addressing military applications resulting from homeland security and new technology in the ECM and radar area as fuelling the need for high quality and low cost products for a new generation of systems. The company believes that due to reduced costs a better market acceptance can be achieved leading to an increased volume of sales of systems and, therefore, also components.

e2v

e2v manufactures a broad range of products used in the transmit and receive sections of microwave radar systems used in defensive and commercial ground, sea and airborne radar systems as well as radar systems used as part of automotive adaptive cruise control (ACC) systems.

Almost all of the vital building blocks needed in a radar system are designed and manufactured by e2v, starting at S-band and going through to W-band. The company is unusual in that it is involved with technology starting at semiconductor level right through to the initial stages of signal processing in a radar system. Products include travelling wave tubes (TWT), high reliability microprocessors, magnetrons, thyratrons, compact modulators, G3 diodes, microwave receiver protection and microwave receivers.

The company sees a trend to move away from traditional Doppler radars particularly at the low cost end of the market, and is therefore developing new all solid state coherent radars, which will be able to offer the required performance, particularly in marine applications.

It is continuing to develop radars operating at mm-wave frequencies, particularly at 77 GHz. For example, it is a member of a consortium that has just been awarded funding from a recent DTI Technology initiative. This is to develop a new radar system, which will be used in security applications and will be capable of detecting unauthorised movement in large enclosed areas such as airfields.

Focussing on emerging technologies that are of significance to e2v, Nigel Priestley, chief engineer at e2v's Lincoln facility, commented, "Semiconductor technology is a very important area to us; in particular the increasing use of high power wide band-gap devices for higher power amplification. Novel antenna structures using microfabrication techniques and MEMS are also likely to have a major impact."

As for the development of technology, Priestley states, "The microwave industry is entering a period where the pace of innovation needs to accelerate. With a few notable exceptions, for example the Eurofighter Typhoon, there has been a slow down in the development of new designs and technology advancement following the end of the Cold War and a delay in some major defence programmes—now there is a need to recover the lost ground."

Priestley sees environmental, standardisation and political factors impacting on manufacturing methods and comments, "This has driven the use of new materials to comply with new stringent environmental standards. The regulatory groups for example, ETSI and FCC, have a major bearing on the design and performance of new component and sub-system design. On a political front, the trend for European manufacturers to make increasing use of lower cost economies for volume manufacture is more important now then ever before."

As for the future, he believes the next few years will see the introduction of technologies which will make radars smaller, lower cost and easier to build as a working system. From semiconductor (and tube) level upwards there will be a faster rate of progress. He sees radar being accepted in other markets, outside of the traditional defence and aerospace sectors, as an affordable and highly capable sensor technology—a situation that is beginning to be recognised.

MESL Microwave

MESL Microwave (formerly Thales MESL) designs and manufactures active and passive microwave sub-systems and components. It was one of the first companies to supply surface acoustic wave pulse compression subsystems to European radar manufacturers and has a long history of supplying waveguide components such as duplexers and ferrite phase shifters for radar antennas. With the advent of the active array the company developed a range of package drop-in and microstrip circulators for duplexing on Tx/Rx modules and has a first-class capability in microwave module design and assembly.

The telecoms market drives many of the new developments in MESL Microwave, but there are areas in the defence market that the company is specifically developing new technologies for. Developments in conformal arrays and broadband multi-function active arrays, is prompting the company to look at the products required to realize these emerging technologies, for example: lightweight, packaged broadband circulators and isolators. Module manufacturers are looking for all components on a MIC module to be surface mountable and MESL is addressing this by developing more surface-mount solutions such as a new range of surface-mount duplexer designs to address customers requirements for reflow processing. The company is also looking at novel packaging approaches to reduce the footprint and mass of circulators.

The company is active in MIC module design in Ku- and Ka-band, but the increase in applications operating in the 60 to 100 GHz range means it will focus more development activity on components and modules in this market in the future. For example, the company has recently evolved its packaging solutions for 77 GHz modules.

MESL Microwave's separation from Thales creates new opportunities for the company. Previously as part of Thales it had been viewed as part of a group that competes with the companies that MESL was trying to sell to. With divestment from Thales such barriers have been removed and it can look forward to increased involvement with the major defence OEMs.

The company trades around the globe but India, the Far East and the US are areas it can foresee growth in. There are ITAR hurdles that make doing business in the US more challenging; nevertheless the company had some significant successes both in the defence and homeland security markets. There has been increased dialogue between the UK and the US to try and relax the export control rules between the countries and this is something the company is monitoring with interest since it could facilitate increased business in the US.

Looking to the future, MESL believes that as an independent company it is well positioned to address the requirements for low cost microwave sub-systems, Tx/Rx modules and components that defence OEMs will require to realize their vision of smaller, lighter, lower cost radars and seekers.

INTERNATIONAL PERSPECTIVE

Those are the views of those from and operating in Europe. Are they shared by companies from outside the continent or do they have a different perspective with regards to doing business in Europe? To find out we took a small snapshot of companies from across the globe. It is not claimed to be a comprehensive survey, but is designed to give a flavour of how the European microwave industry and market is perceived worldwide. This report cannot comprehensively cover a large number of companies. However, it has canvassed companies in North America and Asia—Japan, Korea and Taiwan—to offer a contrast of established and evolving industries, household names and new market entrants.

COMPANY SURVEYS

North America

Anaren

Manufacturing at three ISO-certified facilities worldwide, the company supplies microwave/RF-based technology for the wireless infrastructure, satellite communications, medical, automotive, consumer products and defence sectors. Product lines include passives (couplers, power dividers, baluns, splitter/combiners), actives (vector modulators, mixers), resistive components (resistors, terminations, attenuators), ferrites (circulators, isolators) and complex assemblies (switch networks, beamformers, antenna feed networks, DRFMs, IMAs).

The company is currently focussed on technological development on four fronts. First among these are entirely new generations of surface-mount component lines aimed at wireless infrastructure targeting sizable gains in performance, size and price reductions, along with reduction of the bill of materials. Second, in the infrastructure sector, the emphasis is on custom solutions for a handful of key customers, including a unique approach to a high-power combiner for large European OEMs.

Third, based on size reductions and materials breakthroughs the company has made on the infrastructure side, Anaren is now carving out a niche in select wireless consumer electronics applications such as handsets, broadcast applications like HD set-top boxes, and some Bluetooth products, available in form factors as small as 1 × 1 mm. Lastly, the company plies its expertise with complex, high density microwave design to defence and space sector OEMs. Applications range from assisting on a DoD technology that detects wireless roadside explosives to satellite-based beamforming solutions.

"We continue to see solid demand for our technology in support of 2G systems worldwide, as well as an up tick in orders and design assistance relating to 3G infrastructure, which is finally gaining traction," says Bo Jensen, business development manager for the company's Wireless Unit, with regard to current market activity. "Beyond that, of course, there has been a significant amount of noise in the market related to WiMAX and similar systems; to that end, we've had significant design work going on and have developed components to support these opportunities."

The company's products and technologies are partly targeted at a handful of infrastructure OEMs, many of whom are based in Europe, but whose footprints and markets are truly global. Its efforts rely on close coordination with distribution partners and its own international technical sales offices. With both European-based technical sales offices and robust travel schedules for several of its top engineers, the company believes its European OEM customers are well served.

"Like most component suppliers, we are attuned to and proactively achieving compliance with important EU standards that may apply to us: the lead-free RoHS standard is an environmental example," elaborates Jensen.

"Beyond that—and being mindful of the fact that demand for higher data rates certainly exist in the EU compared to developing nations—our customers are generally not developing infrastructure totally unique to Europe, so we in turn are not typically charged with developing regionally distinct technology at our level."

Moving on to the wider market he adds, "There is clearly a cyclical relationship between 'market stimulation' and technological advances. For example, as new manufacturing techniques, materials processes, or altogether new uses of materials enable us to support smaller, smarter and more cost-efficient base station equipment being developed, our customers can reduce operating costs and establish coverage where resources are not so readily available. In essence, the demand cycle has moved forward based on technology improvement."

Focussing specifically on the European market, the company has seen consolidation among OEMs in Europe, and expects the resulting organizations to consolidate their supplier base in turn. As for forecasting overall demand for wireless services in Europe, Jensen notes that there is very high penetration in this market. As such, one might assume that unfailing system performance and ever-higher data rates will become increasingly 'standard', while differentiators such as new services, service bundling, or decreased prices to the consumer will increase as service providers battle for rare 'new' market share.

Mimix Broadband Inc.

The company designs, develops and supplies GaAs semiconductors from DC to 50 GHz for commercial and military applications. It uses its semiconductor design capabilities and systems level expertise to meet customer and market requirements for lower acquisition and assembly costs and is currently developing higher power/more linear power amplifiers and more highly integrated devices at higher frequencies in plastic QFN packaging.

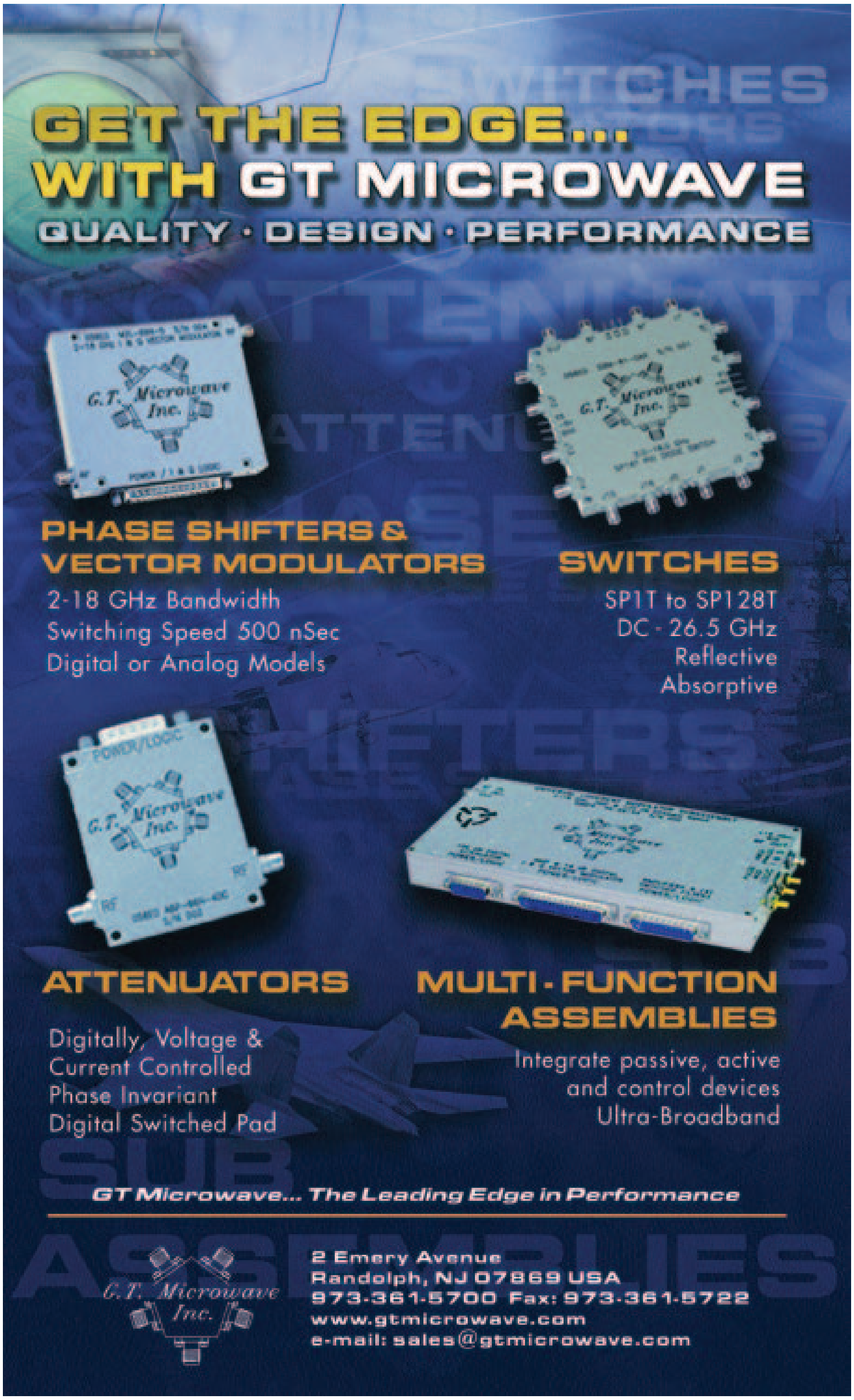
Current market demands in wireless communications require that equipment suppliers lower costs and increase performance. In Mimix' opinion, this trend forces design engineers to develop higher levels of product integration to meet these requirements, with the key being the integration of four functions or more into a single MMIC. Integration offers a number of benefits for millimetre-wave components, including lower costs and variability of transceivers from using fewer parts, a smaller footprint area and a simpler design. It also reduces the need for off-chip interstage matching between RF components.

Rick Montgomery, CEO of Mimix Broadband, comments, "In addition to the development of highly integrated devices, increasingly more microwave and millimetre-wave devices are being housed in standard QFN surface-mount packages. The continued growth in wireless communications has placed tremendous pressure on component manufacturers to provide standard QFN surface-mount packaged products for large scale PCB assembly flow, in order to lower costs and ease handling and assembly for mass production."

In Europe the company is particularly active in Finland, France, Germany, Israel, Italy, Norway, Russia, Spain and Sweden, and does develop RF and microwave products specifically for European customers, in particular for the PTP radio market and wireless infrastructure market. In addition to catalogue products, it also offers custom designs that meet specific customers' needs.

The company also believes that offering highly integrated devices, housed in plastic packages enhances the value proposition with respect to lowering cost, standardizing manufacturability, increasing reliability, reducing footprint area and simplifying design.

Mimix has been a pioneer in developing highly integrated devices, offering 3-Chip Solutions for several years now. Initially, customers had to be convinced, but in the last 12 months there has been a shift with customers now purchasing large volumes of integrated devices.



Montgomery explains, "A convergence of market imperatives is occurring, with the result being customers purchasing not only highly integrated devices, but those which are housed in standard QFN surface-mount packages. Now customers require only three to four packaged high frequency devices to complete an entire transceiver."

Over the next few years, the company expects to see greater adoption of highly integrated and packaged devices across all applications and markets. This shift will be required to meet the price pressures and also the greater demands for reduced time to market in new product development cycles.

Japan

Hirai Seimitsu Kogyo

Established in 1967 the company provides high precision photo-etching including the fabrication of multi-layered LTCC substrates, precision photo etching of various metals and polyimide. It is also a world leader in the field of metal etching. Other capabilities include the plating of metals and other surface treatment along with mechanical forming such as NC machining, laser cutting, wire EDM, welding, thermally pressurized bonding and stamp forming. Specifically in the RF field the company provides in-house plated LTCC substrates for RF modules and lead frames for RF and/or RF power devices.

New technologies that Hirai SK is currently developing include: thin film metallization of the LTCC substrates for the higher Q at micro and millimetre-wave frequency bands and for finer pitch patterning, improvement of the metal paste printing, shape and materials for the higher Q or lower resistivity at mm-waves, and microwave sintering to reduce the costs of LTCC. The company also sees thin film metallization, artificial dielectric materials/nano technologies and frequency agile or tunable materials as being key issues impacting on development.

Hirai SK sees itself as having the traits of a typical Japanese company as it is good at precision handling, has high yield and quality, is traditionally good at ceramics fabrication, can carry out a large number of iterations to optimize processes and can ship samples quickly (generally within one week).

The intention is to capitalise on these qualities and its presence at the European Microwave Exhibition to establish itself in Europe. Target countries are broad, including Germany, UK, France, the Netherlands, Belgium, Switzerland, Austria, Denmark, Italy, Spain, Portugal and Scandinavia.

Particular effort is going into providing a design library or RF design support for the LTCC foundry service and miniaturization of LTCC substrates, resulting in highly integrated modules as more multi-bands and multi-modes are required in Europe.

With regards to the future Hirai SK believes that in the field of low power, the integration to the chip will be enhanced and the chip will be mounted onto the motherboard directly, leading to a reduction in the number of modules, resulting in low output power. The company also envisages millimetre-wave applications developing with the emergence of CMOS devices, integrating the high speed basebands. As a result, higher Q and finer patterns may be required as the module substrates.

Korea

Yeeun Tech

The development and manufacture of RF technology products are the company's core activities and its product range includes RF coaxial connectors and adaptors in most of the standard worldwide standards—MMCX, MCX, SMA, N, 7-16, BNC, TNC, etc. In addition, it offers a range of RF/microwave components including filters, power splitters, couplers, attenuators, up/down conversion products, PLL and terminations. As well as standard products the company produces customise products to short time scales at competitive prices.

In the marketplace, Yeeun Tech is experiencing renewed growth in the telecommunications market. The WLAN repeater sector is particularly strong as is the deployment of WiMAX, where the company offers connectors, cable assemblies, terminations and attenuators.

Traditionally, the company is strong in the key Asian markets of Korea and Singapore and exports to the Middle East, North America and Europe. It is currently targeting new business in the UK and Germany and plans to establish a European branch in the UK. The aim is to give a company that is headquartered and manufacturing in Asia a greater local presence and therefore aid efficiency.

The company sees having the ability to satisfy quality and cost requirements as being paramount to continued growth in Europe, together with compliance with 'local' regulations. In particular, it ensures that all of its products meet RoHS requirements.

The future trends that Yeeun Tech identifies include the widespread adoption of WiMAX products and services in Europe, giving the end consumer another wireless option to explore, with high data rates of up to 65 Mbits/s at close range, to 16 Mbits/s at distances of around 9 to 10 km. It also predicts the continued growth of 3G telecommunications.

Taiwan

Daa-Sheen Technology Co. Ltd.

Since 1986 the company has been designing and manufacturing RF and microwave coaxial connectors and adaptors, including SMA, SMB, SMC, MMCX, MCX, N, BNC, TNC, FME, 7/16, 1.6/5.6, SMZ, SMP, MIMI UHF, VHF and CATV/satellite. As well as standard designs it also custom designs to customer requirements in all its fields of operation: telecommunication, military, aerospace, automotive and medical.

As a specialist in customised connectors and adaptors, Daa-Sheen is developing innovative manufacturing techniques. It is continually updating the processes and materials it uses, with every effort being made to keep up to date with the latest equipment and materials available.

The company is a global enterprise with customers in Australia, US, South America and Japan as well as Europe. In Europe, its main markets are Germany, Holland, the UK, France, Switzerland, Italy, Belgium, Finland, Spain and Poland, but the company is currently in the process of talking to new customers in a number of European countries. It develops its products to meet the growing needs of customers, with particular emphasis on supplying customised parts.

When considering what the company brings to the European market it cites quality products, aligned with affordable, accurate, and reliable performance at a low price, aimed at giving its customers a competitive edge. One reason that this can be achieved is down to the flexibility of production management and the workforce in Taiwan, enabling the company to focus on the needs of its global customers, with their particular requirements.

With regards to the future, Daa-Sheen envisages closer trade relations between the East and West and technologically greater moves towards the miniaturization of components with more capacity and power.

CONCLUSION

This report began by recalling the first EuMW a decade ago, evaluated the status of the European microwaves industry at that time and outlined the key economic, political and commercial landmarks of the intervening 10 years. However, its aim is not to dwell on the past but to provide an insight into current activity, an understanding of the marketplace and identify the drivers taking the industry forward into the next decade and beyond.

What has emerged, particularly from the overviews and surveys, is optimism in the fact that the European microwave industry has continued to consolidate and is on a stable economic upturn. It should not be distracted by the general preoccupation with globalisation and the ‘threat’ posed by low cost mass production emanating from emerging markets, but concentrate on its own strengths. The European microwave industry’s core competencies of a highly skilled research and development capability and the production of added value products and services are valuable commodities to be exploited.

To do so on a pan-European scale requires long-term, forward thinking structured co-operation and coordination throughout the continent. Significant initiatives are in place and are bearing fruit. In particular, the European Union’s Competitiveness and Innovation Framework Programmes are doing just what their title implies—identifying, promoting and stimulating competitiveness and innovation. The newly introduced 7th Framework Programme and the associated Networks of Excellence Programmes are specifically encouraging the involvement of industry alongside academia to address Europe’s traditional weakness in commercialising the results of research and identifying the market potential of new technology.

As well as the EU, the European Space Agency and the European Research Advisory Board are familiar agencies, but for almost all sectors of industry and research there are like bodies co-ordinating, sponsoring and financing technological development across Europe.

As this report testifies the depth and variety of the development work currently being undertaken in Europe is substantial, which does not make identifying future technological trends easy. However, in the RF and microwaves sector higher frequencies are being exploited with the upper mm-wave and terahertz region opening up new markets and opportunities. Wireless sensors integrating novel sensor technologies are finding applications ranging from RFID, climate monitoring and biomedical systems. Wireless communication is an area rife with innovation and the parallel development and long-term adoption of WiMAX and LTE is worth monitoring. Semiconductor technology is moving apace with Si-based components and ICs providing competition to GaAS particularly in the low frequency and low power domain. For power applications the pressure is on to bring gallium nitride to market. In the radar sector the application of radar sensors and imaging for security using active and passive millimetre-wave techniques are warranting attention.

As EuMW marks its first decade the European microwave industry can celebrate its well being and potential for growth. ■

ACKNOWLEDGMENTS

The author would like to thank the EuMW and conference chairmen and company executives who shared their in-depth knowledge and expertise. Their contributions have given a rare insight into the microwave industry from those working at the forefront of academia and industry.

NOISE MINIMIZATION TECHNIQUES FOR RF AND MW SIGNAL SOURCES

Low noise RF and microwave (MW) signal sources (oscillator/VCOs) are crucial for the development of high bit rate wireless link multi-standard systems such as point-to-point radios or multipoint radios. Since the oscillator/VCO is one of the key contributors to overall phase noise performance, its contribution must be minimized as much as possible. This article presents an analytical method to minimize the noise with which it is possible to determine the component parameters that mostly affect the phase noise performance for a given class and topology.

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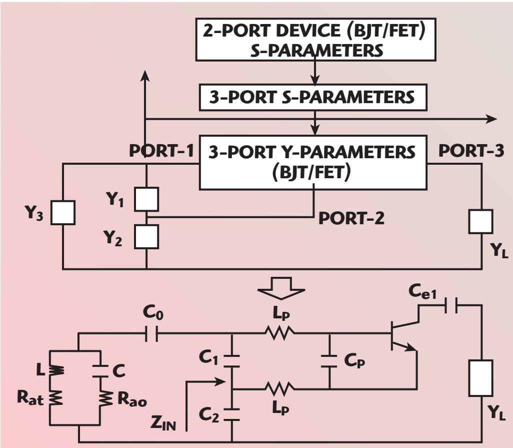
The phenomenon of phase noise generation in oscillator/VCOs has been the main focus of important research efforts and is still an open issue, despite significant gains in practical experience and modern CAD tools for design. In the design of oscillator/VCOs, minimization of the phase noise is the prime task and this objective has been accomplished using empirical rules. Therefore, the predictive power of the model is limited.[1–5] The phase noise is a critical figure-of-merit because it affects the dynamic range, selectivity and sensitivity of a receiver.[2–4] The ability to achieve minimum phase noise performance is paramount in most RF and MW designs, and the continued minimization of phase noise in oscillator/VCOs is required for the efficient use of the frequency spectrum. This article presents an analytical approach for noise minimization techniques in terms of the oscillator circuit component parameters, leading to minimum phase noise for a given class of VCO topology.[5–27]

Fig. 1 Colpitts oscillator with base lead inductance and package capacitance using a three-terminal active device.



OSCILLATOR THEORY

Figure 1 shows a simplified Y matrix approach to describe a typical oscillator circuit and the flow chart on how to convert two-port S-parameters to a three-port configuration, using a three-terminal active device. The expression for the input impedance of the oscillator circuit shown is given by

$$
\begin{aligned}
&Z_{IN}\big|_{package} = \\
&-\left[\frac{Y_{21}}{\omega^2\left(C_1+C_p\right)C_2}\,\frac{1}{\left(1+\omega^2Y_{21}^2L_p^2\right)}\right] \\
&-j\left[\frac{\left(C_1+C_p+C_2\right)}{\omega\left(C_1+C_p\right)C_2}\,\frac{\omega Y_{21}L_P}{\left(1+\omega^2Y_{21}^2L_p^2\right)}\right. \\
&\left.\frac{Y_{21}}{\omega\left(C_1+C_p\right)C_2}\right] \Rightarrow Z_{IN}\big|_{withoutpackage} = \\
&-\left[\frac{Y_{21}}{\omega^2C_1C_2}\right]-j\left[\frac{\left(C_1+C_2\right)}{\omega C_1C_2}\right] \qquad (1)
\end{aligned}
$$

where

Y_{ij} (i,j=1,2)= Y-parameters
L_p = base-lead inductance
C_p = base-emitter package capacitance of the BJT

From Equations 1 and 2, the base-lead inductance makes the input capacitance appear larger and the negative resistance appears smaller. The equivalent negative resistance R_{NEQ} and capacitance C_{EQ} can be defined as[4]

$$
\begin{aligned}
&\frac{1}{C_{EQ}} = \left\{\left[\frac{\left(C_1+C_2+C_p\right)}{\left(C_1+C_p\right)C_2}\right]\right. \\
&\left.-\left[\frac{\omega^2Y_{21}L_P}{\left(1+\omega^2Y_{21}^2L_p^2\right)}\right]\left[\frac{Y_{21}}{\omega\left(C_1+C_p\right)C_2}\right]\right\}
\end{aligned}
$$

$$
R_{NEQ} = \frac{R_n}{\left(1+\omega^2Y_{21}^2L_p^2\right)}
$$

where

$$
R_n\Big|_{without-package} = -\frac{Y_{21}}{\omega^2C_1C_2}
$$

The oscillator resonance condition is given by[16]

$$
\begin{aligned}
&j\left[\frac{\omega L}{1-\omega^2LC}-\frac{1}{\omega C_C}\right] \\
&-j\left[\frac{\left(C_1+C_p+C_2\right)}{\omega\left(C_1+C_p\right)C_2}-\frac{\omega Y_{21}L_p}{\left(1+\omega^2Y_{21}^2L_p^2\right)}\right. \\
&\left.\frac{Y_{21}}{\omega\left(C_1+C_p\right)C_2}\right]_{\omega=\omega_0} = 0 \qquad (2)
\end{aligned}
$$

$$
\omega_0 = 2\pi f_0 \Rightarrow f_0 = \frac{1}{2\pi}\sqrt{\frac{\left[C_2C_1+C_1C_c+C_2C_c\right]}{L\left[C_1C_2C_c+C_1C_2C+C_1CC_c+C_2CC_c\right]}} \qquad (3)
$$

where

f_0 = oscillator resonance frequency

The performance of an oscillator can be evaluated by the figure-of-merit (FOM) and can be described by

$$
\begin{aligned}
\mathrm{FOM} &= \mathscr{L}(\omega) - 20\log\left(\frac{\omega_0}{\omega}\right) \\
&+10\log\left(\frac{P_{DC}}{1\mathrm{mW}}\right)\mathrm{dBc/Hz} \qquad (4)
\end{aligned}
$$

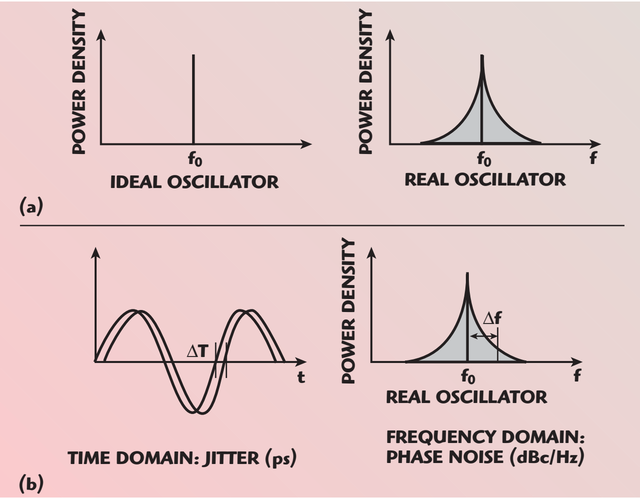
The first and third terms of Equation 11 represent the contributions of phase noise and power consumption (P_{DC}) to FOM, respectively. From Equation 11, the phase noise for a given offset has a greater impact on FOM than the power consumption does for a given oscillator frequency f_0. From Equation 3, the degree to which an oscillator generates a constant frequency f_0 throughout a specified period of time is defined as the frequency stability of the signal source. The frequency instability, due to the presence of the noise in the oscillator circuit, modulates the signal, causing a change in frequency spectrum commonly known as phase noise. ***Figure 2*** illustrates the frequency spectra of ideal and real oscillators and the frequency fluctuation corresponding to jitter in the time domain, which is a random perturbation of the zero crossing of a periodic signal.

Phase noise and timing jitter are both measures of uncertainty in the output of an oscillator. Phase noise defines the frequency domain uncertainty of an oscillator, whereas timing jitter is a measure of oscillator uncertainty in the time domain. The equation for an ideal and real oscillator in the time domain is given by[4]

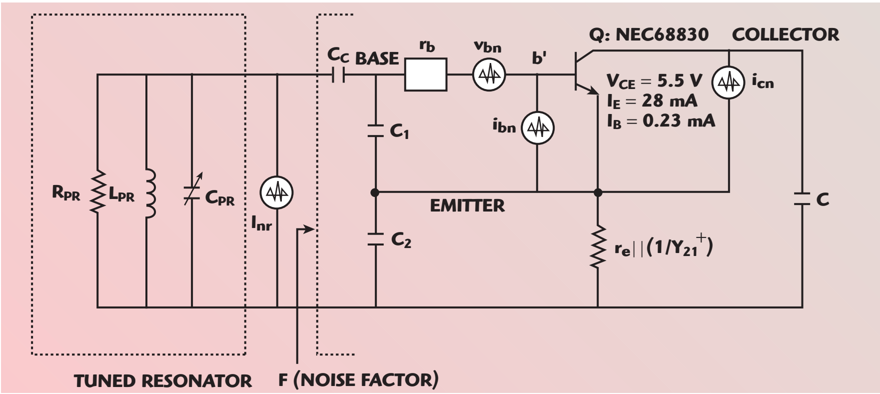
$$
\left[V_{out}(t)\right]_{ideal} = A_0\cos\left(2\pi f_0 t+\phi_0\right) \qquad (5)
$$

$$
\left[V_{out}(t)\right]_{real} = A(t)\cos\left[2\pi f_0 t+\phi(t)\right] \qquad (6)
$$

where A_0, $A(t)$, ϕ_0, $\phi(t)$ and f_0 are the fixed amplitude, time variable-ampli-



▲ *Fig. 2 Frequency spectrum of ideal and real oscillators (a) and jitter in time domain relating to phase noise in the frequency domain (b).*



▲ *Fig. 3 Equivalent circuit of a Colpitts oscillator with noise sources.*

tude, fixed phase, time variable-phase and free running frequency of the oscillator.

From Equations 5 and 6, the fluctuations introduced by A(t) and $\phi(t)$ are functions of time and lead to sidebands around the center frequency f_0, giving a direct relationship between phase noise and the spectral output of the oscillator. The phase noise is defined in terms of the noise spectral density, in unit of decibels below the carrier per Hertz and is given by

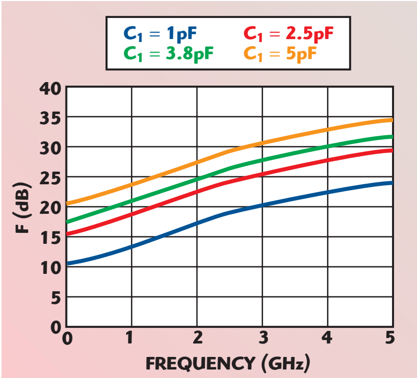
$$\mathcal{L}((f_m) = 10\log\left[\frac{P_{sideband}(f_0 + f_m, 1\text{Hz})}{P_{carrier}}\right] = 10\log\left[S_\phi(f)\right](\text{dBc/Hz}) \quad (7)$$

From Equation 7, the expression for the phase noise is given by[16]

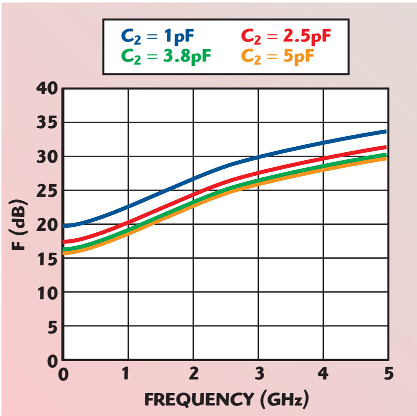
$$\mathcal{L}(f_m) = 10\log\left\{1 + \left[\frac{f_0^2}{(2f_mQ_L)^2\left(1 - \frac{Q_L}{Q_0}\right)^2}\right]\left(1 + \frac{f_c}{f_m}\right)\frac{FkT}{2P_o} + \frac{2kTRK_0^2}{f_m^2}\right\} \quad (8)$$

where $\mathcal{L}(f_m)$, f_m, f_0, f_c, Q_L, Q_0, F, k, T, P_o, R and K_0 are the ratio of the sideband power in a 1 Hz bandwidth at f_m to total power in dB, offset frequency, flicker corner frequency, loaded Q, unloaded Q, noise factor, Boltzman's constant, temperature in Kelvins, average output power, equivalent noise resistance of tuning diode and voltage gain.

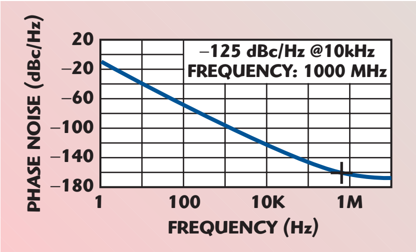
From Equation 8, the phase noise performance depends on the noise factor F of the oscillator circuit for a given resonator network and oscillator/VCO topology; therefore, optimization of the noise factor will lead to the minimization of the phase



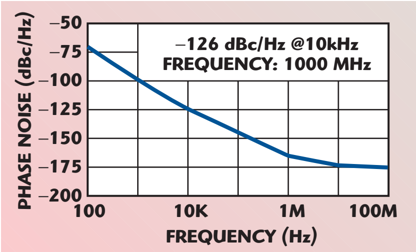
▲ *Fig. 4 Noise figure vs. frequency as a function of C_1 with C_2 = 2.2 pF.*



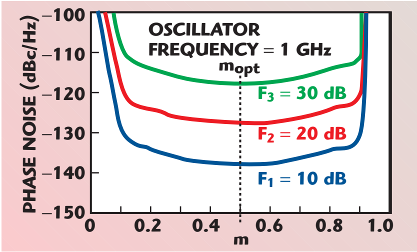
▲ *Fig. 5 Noise figure vs. frequency as a function of C_2 with C_1 = 3.3 pF.*



▲ *Fig. 6 Calculated phase noise for the Colpitts oscillator.*



▲ *Fig. 7 Simulated phase noise of the Colpitts oscillator.*



▲ *Fig. 8 Phase noise vs. m at 10 kHz offset for different values of F.*

noise. ***Figure 3*** shows the equivalent circuit of a Colpitts oscillator for the purpose of the noise factor analysis.[4,16] The predictive power of Equation 8 is limited due to the parameter noise factor F, which is not known a priori. The approximate expression of the noise factor F in terms of the oscillator feedback components (C_1 and C_2) for the circuit shown is given by[4]

$$F = 1 + \frac{Y_{21}^{+} C_2 C_c}{(C_1 + C_2) C_1} \left[r_b + \frac{1}{2r_e}\left(r_b + \frac{(C_1 + C_2) C_1}{Y_{21}^{+} C_2 C_c} \right)^2 \left(\frac{1}{\beta} + \frac{f^2}{f_T^2} \right) + \frac{r_e}{2} \right] \tag{9}$$

From Equations 3 and 4, the free running frequency f_0 of the oscillator circuit is given by[4]

$$f_o = \sqrt{\left\{ \frac{\left(\frac{(C_1^{\circ} + C_p) C_2}{(C_1^{\circ} + C_p + C_2)} + C_c \right)}{L_{PR}\left[\left(\frac{(C_1^{\circ} + C_p) C_2 C_c}{(C_1^{\circ} + C_p + C_2)}\right) + C_{PR}\left(\frac{(C_1^{\circ} + C_p) C_2}{(C_1^{\circ} + C_p + C_2)} + C_c\right)\right]} \right\}} \tag{10}$$

With the transistor (Q) NEC68830, $C_1^{\circ} = 2.2$ pF, $C_P = 1.1$ pF, $C_1 = C_1^{\circ} + C_P = 3.3$ pF, $C_2 = 2.2$ pF, $C_c = 0.4$ pF, $R_{PR} = 18000$, $C_{PR} = 4.7$ pF, $L_{PR} = 5$ nH; the free running frequency is calculated from Equation 10 as $f_0 \cong 1000$ MHz.

With $Y_{21}^{+} = 0.002$ (large-signal Y-parameter), $r_e = 0.9\ \Omega$ at 28 mA, $\beta = 100$, f = 1 GHz, $f_T = 10$ GHz; the noise factor F is calculated from Equation 6, as F = 104.7 ⇒ NF = $\log_{10}(F) = 20.18$ dB.

Figures 4 and ***5*** illustrate the dependency of the noise figure F (dB) on feedback capacitors C_1 and C_2. From Equation 8, the phase noise of the oscillator circuit can be optimized by optimizing the noise factor terms as given in Equation 9, with respect to the feedback capacitors C_1 and C_2. For the example circuit shown, the output power = 13 dBm, $C_1 = 3.3$ pF, $C_2 = 2.2$ pF, $Y_{21}^{+} = 2$ mS, $Q_0 = 1000$, $Q_L = 380$, F = 20 dB (calculated from Equation 9). From Equations 8, 9 and 10, the calculated phase noise plot for the circuit is shown in ***Figure 6***, which closely agrees with the simulated (Ansoft Designer) phase noise plot within the variation of 3 dB, as shown in ***Figure 7***.

From Equation 8,

$$\mathcal{L}(f_m) = 10\log \left\{ \left[1 + \frac{f_0^2}{(2f_m Q_0)^2 m^2 (1-m)^2} \right] \left(1 + \frac{f_c}{f_m} \right) \frac{FkT}{2P_0} + \frac{2kTRK_0^2}{f_m^2} \right\} \tag{11}$$

where

m = ratio between the loaded and unloaded Qs

From Equations 8 and 11, the minimum phase noise can be found by differentiating Equation 11 with respect to m, and equating to zero for maxima and minima as[4]

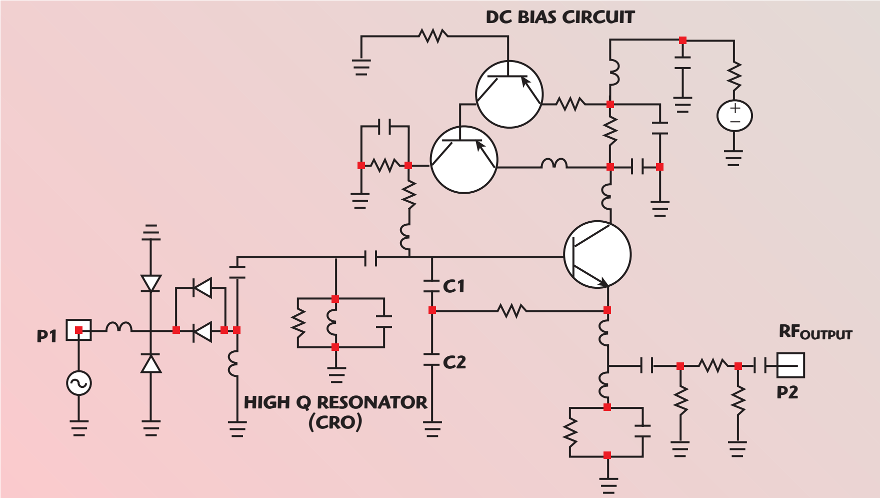
$$\frac{\partial}{\partial m}\left[\mathcal{L}(f_m)\right]_{m=m_{opt}} = 0$$

$$\frac{d}{dm}\left[10\log \left\{ \left[1 + \frac{f_0^2}{(2f_m Q_0)^2 m^2 (1-m)^2} \right] \left(1 + \frac{f_c}{f_m} \right) \frac{FkT}{2P_0} + \frac{2kTRK_0^2}{f_m^2} \right\} \right] = 0 \Rightarrow m_{opt} = 0.5 \tag{12}$$

Figure 8 shows the typical phase noise plot at 10 kHz offset with respect to m for the 1 GHz oscillator circuit. For different values of the noise figure F ($F_3 > F_2 > F_1$), the phase noise is minimum at m_{opt}, and the plot is typically like a bathtub curve, which is shifted symmetrically about m_{opt}. This implies that for low noise wideband application, the value of m should be dynamically controlled over the tuning range and should lie in the vicinity of m_{opt} for minimum phase noise performance.[14–26]

From Equation 9, the circuit topology and the resonator are selected in such a way that the feedback parameters (C_1 and C_2) are dynamically tuned for minimum noise figure (F), and m = 0.5 over the desired tuning range. From Equation 8, the phase noise of the oscillator circuit can be described exclusively in terms of the prior known circuit parameters as[16]

$$\mathcal{L}(\omega) = 10\log \left\{ \left[4kTR_L + \frac{4qI_c g_m^2 + \frac{K_f I_b^{AF}}{\omega} g_m^2}{\omega_0^2 C_1^2 \left(\omega_0^2 (\beta^+)^2 C_2^2 + g_m^2 \frac{C_2^2}{C_1^2} \right)} \right] \left[\frac{\omega_0^2}{4\omega^2 V_{cc}^2} \right] \left[\frac{1}{Q_L^2} + \frac{[C_1 + C_2]^2}{C_1^2 C_2^2 \omega_0^4 L^2} \right] \right\} \beta^+ = \left[\frac{Y_{21}^+}{Y_{11}^+}\right]\left[\frac{C_1}{C_2}\right]^p ; g_m = \left[Y_{21}^+\right]\left[\frac{C_1}{C_2}\right]^q \tag{13}$$



▲ *Fig. 9 Schematic of a high Q resonator-based 1 GHz Colpitts VCO.*[14]

where $y+_{21}$, $y+_{11}$ are the large-signal [Y] parameters of the active device, K_f is the flicker noise coefficient, AF is the flicker noise exponent, R_L is the equivalent loss resistance of the tuned resonator circuit, I_c is the RF collector current, I_b is the RF base current, V_{cc} is the RF collector voltage, C_1, C_2 are the feedback capacitors, and p and q are constants depending upon the drive level across the base-emitter of the device.[16] To test the validity of the noise models, a 1 GHz Colpitts VCO was built, which is shown in ***Figure 9***. ***Figure 10*** shows the measured plot of the phase noise, which is in good agreement within 2 to 3 dB with the calculated and simulated results shown previously.

NOISE MINIMIZATION TECHNIQUES

Noise Impedance Matching

Minimizing of the noise level can be done by a noise impedance matching analog to power matching by means of a transformer. For high frequency oscillation, noise impedance matching using a transformer winding is practically limited. The other alternative is to match the impedance by incorporating a capacitive tapping factor n of the resonator network for optimum noise impedance level. Here, the tapping factor n is analogous with the conventional transformer-winding ratio. ***Figure 11*** shows the equivalent representation of a capacitively tapped series resonator network. As shown, capacitive tapping increases the impedance level at the terminals of the resonator network, which is required for the impedance matching for minimum noise factor, thereby improving the phase noise performance. However, the tapping mechanism introduces an additional parallel capacitance, $C_{resonator}$ and C_{tap}, which yields an unwanted mode of oscillation.

Care must be taken to avoid the unwanted parasitic mode of oscillations, which otherwise degrades the loaded quality factor of the resonator when the parallel parasitic resonance is relatively close to the fundamental series resonance. The fundamental resonance frequency and transformed resonator impedance can be described by

$$\left[\omega_0^2\right]_{\omega=\omega_0} = \frac{1}{C_{resonator}L_{resonator}} \qquad (14)$$

$$\left[Z(\omega_0)\right]_{resonator} = \frac{n^2 R_{Loss}}{1+\left(\frac{n-1}{Q}\right)} \approx n^2 R_{Loss} \qquad (15)$$

where

$$Q = \frac{\omega_0 L_{resonator}}{R_{Loss}}$$

$$C_s = \left[C_{resonator} + C_{tap}\right]$$

$$n = 1+\left[\frac{C_{resonator}}{C_{tap}}\right]$$

From Equation 15, the transformed resonator impedance $[Z(\omega_0)]$ depends upon the tapping factor n, and can be optimized for maximum signal-to-noise ratio to minimize the phase noise. Due to the tapping

$$\left[L_{resonator}\right] \rightarrow n^2\left[L_{resonator}\right] \quad (16)$$

$$\left[R_{loss}\right] \rightarrow n^2\left[R_{loss}\right] \quad (17)$$

$$\left[C_{resonator}\right] \rightarrow \left[C_{resonator} + C_{tap}\right]n^{-2} = \left[C_s\right]n^{-2} \quad (18)$$

$$\left[\frac{C_{resonator}C_{tap}}{C_{resonator} + C_{tap}}\right] = C_s\left[\frac{1}{n} - \frac{1}{n^2}\right] \approx \left[\frac{C_s}{n}\right] \quad (19)$$

From Equation 19, as the tapping factor n increases, the parallel unwanted parasitic resonance mode tends to shift towards the fundamental series resonance mode. The effective quality factor Q of the resonator decreases due to the tapping for noise impedance matching,[4] and can be described by

$$Q_{effective} = \frac{\omega_0}{2}\left[\frac{d\phi(\omega)}{d\omega}\right]_{\omega=\omega_0} \Rightarrow$$

$$Q_{effective} = \frac{Q}{1+\left(\frac{n-1}{Q}\right)^2} \quad (20)$$

From Equation 20, when the tapping factor n is small, the degradation of the quality factor is negligible. The parasitic mode of the frequency can be given by

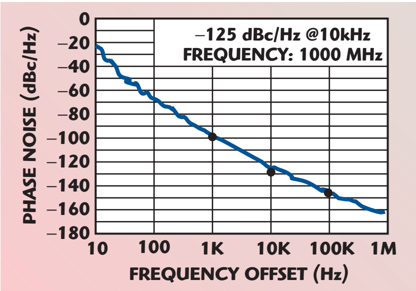
$$\omega_{parasitic-mode} = \frac{1}{n^2R_{loss}\left[\frac{C_{resonator}C_{tap}}{C_{resonator} + C_{tap}}\right]} = \omega_0\left[\frac{Q}{n-1}\right] \quad (21)$$

To prevent the unwanted parasitic mode of resonance, the tapped resonator should be compensated by the negative resistance and the negative capacitance. The negative resistance will compensate the loss resistance n^2R_{loss}, and the negative capacitance cancels the effect of the positive the $C_{resonator}$ and C_{tap}. By proper selection of an optimum tapping factor n_{opt}, which depends on the loss resistance of the resonator and the active device (BJT/FET) parameters (especially the base resistance of the bipolar transistor), the noise impedance matching can be done for improved phase noise performance.

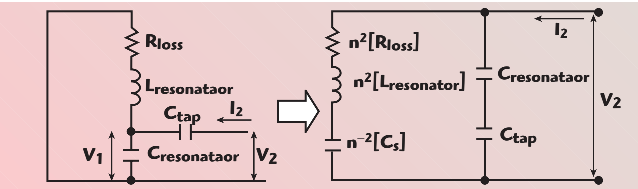
An oscillator circuit can support more than one resonant mode (unwanted parasitic oscillations due to the bonding wire inductance L_p), which can be described by the admittance equation as

$$Y_{effective}(\omega) = \left[j\omega C_{in}\right] + \frac{1}{j\omega L_p + \frac{1}{\frac{1}{\frac{1}{j\omega C}+R_{sc}} + \frac{1}{j\omega L + R_{sl}} + \frac{1}{R_p}}} \quad (22)$$

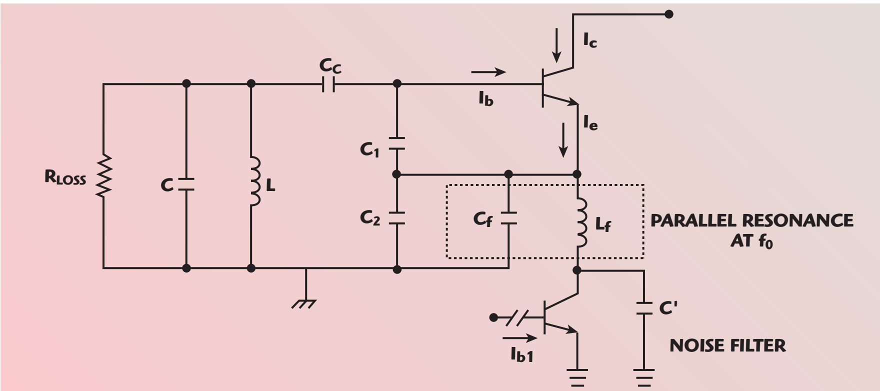
From Equation 22, the fundamental parallel mode of oscillation is given by the parallel combination of L and $[1/j\omega\,(C_{in}+C)]$, but there is a second parasitic mode associated with $[1/j\omega C_{in}]$ in parallel with $[j\omega L_p + j\omega L]$ and $[1/j\omega C]$, which is due to the parasitic bonding wire inductance L_p. The parasitic oscillation mode can be overcome by incorporating a resistor R_s to L_b, which will damp the spurious parasitic oscillation mode and has negligible effect on the fundamental resonance mode. However, care needs to be taken in the design, since a large value of Rs increases the noise factor, thereby degrading the overall noise performance of the Colpitts oscillator circuits.



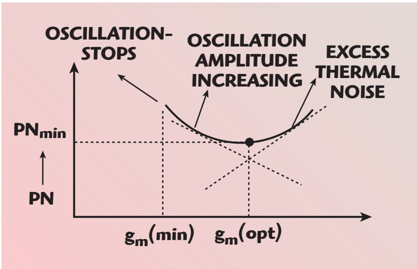
▲ *Fig. 10 Measured phase noise of the fabricated VCO.*



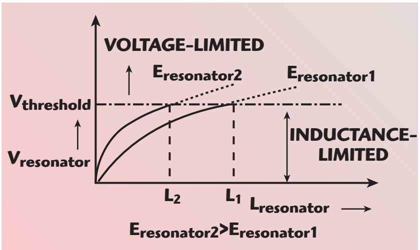
▲ *Fig. 11 Equivalent representation of a capacitively tapped series resonator.*



▲ *Fig. 12 Typical Colpitts oscillator circuit with a noise filtering network.*



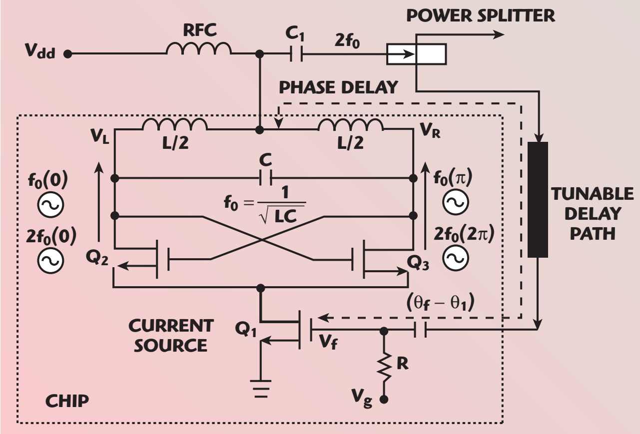
▲ *Fig. 13 Typical plot of phase noise vs. transconductance.*



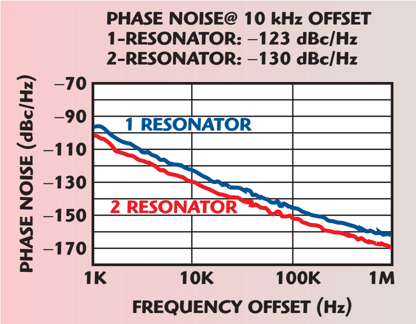
▲ *Fig. 14 Two zones: Voltage limited and inductance limited.*

NOISE FILTERING

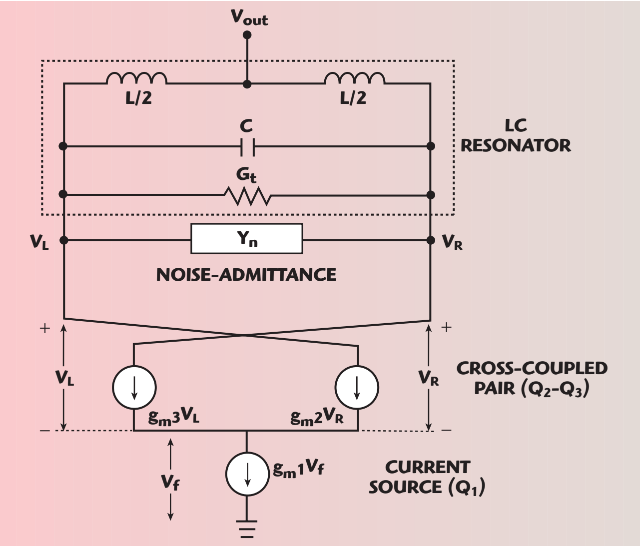
Figure 12 shows the noise-filtering network at the emitter bias current (I_e) in a typical Colpitts oscillator circuit. The feedback capacitor C_2 should remain unaffected by the insertion of the filter, which means that an additional capacitance C_f may be required to cancel the inductor reactance L_f at the fundamental oscillation frequency. The single-ended bipolar transistor circuit in which filter inductor L_f tunes the parasitic capacitance to the oscillation frequency can serve this purpose. Simulation CAD and measured data confirm the improvement by 3 to 6 dB of the phase noise.[14]



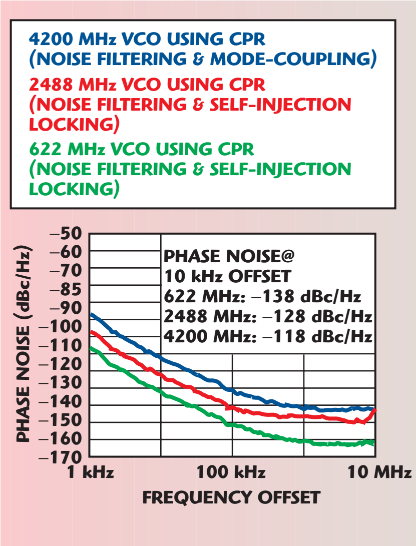
▲ *Fig. 15 Self-injected coupled oscillator.*



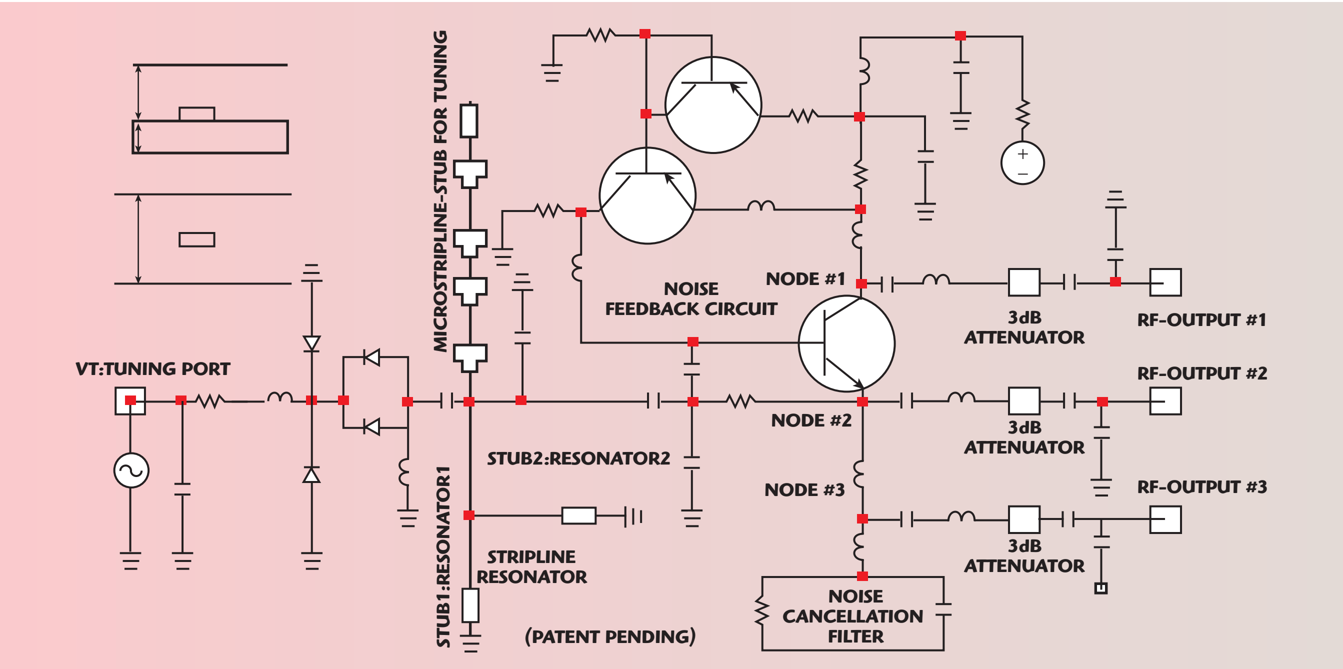
▲ *Fig. 17 Measured phase noise plots of 2488 MHz oscillators using a CPR configuration (two resonators) and uncoupled resonator oscillator (one resonator).*



▲ *Fig. 16 Simplified model of the self-injected coupled oscillator.*



▲ *Fig. 18 Measured phase noise of 622/2488/4200 MHz VCOs using CPR.*



▲ *Fig. 19 Schematic of a self-coupled, shorted-stubs resonator oscillator (patented).*

OPTIMUM TRANSCONDUCTANCE (gm)

There are mainly two noise sources that mostly contribute to the phase noise: thermal noise (broadband noise) and flicker noise (low frequency noise). Flicker noise up-conversion is related to the symmetry of a signal waveform and can be reduced by designing the signal swings symmetrically.

The active device in the oscillator circuit generates the negative conductance to compensate for the loss in the resonator network in order to sustain a steady-state oscillation, thereby generating a broadband thermal noise proportional to the negative transconductance of the device. If the negative transconductance is very small, then it does not support steady-state oscillation, whereas, if it is very large, it generates an excess thermal noise that may increase the oscillator phase noise drastically. Therefore, the transconductance of the device should be optimized in order to maintain stable oscillation without introducing excessive noise. ***Figure 13*** shows a typical plot of the phase noise versus device transconductance. The oscillator starts oscillating when the transconductance reaches $g_{m(min)}$ and it is just sufficient enough to compensate the loss in the resonator tank. As the transconductance increases from $g_{m(min)}$, the phase noise decreases till it reaches $g_{m(opt)}$. Any further increase in transconductance creates a counter effect and the thermal noise in the active device increases and follows the transconductance curve. Therefore, corresponding to $g_{m(opt)}$, the phase noise reaches the minimum point and, after that, the increase in oscillation amplitude is completely nullified by the increase in thermal noise. After crossing the minimum point, the phase noise increases as the signal amplitude is limited to the supply voltage, while the thermal noise continuously increases with the increase in conductance. Therefore, for a given oscillator topology, there exists an optimum transconductance for the minimum phase noise.

OPTIMUM INDUCTANCE (L)

As shown in ***Figure 14***, two modes of operation exist for an LC oscillator, namely current and voltage regimes. Considering the bias current as an independent variable, the voltage across the resonator network can be described by

$$V_{resonator} = \frac{I_{bias}}{g_{resonator}} \quad \text{(current-limited zone)} \tag{23}$$

$$V_{resonator} = V_{threshold} \quad \text{(voltage-limited zone)} \tag{24}$$

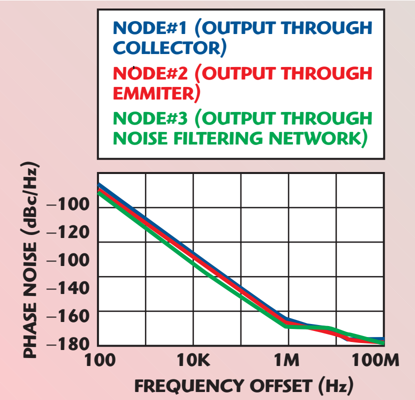
In the current-limited zone, the resonator tank amplitude $V_{resonator}$ linearly increases the bias current according to the relationship, until the oscillator enters the voltage-limited zone, whereas, in the voltage-limited zone, the amplitude is limited to the $V_{threshold}$, which can be determined by the available supply voltage.

$$E_{resonator} = \frac{1}{2} C_{resonator} V_{resonator}^2 \Rightarrow$$

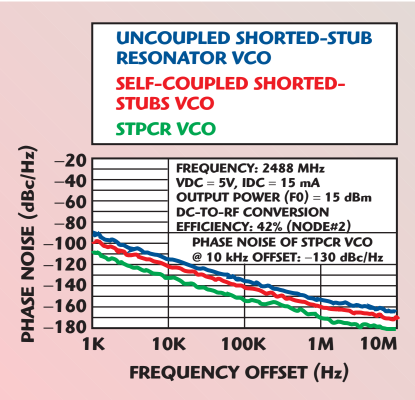
$$V_{resonator}^2 = \frac{2E_{resonator}}{C_{resonator}} \tag{25}$$

$$\left[C_{resonator}\right]_{\omega=\omega_0} = \frac{1}{\omega_0^2 L_{resonator}} \Rightarrow$$

$$V_{resonator}^2 = 2E_{resonator}\,\omega_0^2 L_{resonator} \tag{26}$$



▲ *Fig. 20 Simulated phase noise of the self-coupled, shorted-stubs resonator oscillator.*



▲ *Fig. 21 Measured phase noise of the STPCR VCO.*

$$\left[V^2_{resonator}\right]_{\omega=\omega_0} \propto \left[L_{resonator}\right]_{E_{resonator}} \quad (27)$$

The equivalence of the current and inductance-limited zone can be combined to determine the relation between $E_{resonator}$ and I_{bias} in the inductance-limited zone.

$$E_{resonator} \propto \frac{1}{L_{resonator}\, g^2_{resonator}} I^2_{bias} \quad \text{(inductance} - \text{limited)} \quad (28)$$

$$V^2_{resonator} = 2E_{resonator}\,\omega_0^2 L_{resonator} \quad \text{(inductance} - \text{limited)} \quad (29)$$

$$V^2_{resonator} = V^2_{threshold} \quad \text{(voltage} - \text{limited} : V - \text{limited)} \quad (30)$$

The noise-to-carrier ratio can be given as

$$\frac{\left|\overline{v_n^2(\omega)}\right|}{\left|V^2_{threshold}(\omega)\right|} \propto \frac{1}{E_{resonator}} (L - \text{limited})$$

$$\frac{\left|\overline{v_n^2(\omega)}\right|}{\left|V^2_{threshold}(\omega)\right|} \propto L\ (V - \text{limited}) \quad (31)$$

From Equation 31, the noise-to-carrier ratio remains constant in the L-limited zone and does not depend on the value of the inductor. However, once the oscillator enters the voltage limited zone, the noise-to-carrier ratio increases with L. Therefore, selecting an L, which transfers the oscillator in the voltage-limited zone, yields a waste of L and increases the noise. For a given energy $E_{resonator}$, a larger $V_{resonator}$ obtained by increasing the L does not offer a better noise performance since the oscillator has a similar response to both the $E_{resonator}$ and the thermal energy.

Self-injection Mechanism

Minimizing of the noise can be done by employing a self-injection locking mechanism in a coupled oscillator, which is a cost-effective and power-efficient alternative and has recently emerged as a strong contender for low noise signal sources in modern wireless communication systems.[2–4] ***Figure 15*** shows the second-harmonic self-injected coupled oscillator topology, which consists of a cross-coupled pair (Q_2–Q_3), a current source (Q_1), a power splitter, and a tunable delay path containing a delay-line cable and a tunable phase shifter.[27] ***Figure 16*** shows the simplified oscillator model consisting of an LC tank, a conductance (G_t) representing the tank loss, a feedback signal $V_f(t)$ and the mildly nonlinear transconductance (g_{m1} to g_{m3}). For the self-injected coupled oscillator, part of the output signal feeds back to the current source. The current source with the mildly nonlinear transconductance (g_{m1}) transforms the feedback signal $V_f(t)$ to a larger current format $[I_f(t) = g_{m1}V_f(t)]$. With the equivalent parallel resistance of the tank R_{eq} for the second-harmonic ($2f_0$), the feedback signal amplitude crossing the tank (V_{inj}) is produced $[V_{inj}(t) = I_f(t).R_{eq}]$. The expression of the phase fluctuation (phase noise) of the self-injected coupled oscillator is[27]

$$\overline{\left|\delta\theta(\omega)\right|^2}_{coupled} = \frac{\overline{\left|\delta\theta(\omega)\right|^2}_{free}}{\left[1+\frac{A_1}{\Delta A_1}\frac{2g_{m1}}{K}\cos\left[\theta_f-\theta_1\right]\frac{\omega_{3dB}R_L}{\omega}\right]^2} \quad (32)$$

For $(\theta_f - \theta_1) \Rightarrow 2n\pi$ Equation 32 can be given by

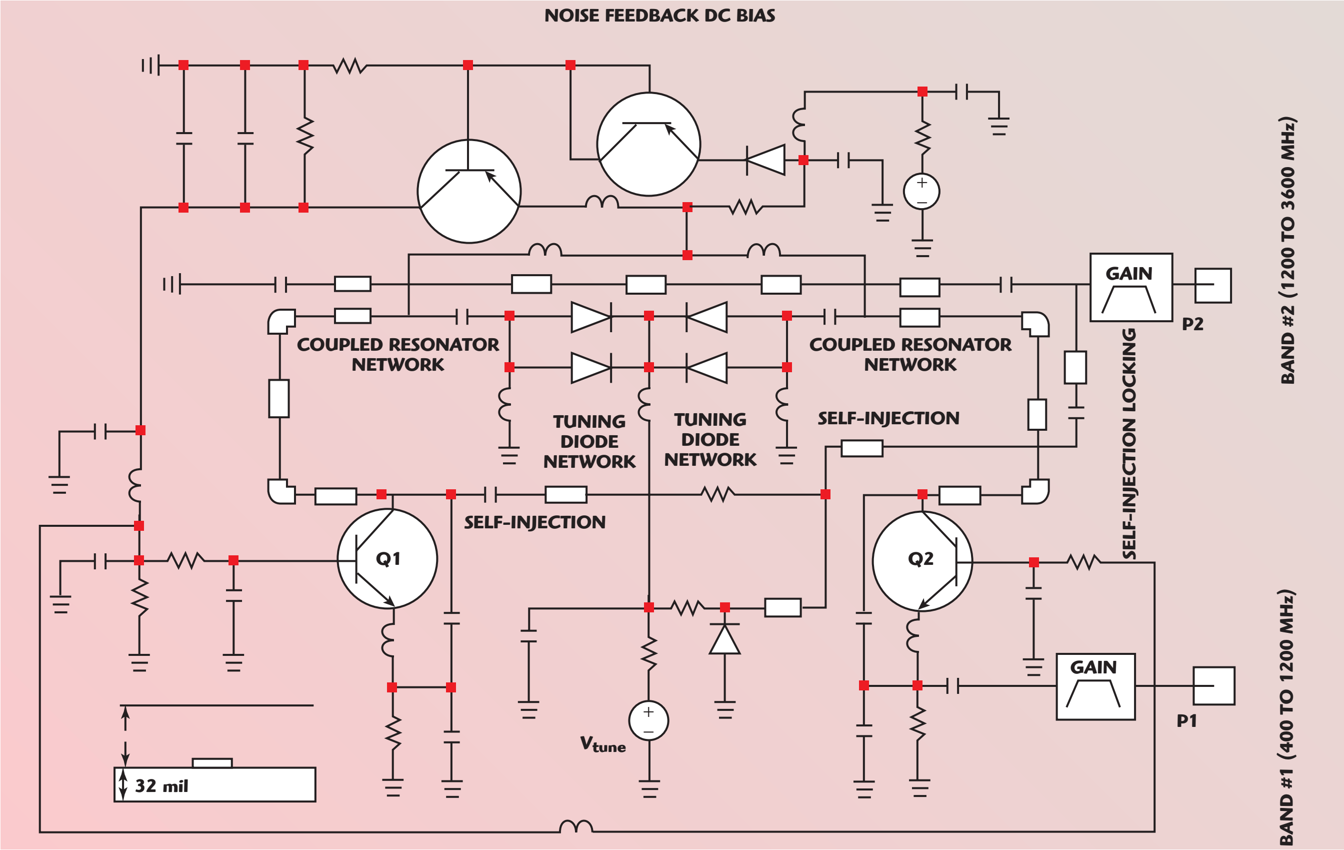
$$\overline{\left|\delta\theta(\omega)\right|^2}_{coupled} = \frac{\overline{\left|\delta\theta(\omega)\right|^2}_{free}}{\left[1+\frac{A_1}{\Delta A_1}\frac{2g_{m1}}{K}\frac{\omega_{3dB}R_L}{\omega}\right]^2} \quad (33)$$

From Equation 33, the noise can be further minimized by increasing the transconductance (g_{m1}) of the current source, increasing the equivalent parallel-resistance of the tank (R_L) for the fundamental signal (f_0), reducing the amplitude imbalance (ΔA_1) for the second-harmonic signal and increasing the second-harmonic amplitude (A_1).

EXAMPLES: LOW NOISE OSCILLATORS

Coupled Planar Resonator-based 2488 MHz Oscillator

The following example describes the use of coupled planar resonator (CPR) and noise minimization tech-



▲ *Fig. 22 Schematic of a coupled oscillator self-injection locked VCO.*

niques as discussed in the previous section for a high performance, low noise, high quality microwave source. A CPR-based 2488 MHz VCO was designed and fabricated on a 0.35" × 0.35" × 0.16" substrate and experimental results have validated the novel techniques proposed in this work. ***Figure 17*** shows the phase noise plot of the 2488 MHz VCO using CPR resonators in a hybrid medium (transverse coupling between stripline and microstrip line coupled resonators, PCB: six-layer board with Rogers substrate) and the operating bias conditions are $V_{cc} = 5$ V, $I_c = 15$ mA. The measured phase noise plot of the oscillator minimizes the noise and shows a 7 dB reduction in phase noise, with respect to the uncoupled planar resonator-based oscillator with a typical power output of 5 dBm (minimum) and 30 dB harmonic rejections.

For the validation of the approach, 622, 2488 and 4200 MHz VCOs were designed and fabricated, where the resonator is self-injection locked and tuned to their respective fundamental frequencies (without frequency mul-

tiplication). ***Figure 18*** shows the phase noise plot for comparative analysis of 622, 2488 and 4200 MHz VCOs using CPR and noise reduction techniques.

Power Efficient and Low Microphonics VCOs

An object of this research work is to provide a cost-effective solution to solve the problem of microphonics and conversion efficiency by using stubs tuned planar-coupled resonators (STPCR) in a stripline medium (since they are self-shielding due to their dual ground plane) for low noise signal sources, which can replace a low power oscillator followed by an amplifier, in order to reduce the size and cost of the wireless communication systems.[3,14,15,19] DC-to-RF conversion efficiency is related to the fundamental signal RF output power and DC power consumption, which can be described by

$$\eta_{efficiency} = \frac{P(\omega_o)}{P_{DC}} = \frac{P(\omega_0)}{V_{DC} \times I_{DC}} \quad (34)$$

where

$\eta_{efficiency}$ = DC-to-RF conversion efficiency
$P(\omega_0)$ = RF output power of the fundamental signal
P_{DC} = DC power consumption

For higher conversion efficiency, the oscillator circuit topology should be such that it operates at low DC power and at the same time produces high RF output power at the desired fundamental frequency. The RF output power for a typical oscillator circuit can be described in terms of the higher order harmonics as

$$P_{out} = V_0 I_0 + \frac{1}{2} V_1 I_1 \cos\theta_1 + \frac{1}{2} V_2 I_2 \cos\theta_2 + \ldots \frac{1}{2} V_n I_n \cos\theta_n \quad (35)$$

where V_1, I_1, V_2 I_2 and V_n, I_n are the amplitudes of the voltage and currents of the fundamental, second and nth harmonic components, respectively; the angles θ_1, θ_2 and θ_n are the phase angles between the voltage and the current of the respective harmonic components present at the output node of the oscillator circuit. For a high value of $\eta_{efficiency}$, other higher order harmonics must be suppressed; otherwise, they will degrade the conversion efficiency of the generated fundamental signal tone (ω_0) from the given input DC power ($V_{DC} \times I_{DC}$). ***Figure 19*** shows the schematic of a typical 2488 MHz STPCR oscillator circuit, where the RF output is extracted from three different nodes (Nodes 1, 2 and 3) for comparative analysis of the DC-to-RF conversion efficiency and phase noise performances. ***Figure 20*** shows the simulated (CAD: Ansoft Designer Nexxim V3) phase noise plot for the oscillator circuit, which shows that the RF output extracted through Node 3 ultimately offers the best phase noise performance. As depicted, Node 3 gives a higher level of second-order harmonic rejections (45 dB) in comparison to Node 2 (30 dB) and Node 1 (15 dB). However, Node 2 offers higher efficiency (40 percent) in comparison to Node 1 (10 percent) and Node 3 (20 percent); therefore, there is trade-off between phase noise and harmonic rejection based on the applications.

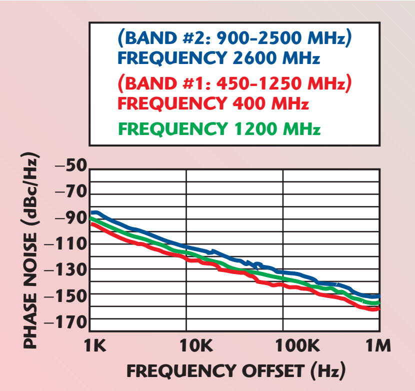
Figure 21 shows the phase noise plot of the STPCR-based, high spectral pure signal source at 2488 MHz in accordance with the present novel techniques (patent-pending), which can be tuned (user-defined frequency) and where the frequency can be extended without changing the dimensions of the stub-tuned resonators (stripline domain PCB: six-layer). The design is based on an innovative topology, which supports the fast convergence by dynamically tuning the noise impedance transfer function of the resonating network and the negative resistance generating device for optimum noise performance over the tuning range. The measured phase noise for a 2488 MHz carrier frequency is typically –128 dBc/Hz at 10 kHz offset from the carrier with 40 percent DC-to-RF conversion efficiency. The measured RF output power at the fundamental frequency f_0 is typically 15 dBm for a given operating DC bias condition (V_{DC} = 5 V, I_{DC} = 15 mA).

Coupled Oscillators Self-injection Locked Wideband VCO

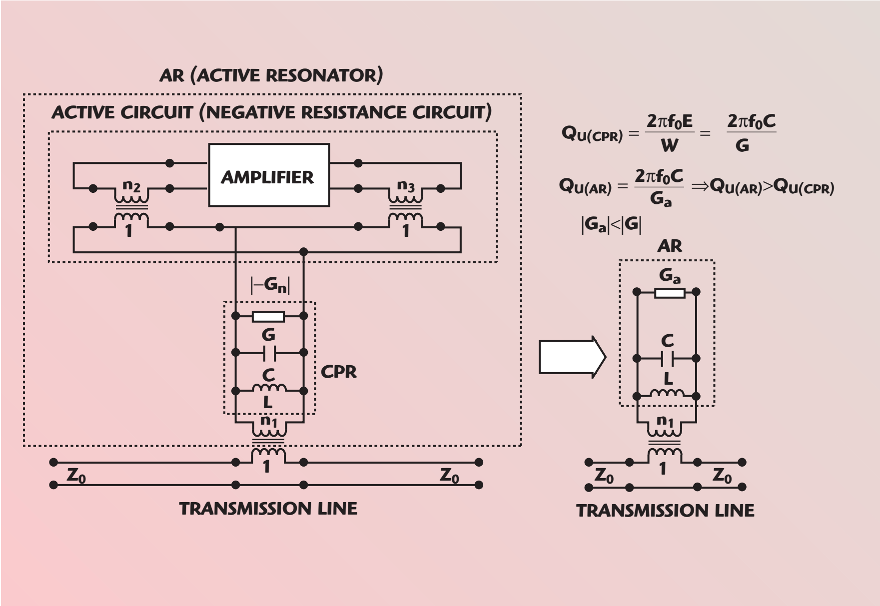
Figure 22 shows the schematic of the configurable signal source by using the coupled oscillator self-injection locked mechanism and noise reduction techniques discussed previously. The circuit works at 5 V and 32 mA and the tuning voltage is 0 to 28 V. The typical RF output power is 5 dBm over the tuning range and sub-harmonic rejection is better than 20 dB. ***Figure 23*** shows the measured phase noise plot of the configurable signal source, which is better than –105 dBc/Hz at 10 kHz offset from the carrier for the frequency band.

Active Resonator (AR)-based Low Noise Oscillator

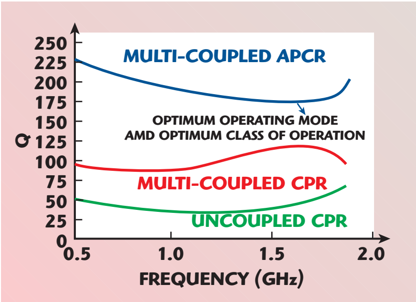
Normally, in the AR topology, the CPR is coupled to the negative resistance generating device network so that, in principle, an AR element similar to the general oscillator is being created. A general oscillator needs both the amplitude and phase conditions to be satisfied for oscillation build up at f_0. In the case of the AR, only the phase condition for oscillation build up at f_0 is required for stable and sustained oscillations and no amplitude condition is required to compensate for the loss of the AR from the active device network.[28] As shown in ***Figure 24***, the oscillations will not build up in AR and growth is restricted; therefore, an active amplifier can work in the small-signal linear regime. The gain and power of the amplifier added to the circuit will compensate the inner losses of the AR circuits, and full compensation ($-|G_n| + G = 0$) of W (energy losses) will result in infinite unloaded Q and improved loaded Q when coupled to a transmission line or equivalent oscillator circuit. AR based on a negative resistance approach offers improved Q factors, but they have drawbacks: the schematic is complex and must have a feedback element and matching networks to produce the negative conductance $|-G_n|$, sensitive to spurious oscillation (if the oscillation start-up condition is satisfied). A normal oscillator requires the amplitude and phase condition to be satisfied for guaranteed and sustained oscillation build up at the desired frequency, whereas, for an active resonator element, only the phase condition needs to be satisfied. Hence, the oscillation will not build up across the active resonator and, therefore, the active resonator module can work in the small-signal regime (instead of the large-signal regime condition required for sustained and guaranteed oscillations). Moreover, the negative resistance, added to the active resonator circuit, will reduce the intrinsic losses of the passive resonators used as active resonators. This approach yields high Q



▲ *Fig. 23 Phase noise of the dual-band coupled oscillator self-injection locked VCO.*

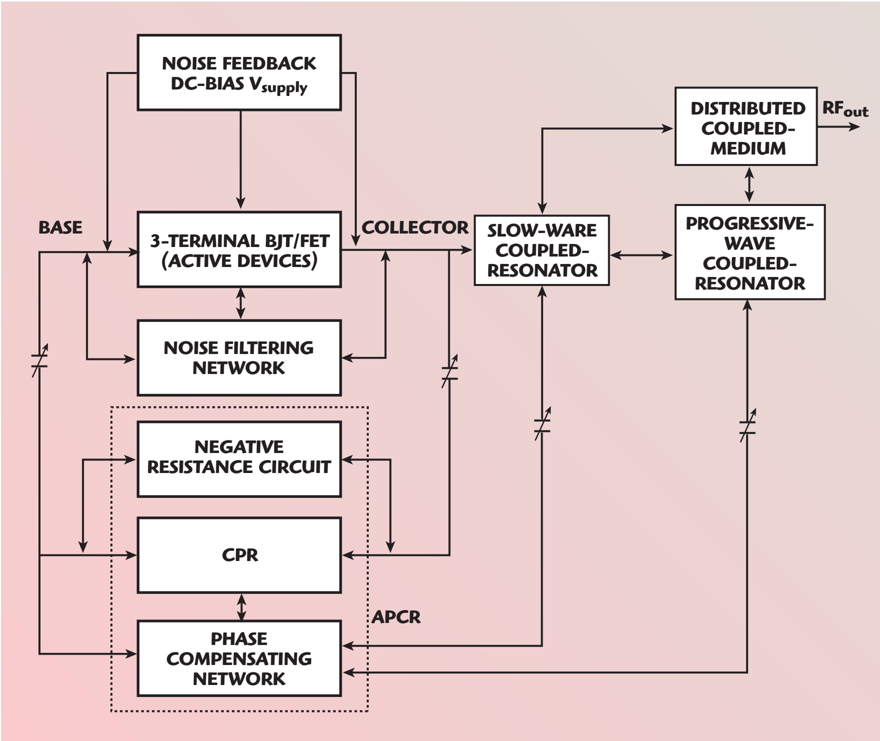


▲ *Fig. 24 Active resonator with feedback arrangement.*



▲ *Fig. 25 Measured Q of planar resonators.*

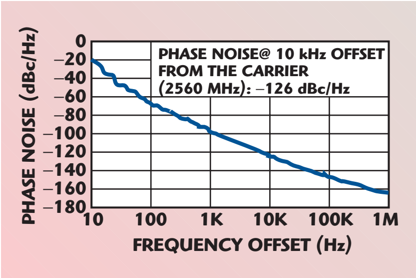
resonators; however, active resonator elements are sensitive to spurious oscillations that may cause an unwanted oscillation mode in the event of satisfying the start-up oscillation condition. Since the conventional planar microstripline resonator itself is a lossy element, the unloaded Q factor is low and finite. Moreover, coupling the planar resonator to the external circuits (oscillator, filter, diplexer, etc.) results in loosing a finite amount



▲ *Fig. 26 Block diagram of the APCR VCO (patent pending).*

of energy due to the coupling and other mechanism, thereby resulting in further degradation in the loaded Q factor. In addition, the excitation of other higher order oscillation modes across the resonators increases the resistive loss, which has to be compensated by the active resonator topology for low phase noise performance.

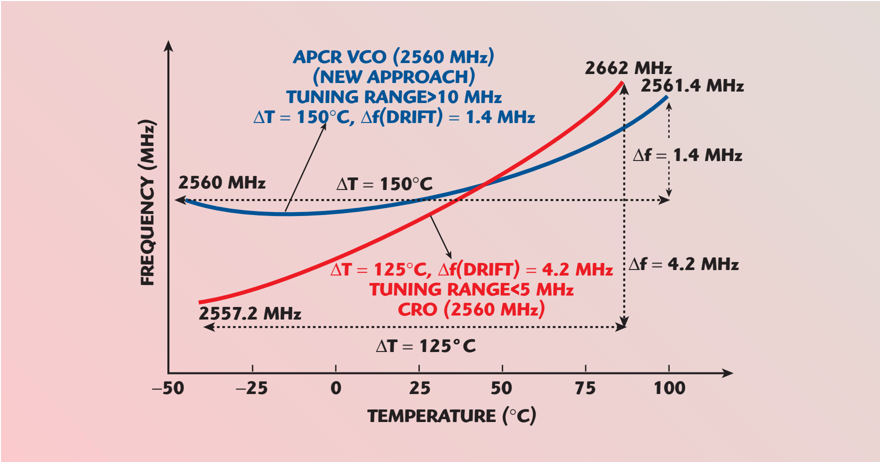
Figure 25 illustrates the measured Q of the typical planar-coupled resonators (uncoupled, coupled, ACPR) for the purpose of comparative analysis. ***Figure 26*** shows the block diagram of an APCR (active planar-coupled resonator) VCO, which is based on a novel topology that supports minimum phase hits and broadband tunability, to compensating for the frequency drift due to temperature and aging, in a compact size and also amenable for integration in current IC technology. To overcome these problems, the active resonator is realized by incorporating an injection mechanism based on a feedback approach that can be dynamically controlled over the desired frequency band. By adjusting the feedback factor of the negative resistance



▲ *Fig. 27 Measured phase noise of an APCR VCO at 2560 MHz.*

generating circuit, the optimum value of the negative resistance to compensate for the loss of the CPR can be achieved. In this way, the conduction angle, the injection level and the group delay can be optimized towards the steepest phase characteristic curve for a given resonance condition across the active resonators. This condition leads to the operation of the APCR oscillator circuit in the vicinity of the evanescent domain. Hence, an improved group delay and phase characteristic curve are obtained, thereby increasing the effective dynamic loaded Q by many folds, resulting to low phase noise.

The layout of the APCR VCO is a six-layer board, fabricated on a 64 mil thick Rogers substrate of dielectric constant 3.38 and loss tangent 2.7(10^{-4}). The choice of substrate depends on size, higher order modes, surface wave effects, implementations (couplings, line length, width, spacing and spacing tolerances), dielectric loss, temperature stability and power handling (dielectric strength and thermal conductivity). The APCR circuit works at 5 V and 25 mA, with an output power of 2 dBm, and second-harmonic rejection is better than -20 dBc. Unfortunately, each development design of a VCO, using APCR technology, has its price, since they occupy larger PCB area and, for the same space, exhibit much lower Qs compared to a high Q, CRO/SAW resonator. For the most part, these disadvantages have been overcome by means of a mode coupling approach, which acts as a Q-multiplier, and minimization of noise



▲ *Fig. 28 Measured thermal drift and frequency tuning range of commercially available CROs and the new APCR VCO.*

over the band is achieved by incorporating a noise-filtering network, a noise cancellation network, a phase compensating network and a noise feedback bias circuit.[16] ***Figure 27*** shows the measured phase noise plot of the APCR VCOs at 2560 MHz with a 1 percent tuning range. ***Figure 28*** shows the temperature and frequency drift profile of commercially available CROs and the new APCR VCOs (this work) for the purpose of the comparative analysis about the thermal drift profile and frequency tuning range (Δf). As depicted, the APCR VCO offers broadband tunability, extended operating temperature range and overcome the limiting performance of the frequency drift due to temperature and component tolerances.

CONCLUSION

With regard to the state-of-the-art of the configurable signal source, this novel approach provides a general concept of reducing the noise over the frequency bands; it can help to avoid pitfalls that can increase the time required to achieve minimum phase noise over the band, and offers a promising alternative for high Q planar resonators in the context of a planar fabrication process, compatible with existing IC and MMIC processes. ■

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NONLINEAR ANALYSIS OF POWER AMPLIFIERS

The function of a power amplifier (PA) in a radio communications system is to boost a signal to a power level suitable for transmission. In modern RF power amplifier applications, there are two conflicting design requirements: the need for linearity to preserve the fidelity of the signal and the demand for efficiency of the PA.

All RF power amplifiers distort the signals that pass through them. Distortion is defined as the change in the signal shape that occurs when that signal is passed through a nonlinear system. This results in an increase in the number of frequency components present in the output signal when compared to the input signal.

High frequency power amplifiers operate most efficiently at saturation in the nonlinear range of their behavior. In modern communication systems, the signals are amplitude and phase modulated to achieve better spectral efficiency: using the smallest bandwidth to transmit a given amount of information.[1] Such signals exhibit a large peak-to-average power ratio (PAR), meaning that the average power of the signal that is to be amplified by the PA can be many times smaller than the peaks of the signal. The PA must be able to handle the peaks, which means that the PA is usually operating well below its peak efficiency point.

Attempts to balance the nonlinearities in saturation against the improved efficiency lead to interesting circuit techniques that often achieve improved efficiency as a result of the control of the harmonic content of the amplified signal, and not simply its elimination as in traditional designs.

A modulated carrier that has amplitude variations will exhibit a spread of the transmitted spectrum (spectral regrowth) as a result of nonlinearities in the amplifier. These new spectral components (distortion) are generated by the nonlinearities of the circuit and degrade the spectral efficiency of the system. Given a known stimulus and a representation of the nonlinear system, these nonlinearities can be derived to explain how they arise.

NONLINEAR ANALYSIS OF POWER AMPLIFIERS

The typical input for a power amplifier in a telecommunications application is usually sinusoidal in nature and contains both amplitude and phase modulation characteristics,

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which represent the baseband information signal.[2] The signal has the following structure

$$x(t) = A(t)\cos[\omega_c t+\theta(t)] \quad (1)$$

where

$A(t)$ = amplitude modulation (AM) on the input signal
$\theta(t)$ = phase modulation (PM) on the signal

Representing the system as a low order polynomial, $y(t) = f(x(t))$, gives

$$y_L(t) = \alpha_1 x(t-\tau_1) \quad (2)$$

for linear response when the input signal is small, and a nonlinear response of

$$y_{NL}(t) = \alpha_1 x(t-\tau_1) + \alpha_2 x(t-\tau_2)^2 + \alpha_3 x(t-\tau_3)^3 + \ldots \quad (3)$$

The response of the system (linear and nonlinear) to Equation 1 is

$$y_L(t) = \alpha_1 A(t-\tau_1)\cos[\omega_c t+\theta(t-\tau_1)-\phi_1],\quad \phi_1 = \omega_c\tau_1 \quad (4)$$

$$\begin{aligned} y_{NL}(t) = {} & \alpha_1 A(t-\tau_1)\cos[\omega_c t+\theta(t-\tau_1)-\phi_1] \\ & +\alpha_2 A(t-\tau_2)^2\cos[\omega_c t+\theta(t-\tau_2)-\phi_2]^2 \\ & +\alpha_3 A(t-\tau_3)^3\cos[\omega_c t+\theta(t-\tau_3)-\phi_3]^3, \\ & \phi_1 + \omega_c\tau_1,\ \phi_2 = \omega_c\tau_2,\ \phi_3 = \omega_c\tau_3 \end{aligned} \quad (5)$$

where the expression is truncated to the third degree, ω_c represents the carrier frequency and the τ_i are constant. Using trigonometric identifiers Equation 5 may be rewritten as

$$\begin{aligned} y_{NL}(t) = {} & \\ & \alpha_1 A(t-\tau_1)\cos[\omega_c t+\theta(t-\tau_1)-\phi_1] \\ & +\frac{1}{2}\alpha_2 A(t-\tau_2)^2 + \frac{1}{2}\alpha_2 A(t-\tau_2)^2 \\ & \cos[2\omega_c t+2\theta(t-\tau_2)-2\phi_2] \\ & +\frac{3}{4}\alpha_3 A(t-\tau_3)^3 \\ & \cos[\omega_c t+\theta(t-\tau_3)-\phi_3] \\ & +\frac{1}{4}\alpha_3 A(t-\tau_3)^3 \\ & \cos[3\omega_c t+3\theta(t-\tau_3)-3\phi_3]^3 = \\ & \frac{1}{2}\alpha_2 A(t-\tau_2)^2 + \alpha_1 A(t-\tau_1) \\ & \cos[\omega_c t+\theta(t-\tau_1)-\phi_1] \\ & +\frac{3}{4}\alpha_3 A(t-\tau_3)^3 \\ & \cos[\omega_c t+\theta(t-\tau_3)-\phi_3] \\ & +\frac{1}{2}\alpha_2 A(t-\tau_2)^2 \\ & \cos[2\omega_c t+2\theta(t-\tau_2)-2\phi_2] \\ & +\frac{1}{4}\alpha_3 A(t-\tau_3)^3 \\ & \cos[3\omega_c t+3\theta(t-\tau_3)-3\phi_3]^3 \end{aligned} \quad (6)$$

The τ_i in Equations 2–6 are a result of memory effects.

MEMORY EFFECTS

RFPA memory effects can be classified as long term or short term. Long-term memory effects, which will not be addressed in this article, are the result of thermal transients, supply variability and electron traps. Short-term electrical memory effects are caused by transistor time delays that are modeled by energy storage elements such as capacitances or inductances.[3]

With memory, the response of the circuit or system becomes dependent on prior values of the input and the time response of the system is no longer instantaneous. Taking a linear time-invariant capacitor, for example, the voltage across the capacitor at time t is

$$v(t) = \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau \quad (7)$$

assuming that there was no initial charge when the capacitor was manufactured.[4] If a charge is placed on the capacitor and the voltage is given at t = t_0, then Equation 7 becomes

$$v(t) = v(t_0)\frac{1}{C}\int_{t_0}^{t} i(\tau)d\tau \quad (8)$$

Equation 7 demonstrates that the capacitor voltage, unlike the voltage across a linear resistor, is dependent on the entire past history of the current through the capacitor. Equation 8 shows that knowledge of the entire past history of the capacitor voltage is not required if the voltage is known at some initial time, t_0. Equations 7 and 8 can be applied to inductors in a similar fashion.

The resulting effect of these elements is a frequency dependent gain and phase shift of the output signal compared to the input signal. Electrical memory effects add poles and zeros to the response of the linear system causing changes in gain and phase across frequency.

In the nonlinear representation of a system the impact of memory lends greater complexity to the analysis. In PAs in particular, memory effects contribute not only to amplitude distortion (AM-AM) but to phase distortion as well (AM-PM). This will be demonstrated in the analysis in the following section.

DISTORTION ANALYSIS

The two-tone test is widely used for analysis of communication system components. This test effectively varies the envelope of the input signal through its complete range, testing the amplifier over its entire transfer characteristic[3] with the application of a sinusoidal signal to the RF carrier. The two-tone test can reveal both phase and amplitude distortions present in an amplifier. The following evaluation of distortion products will neglect phase modulation for the purpose of simplicity, but the procedure is the same. In the case of a PA, the two-tone input signal stimulating the device is in the form

$$x(t) = A_1\cos(\omega_1 t) + A_2\cos(\omega_2 t) \quad (9)$$

Rewriting the expressions for the linear and nonlinear responses to a two-tone to include a time delay for systems with memory

$$y_L(t) = \alpha_1(A_1\cos(\omega_1 t-\omega_1\tau) + A_2\cos(\omega_2 t-\omega_2\tau)) \quad (10)$$

and

$$\begin{aligned} y_{NL}(t) = {} & \alpha_1(A_1\cos(\omega_1 t-\omega_1\tau_1) + A_2\cos(\omega_2 t-\omega_2\tau_1)) \\ & +\alpha_2(A_1\cos(\omega_1 t-\omega_1\tau_2) + A_2\cos(\omega_2 t-\omega_2\tau_2))^2 \\ & +\alpha_3(A_1\cos(\omega_1 t-\omega_1\tau_3) + A_2\cos(\omega_2 t-\omega_2\tau_3))^3 = \\ & \alpha_1(A_1\cos(\omega_1 t-\phi_{11}) + A_2\cos(\omega_2 t-\phi_{21})) \\ & +\alpha_2(A_1\cos(\omega_1 t-\phi_{12}) + A_2\cos(\omega_2 t-\phi_{22}))^2 \\ & +\alpha_3(A_1\cos(\omega_1 t-\phi_{13}) + A_2\cos(\omega_2 t-\phi_{23}))^3, \\ & \phi_{11} = \omega_1\tau_1,\ \phi_{21} = \omega_2\tau_1,\ \ldots\ \phi_{ij} = \omega_i\tau_j \end{aligned} \quad (11)$$

The ϕ_{ij} terms in Equation 11 represent the phase shift associated with each polynomial term and are considered constant in this analysis. Equation 11 can then be expanded to

$$
\begin{aligned}
y_{NL}(t) = {} & \alpha_1 \begin{pmatrix} A_1\cos(\omega_1 t - \phi_{11}) \\ +A_2\cos(\omega_2 t - \phi_{21}) \end{pmatrix} \\
& +\alpha_2 \begin{pmatrix} \frac{1}{2}\left(A_1^2 + A_2^2\right) \\ +A_1A_2\cos\left((\omega_1-\omega_2)t - (\phi_{12}-\phi_{22})\right) \\ +A_1A_2\cos\left((\omega_1+\omega_2)t - (\phi_{12}+\phi_{22})\right) \\ +\frac{1}{2}A_1^2\cos(2\omega_1 t - 2\phi_{12}) \\ +\frac{1}{2}A_2^2\cos(2\omega_2 t - 2\phi_{22}) \end{pmatrix} \\
& +\alpha_3 \begin{pmatrix} \frac{3}{4}A_1^3\cos(\omega_1 t - \phi_{13}) \\ +\frac{3}{4}A_2^3\cos(\omega_2 t - \phi_{23}) \\ +\frac{3}{2}A_1A_2^2\cos(\omega_1 t - \phi_{13}) \\ +\frac{3}{2}A_1^2A_2\cos(\omega_2 t - \phi_{23}) \\ +\frac{3}{4}A_1^2A_2\cos\begin{pmatrix}(2\omega_1-\omega_2)t \\ -(2\phi_{13}-\phi_{23})\end{pmatrix} \\ +\frac{3}{4}A_1^2A_2\cos\begin{pmatrix}(2\omega_1+\omega_2)t \\ -(2\phi_{13}+\phi_{23})\end{pmatrix} \\ +\frac{3}{4}A_1A_2^2\cos\begin{pmatrix}(2\omega_2-\omega_1)t \\ +(\phi_{13}-2\phi_{23})\end{pmatrix} \\ +\frac{3}{4}A_1A_2^2\cos\begin{pmatrix}(2\omega_2+\omega_1)t \\ -(\phi_{13}-2\phi_{23})\end{pmatrix} \\ +\frac{1}{4}A_1^3\cos(3\omega_1 t - 3\phi_{13}) \\ +\frac{1}{4}A_2^3\cos(3\omega_2 t - 3\phi_{23}) \end{pmatrix}
\end{aligned}
\tag{12}
$$

From Equation 12 it can be observed that for a linear system, a sinusoidal input generates a similar sinusoidal response. For the nonlinear model, the response includes second- and third-harmonic distortion terms at $2\omega_i$ and $3\omega_i$ in addition to the linear term in Equation 10. There is a DC offset term of 1/2 $\alpha_2 A(t)^2$ that is manifested as a shift in bias from the quiescent point as well as cross-modulation (CM) and intermodulation (IM) products. For example, at the fundamental frequency, ω_1 (or ω_2), the output can be written as

$$
\begin{aligned}
y(\omega_1) = {} & \alpha_1 A_1\cos(\omega_1 t - \phi_{11}) \\
& +\frac{3}{4}A_1^3\cos(\omega_1 t - \phi_{13}) \\
& +\frac{3}{2}A_1A_2^2\cos(\omega_1 t - \phi_{13})
\end{aligned}
\tag{13}
$$

The first term is the contribution from the linear response, the second is the gain compression or expansion term (AM-AM) and the last term is the cross-modulation term. ***Table 1*** summarizes the classifications of all distortion terms represented above.

TYPES OF DISTORTION

The distortion products of Equation 12 describe the different components resulting from the effects of a nonlinear device. The distortion products that directly impact the fundamental frequency or frequencies of the input signal cause 'in-band' distortion and can be the most challenging to alleviate. Other products describe 'out-of-band' distortion that can often be filtered out. The harmonic responses are examples of 'out-of-band' distortion.

AM-AM Distortion, AM-PM Distortion and the Error Vector

AM-AM distortion comes from the nonlinear relationship between the output amplitude of the fundamental and the input amplitude at a particular frequency regardless of whether a system displays memory effects. AM-PM distortion is only seen when a system demonstrates memory effects. Examining the contributions of the two-tone response at ω_1 gives

$$
\begin{aligned}
y_{NL}(t)\big|_{\omega=\omega_1} = {} & \alpha_1 A_1\cos(\omega_1 t - \phi_{11}) \\
& +\alpha_3\frac{3}{4}A_1^3\cos(\omega_1 t - \phi_{13}) \\
& +\frac{3}{2}A_1A_2^2\cos(\omega_1 t - \phi_{13})
\end{aligned}
\tag{14}
$$

The first term is contributed by the linear response to the input, the second and third terms modify the amplitude and the phase of the linear term. The second term is the result of the input amplitude at ω_1 and is the AM-AM and AM-PM term. The third term is the third-order response to the second tone at ω_1 and is the cross-modulation term. Since the terms are evaluated at a particular frequency, Equation 14 may be represented as a vector sum as

$$y_{NL}(t)\big|_{\omega=\omega_1} = \alpha_1 A_1 \angle\phi_{11} + \alpha_3 \frac{3}{4} A_1^3 \angle\phi_{13} + \alpha_3 \frac{3}{2} A_1 A_2^2 \angle\phi_{13} \quad (15)$$

In the case of a system with no memory, that is, one that has no energy storage elements, there is no phase shift and $\phi_{11} = \phi_{13} = 0$. The distortion terms modify the magnitude of the linear term and there is no impact on phase. The vector sum becomes merely a sum and the distortion terms either decrease (gain compression) or increase (gain expansion) the linear term depending on the sign of a_3. The response at ω_1, shown in ***Figure 1***, becomes

$$y_{NL}(t)\big|_{\omega=\omega_1} = \alpha_1 A_1 + \alpha_3 \left(\frac{3}{4} A_1^3 + \frac{3}{2} A_1 A_2^2 \right) \quad (16)$$

Note that in the response to a two-tone input, the AM and CM distortion terms sum regardless of the system having memory. Without memory the angle between the AM and CM vectors is zero and there is no phase distortion. With memory the AM and CM vectors are separated by a non-zero angle and create phase distortion. The AM at ω_1 increases or decreases with A_1^3, the amplitude of the first tone cubed, whereas the contribution from the CM term at ω_1 grows linearly with A_1 but also grows as the square of A_2, the result of the cross-modulation from the second tone. The error vector is the difference between the linear term and the sum of the AM and CM terms. In systems with no memory the error vector has no phase and is simply the magnitude of the error.

For systems that exhibit memory effects, the phase of the error term obviously has an impact on the response. To illustrate this, Equation 15 is rewritten as

$$y_{NL}(t)\big|_{\omega=\omega_1} = \alpha_1 A_1 \angle\phi_{11} + \alpha_3 \left(\frac{3}{4} A_1^3 + \frac{3}{2} A_1 A_2^2 \right) \angle\phi_{13} \quad (17)$$

The error vector magnitude (EVM) is

$$\text{EVM} = \alpha_3 \left(\frac{3}{4} A_1^3 + \frac{3}{2} A_1 A_2^2 \right) \quad (18)$$

at an angle of ϕ_{13}. The angle ϕ_{11} is set equal to zero and the vectors are shown in ***Figure 2***. In Figure 2(a), the linear response is plotted on the horizontal axis. The fundamental vector is the resultant of the linear vector and the error vector and has an angle θ. In Figures 2(b) and (c), the effect of increasing and decreasing the amplitude, A_1, is demonstrated. The amplitude and phase of the fundamental output signal changes with A_1 as does the EVM. AM-AM distortion is often defined for a single-tone input. Then Equation 18 reduces to

$$\text{EVM} = \alpha_3 \frac{3}{4} A_1^3 \quad (19)$$

Staudinger[5] describes the impact of AM-PM conversion on the PA response and shows the IM products are particularly sensitive to phase distortion. Here, just the impact on the fundamental has been considered.

Harmonic Distortion

The second-harmonic distortion is defined as

$$\text{HD}_2 = \frac{\text{amplitude of the second-harmonic distortion term}}{\text{amplitude of the fundamental}} \quad (20)$$

which for small distortion, where signal compression or expansion is considered negligible, can be expressed as[6]

$$\text{HD}_2 = \frac{\alpha_2}{2\alpha_1} A \quad (21)$$

Similarly, the third-harmonic distortion is defined as

$$\text{HD}_3 = \frac{\text{amplitude of the third-harmonic distortion term}}{\text{amplitude of the fundamental}} \quad (22)$$

and for small distortion is expressed as

$$\text{HD}_3 = \frac{\alpha_3}{4\alpha_1} A^2 \quad (23)$$

A single-tone applied to the nonlinear system will cause new spectral components to be generated. The output consists of the fundamental and harmonics and demonstrates the phenomenon of spectral regrowth. However, amplifier linearity is more often assessed with the two-tone test.

Intermodulation Distortion: AM-AM

In-band intermodulation distortion (IMD) is a result of the odd-order nonlinearities of a system. From Equation 11, it can be observed that there are distortion terms at $\omega_1-\omega_2$ and $\omega_1+\omega_2$. These distortion terms are called the sum and difference second-order intermodulation distortion (IM) terms. The second-order IM products are not in the band of interest in most communications systems, and IM products and harmonics that are out of band can be filtered out. As before with small-signal levels, higher order terms can be neglected, noting that there are higher order sum and difference terms. The amplitudes of the two-tones are set equal and the magnitude of the third-order IM is compared to the magnitude of the second-order term.

Equation 11 is rewritten as

$$y_{NL}(t) = \alpha_1 A(\cos(\omega_1 t) + \cos(\omega_2 t)) + \alpha_2 A^2(\cos(\omega_1 t) + \cos(\omega_2 t))^2 + \alpha_3 A^3(\cos(\omega_1 t) + \cos(\omega_2 t))^3 \quad (24)$$

The second-order intermodulation is

TABLE I

SUMMARY OF DISTORTION TERMS

Distortion Component	*Frequency Component*	*Phase* $\phi_{ij}=\omega_i\tau_j$	*Response*
$\alpha_1 A_1\cos(\omega_1 t-\phi_{11})$	ω_1	ϕ_{11}	linear
$\alpha_1 A_2\cos(\omega_2 t-\phi_{21})$	ω_2	ϕ_{21}	linear
$\frac{\alpha_2}{2}(A_1^2+A_2^2)$	$\omega_1-\omega_1$ $\omega_2-\omega_2$	$\phi_{12}-\phi_{12}$ $\phi_{22}-\phi_{22}$	DC bias shift
$\alpha_2 A_1 A_2\cos((\omega_1-\omega_2)t-(\phi_{12}-\phi_{22}))$	$\omega_1-\omega_2$	$\phi_{12}-\phi_{22}$	IM2
$\alpha_2 A_1 A_2\cos((\omega_1+\omega_2)t-(\phi_{12}+\phi_{22}))$	$\omega_1+\omega_2$	$\phi_{12}+\phi_{22}$	IM2
$\frac{\alpha_2}{2} A_1^2\cos(2\omega_1 t-2\phi_{12})$	$2\omega_1$	$2\phi_{12}$	second-order harmonic distortion
$\frac{\alpha_2}{2} A_2^2\cos(2\omega_2 t-2\phi_{22})$	$2\omega_2$	$2\phi_{22}$	second-order harmonic distortion
$\frac{3}{4}\alpha_3 A_1^3\cos(\omega_1 t-\phi_{13})$	$2\omega_1-\omega_1=\omega_1$	ϕ_{13}	AM/AM conversion—gain compression or expansion—AM/PM conversion
$\frac{3}{4}\alpha_3 A_2^3\cos(\omega_2 t-\phi_{23})$	$2\omega_2-\omega_2=\omega_2$	ϕ_{23}	AM/AM conversion—gain compression or expansion—AM/PM conversion
$\frac{3}{2}\alpha_3 A_1 A_2^2\cos(\omega_1 t-\phi_{13})$	$\omega_1+\omega_2-\omega_2=\omega_1$	ϕ_{13}	CM
$\frac{3}{2}\alpha_3 A_1^2 A_2\cos(\omega_2 t-\phi_{23})$	$\omega_2+\omega_1-\omega_1=\omega_2$	ϕ_{23}	CM
$\frac{3}{4}\alpha_3 A_1^2 A_2\cos((2\omega_1-\omega_2)t-(2\phi_{13}-\phi_{23}))$	$2\omega_1-\omega_2$	$2\phi_{13}-\phi_{23}$	IM3
$\frac{3}{4}\alpha_3 A_1^2 A_2\cos((2\omega_1+\omega_2)t-(2\phi_{13}+\phi_{23}))$	$2\omega_1+\omega_2$	$2\phi_{13}+\phi_{23}$	IM3
$\frac{3}{4}\alpha_3 A_1 A_2^2\cos((2\omega_2-\omega_1)t-(2\phi_{23}-\phi_{13}))$	$2\omega_2-\omega_1$	$\phi_{23}-2\phi_{13}$	IM3
$\alpha_3\frac{3}{4} A_1 A_2^2\cos((2\omega_2+\omega_1)t-(\phi_{13}-2\phi_{23}))$	$2\omega_2+\omega_1$	$\phi_{13}-2\phi_{23}$	IM3
$\frac{1}{4}\alpha_3 A_1^3\cos(3\omega_1 t-3\phi_{13})$	$3\omega_1$	$3\phi_{13}$	third-order harmonic distortion
$\frac{1}{4}\alpha_3 A_2^3\cos(3\omega_2 t-3\phi_{23})$	$3\omega_2$	$3\phi_{23}$	third-order harmonic distortion

$$IM_2 = \frac{\text{amplitude second-order IM component}}{\text{amplitude fundamental}} = \frac{\alpha_2 A^2}{\alpha_1 A} = \frac{\alpha_2}{\alpha_1} A \qquad (25)$$

Thus, when the distortion level is low, IM_2 grows proportionally to signal power.

Expanding the third-order term in a similar manner

$$\begin{aligned}
&\alpha_3\left(A\cos(\omega_1 t)+A\cos(\omega_2 t)\right)^3 = \\
&\alpha_3 A^3\cos^3(\omega_1 t)+\alpha_3 A^3\cos^3(\omega_2 t) \\
&+3\alpha_3 A^3\cos(\omega_1 t)\cos^2(\omega_2 t) \\
&+3\alpha_3 A^3\cos^2(\omega_1 t)\cos(\omega_2 t) = \\
&\alpha_3\frac{A^3}{4}\left(3\cos(\omega_1 t)+3\cos(\omega_2 t)\right) \\
&+\frac{3}{4}\alpha_3 A^3\left(2\cos(\omega_1 t)+2\cos(\omega_2 t)\right) \\
&+\alpha_3\frac{A^3}{4}\left(\cos(3\omega_1 t)+\cos(3\omega_2 t)\right) \\
&+\frac{3}{4}\alpha_3 A^3\begin{pmatrix}\cos((2\omega_1+\omega_2)t) \\ +\cos((2\omega_2+\omega_1)t)\end{pmatrix} \\
&+\frac{3}{4}\alpha_3 A^3\begin{pmatrix}\cos((2\omega_1-\omega_2)t) \\ +\cos((2\omega_2-\omega_1)t)\end{pmatrix} \qquad (26)
\end{aligned}$$

Equation 26 includes a fundamental term that may cause gain compression or expansion, a third-order harmonic distortion term and a sum term that is generally outside the band of interest but that will be close to the third harmonic term. The last term in Equation 26 is the IM term that will appear in the frequency range of interest. The expression for the IM3 is

$$IM_3 = \frac{\text{amplitude third-order IM component}}{\text{amplitude fundamental}} = \frac{3}{4}\frac{\alpha_3 A^3}{\alpha_1 A} = \frac{3}{4}\frac{\alpha_3 A^2}{\alpha_1} \qquad (27)$$

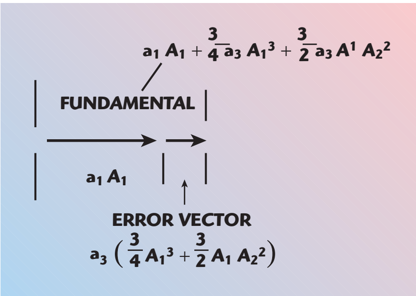

Fig. 1 Amplitude modulation in a memoryless system.

Cross-modulation

Cross-modulation occurs when the amplitude modulation is transferred from one carrier to another by nonlinearity in a circuit. The input consists of two tones or more and the level of cross-modulation present in a system is usually determined with two input signals, one modulated and one non-modulated as in

$$x_i = A_1\cos(\omega_1 t) + A_2(1+m\cos(\omega_m t))\cos(\omega_2 t) \quad (28)$$

where

m = modulation index of the modulated signal
ω_m = modulating frequency

The amount of amplitude modulation transferred to the signal of frequency ω_1 as it passes through the nonlinear circuit determines the cross-modulation for that circuit. Substituting Equation 28 into the power series of Equation 3 yields

$$\begin{aligned}
y_0 = {} & \alpha_1(A_1\cos(\omega_1 t) \\
& + A_2(1+m\cos(\omega_m t))\cos(\omega_2 t)) \\
& + \alpha_2(A_1\cos(\omega_1 t) \\
& + A_2(1+m\cos(\omega_m t))\cos(\omega_2 t))^2 \\
& + \alpha_3(A_1\cos(\omega_1 t) \\
& + A_2(1+m\cos(\omega_m t))\cos(\omega_2 t))^3 + \ldots
\end{aligned} \qquad (29)$$

Expanding the second term in Equation 29 gives

$$\begin{aligned}
& \alpha_2 A_1^2\cos^2(\omega_1 t) + \alpha_2 A_1 A_2 \\
& (1+m\cos(\omega_m t))\cos((\omega_1 \pm \omega_2)t) \\
& + \alpha_2 A_2^2(1+m^2\cos^2(\omega_m t) \\
& + 2m\cos(\omega_m t))\cos^2(\omega_2 t)
\end{aligned} \qquad (30)$$

Since cross-modulation results in a term in the form of $K(1+\delta\cos(\omega_m t)\cos(\omega_1 t))$, it is seen, by inspection, that the second-order nonlinearities do not add to the cross-modulation of a nonlinear system. Cross-modulation contribution from the third term in Equation 29 is

$$\begin{aligned}
& 3\alpha_3 A_1\cos(\omega_1 t) A_2^2\begin{pmatrix}1+2m\cos(\omega_m t) \\ +m^2\cos^2(\omega_m t)\end{pmatrix} \\
& \cos^2(\omega_2 t) = 3\alpha_3 A_1 A_2^2\cos(\omega_1 t) \\
& \left(1+2m\cos(\omega_m t)+m^2\cos^2(\omega_m t)\right) \\
& \frac{1}{2}\left(1+\cos(2\omega_2 t)\right)
\end{aligned} \qquad (31)$$

The term $3\alpha_3 A_1 A_2^2 m\cos(\omega_m t)\cos(\omega_1 t)$ in Equation 31 contributes to cross-modulation (the term involving $\cos^2(\omega_m t)$ does as well but is neglected by convention). Combining the linear term in Equation 29 with Equation 30 in Equation 31 shows that the component of the output at frequency ω_1 has modulation at frequency ω_m transferred to it

$$y_0 = \alpha_1 A_1\left(1+3\frac{\alpha_3}{\alpha_1}A_2^2 m\cos(\omega_m t)\right)\cos(\omega_1 t) \qquad (32)$$

Cross-modulation is defined as

$$CM = \frac{\text{transferred modulation index}}{\text{incoming modulation index}} = 3\frac{\alpha_3}{\alpha_1}A_2^2 \qquad (33)$$

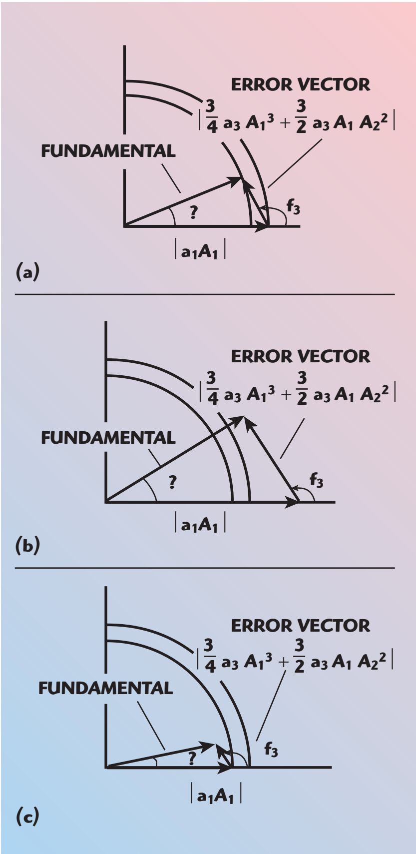

Fig. 2 Illustration of the error vector, and AM/AM and AM/PM distortion.

From this it can be seen that CM is independent of A_1 and m, and depends only on $A_2{}^2$. Equation 28 is valid for small distortion in all applications. If $A_1 = A_2$, then

$$CM = 3\frac{\alpha_3}{\alpha_1}A_1^2 = 3\frac{\alpha_3}{\alpha_1^2}A_{om}^2 \qquad (34)$$

where y_{om} is defined as $y_{om} = \alpha_1 A_1$

Adjacent Channel Leakage Ratio

Adjacent channel leakage ratio (ACLR) is a measure of intermodulation distortion in wireless transmission systems. ACLR describes the leakage of power from one channel to an adjacent channel. It is an extension to the simple two-tone intermodulation test and quantifies how much of a signal spreads into the next channel. ACLR is the ratio of the total integrated power in the channel adjacent to the signal band to power in the signal band itself[7]

$$ACLR = \frac{P_{\text{fundamental bandwidth}}}{P_{\text{lower adjacent bandwidth}} + P_{\text{upper adjacent bandwidth}}} = \frac{\int_{\omega_1}^{\omega_2} S_o(\omega)d\omega}{\int_{\omega_{L1}}^{\omega_1} S_o(\omega)d\omega + \int_{\omega_2}^{\omega_{U2}} S_o(\omega)d\omega} \qquad (35)$$

In Equation 35 $S_o(\omega)$ is the power spectral density function of the in-band output power.

CONCLUSION

In this article a polynomial input-output model has been described along with various figures of merit for communication systems. It has been shown how this polynomial model can be used to demonstrate the impact of various distortions on the communications signal. Several typical descriptions of distortion have been described and their impact on the signal has been illustrated. ■

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OSCILLATOR PHASE NOISE: THEORY AND PREDICTION

Oscillator phase noise is a complex topic that has been explored by several authors from both theoretical and practical perspectives. That perspective has sometimes obscured some of the basic principles involved in low noise oscillator and synthesizer design. Within this technical tutorial, the work of several authors is distilled to the basic elements of low phase noise oscillator and frequency synthesizer design. The basic feedback oscillator circuit topology is explored in order to formulate an equation that specifically addresses the parameters that determine the oscillator output signal phase noise. A mathematical model of the phase-locked oscillator is developed for fixed frequency and frequency synthesizer applications. The models are used to predict the oscillator output signal phase noise.

Signal source spectral quality has become the single parameter that limits achievable performance of many modern communication and radar systems. In communication systems that utilize complex modulation to achieve spectral efficiency, the achievable bit error rate (BER) is often limited by the transmitter and local oscillator phase noise. In many modern radar systems, the sub-clutter visibility, that is the ability to differentiate an object from a complex background, is similarly limited by the transmitter and local oscillator phase noise. Reciprocal mixing is another phenomenon that causes receiver noise to increase in presence of strong signals, thereby limiting detection of weak signals in adjacent channels. The cited degradation in system performance is the result of the phase noise of the signal sources employed within the designated systems. Phase noise may also limit the maximum angular resolution, which can be achieved by an interferometer type of direction-finding receiver. Phase noise is the result of random modulation of the phase component of a signal; it is characterized by the single sideband phase noise normalized to a 1 Hz bandwidth and symbolized by $\mathscr{L}$(fm). Phase noise is similar to the jitter specification common to components used within network and other high speed digital systems. Within this brief tutorial, the topic of phase noise in oscillators is explored. The indigenous sources of phase noise are disclosed and models are developed for phase noise prediction in both free-running and phase-locked oscillators from which specific low phase noise design rules are deduced. The interested reader is referred to the cited references for more detailed information.

Phase noise is the result of random modulation of the phase component of a signal; it is characterized by the single sideband phase noise normalized to a 1 Hz bandwidth and symbolized by $\mathscr{L}$(fm).

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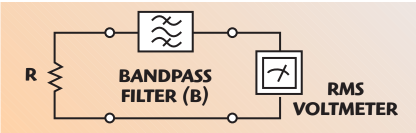
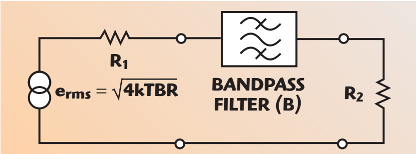
THE SCHERER EQUATION

The Scherer equation[1] relates the phase noise of a free-running oscillator to the constituent parameters of the oscillator system, specifically the noise figure of the active element (F), the resonator quality factor (Q_L), the operating frequency (f_o) and available power (P_{av}). The active element noise figure is a composite parameter that includes the 'flicker' or 1/f noise.

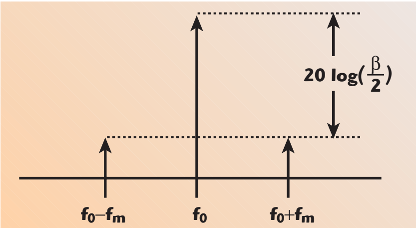
Notwithstanding the uniqueness of various oscillator circuit topologies, the circuit topology utilized for the mathematical development is based upon an explicit feedback loop containing a single-section resonator. The Scherer equation does not account for nonlinear behavior within the active element and is therefore somewhat limited with respect to highly accurate oscillator phase noise estimation in all cases. However, the utility resides within the identification of the parameters contribution and is not significantly diminished by the absence of nonlinear analysis. In addition, the Scherer equation provides an intuitive understanding of the principal factors that determine the phase noise of free-running oscillators. The development begins with an exploration of the phase modulation of a signal by additive noise and proceeds to the examination of the noise-to-signal ratio upon further processing within an explicit feedback loop containing a single-section resonator. The resonator is mathematically characterized by an equivalent low pass element to facilitate representation of phase noise by the conventional, single sideband, noise-to-carrier ratio.



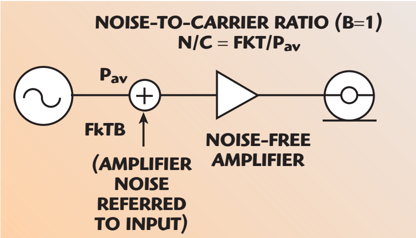
▲ *Fig. 1 Noise voltage measurement.*



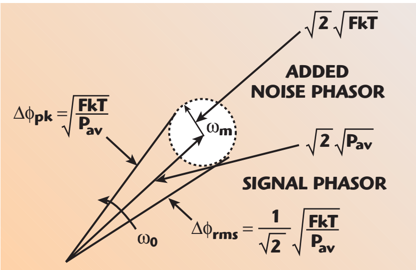
▲ *Fig. 2 Calculation of maximum available power.*



▲ *Fig. 3 Spectrum of a single tone PM (β<<1).*



▲ *Fig. 4 Additive noise at amplifier input.*



▲ *Fig. 5 Phasor representation of signal and noise.*

THE BASICS

The development of the Scherer equation begins with some circuit theory basics required to establish and characterize noise, in this case the Johnson noise—also known as Nyquist or thermal noise. Noise within electrical systems is principally caused by the random thermal agitation of charges. There are other types of noise, such as shot or flicker noise, to be included in the analysis with significant impact to the overall phase noise at various offset frequencies. However, the thermal noise is the basis and accounting for flicker noise is accomplished with a modest adjustment to the active device noise figure. ***Figure 1*** illustrates a circuit topology consisting of a series connected resistor, a bandpass filter and an RMS voltmeter.

The open circuit noise voltage of a resistor may be represented by

$$e_{rms} = \sqrt{4kTBR} \tag{1}$$

where

k = Boltzmann constant (1.38E-23 Joules/K)
T = absolute temperature (K)
B = measurement bandwidth (Hz)
R = resistor value (Ω)

Referring to ***Figure 2***, consider the maximum noise power available from the source resistor, R_1. The voltage across the resistor R_2 may be written as

$$e_{rms\_R_2} = \frac{e_{rms}R_2}{R_1 + R_2} = \frac{\sqrt{4kTBR_1}R_2}{R_1 + R_2} \tag{2}$$

The power dissipated in resistor R_2 may be written as

$$P_{d\_R_2} = \frac{e^2_{rms\_R_2}}{R_2} = \frac{4kTBR_1R_2}{(R_1 + R_2)^2} \tag{3}$$

The maximum available power is found by differentiating Equation 3 with respect to R_2, setting the result to zero and solving for R_2. Executing this procedure produces the expected result for maximum available power transmission

$$R_2 = R_1 \tag{4}$$

Further, upon substitution of $R_1 = R_2 = R$, the maximum available noise power may be written as

$$N_{av} = kTB \tag{5}$$

This result—although obvious—facilitates further development of the phase noise of a free-running oscillator and is a fundamental element of the general topic of noise analysis. The diligent reader is referred to any of numerous available articles (for example, one might search using the text "thermal noise"). Upon normalization with respect to a 1.0 Hz bandwidth, the following result may be written

$$\overline{N}_{av} = kT \text{ or } \overline{N}_{av\_dbm} = -174 \text{ dBm/Hz} \tag{6}$$

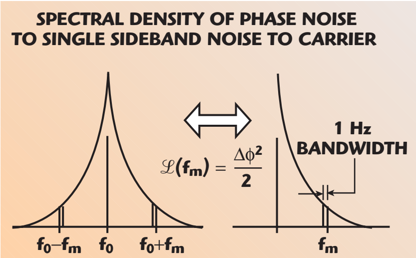
ADDITIVE NOISE AND PHASE MODULATION

Before exploring how additive noise engenders phase modulation to a signal, a short review of elementary phase modulation theory is in order. A single tone sinusoidal signal, s(t), with phase modulation may be mathematically represented as

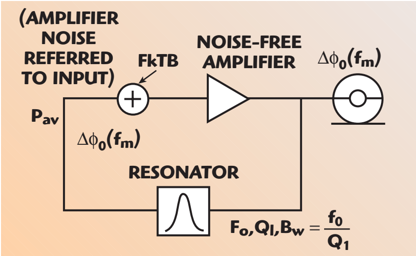
$$s(t) = \alpha_c \cos[2\pi f_o t + \beta \sin(2\pi f_m t)] \tag{7}$$

If β<<1 (small modulation index), s(t) may be represented as

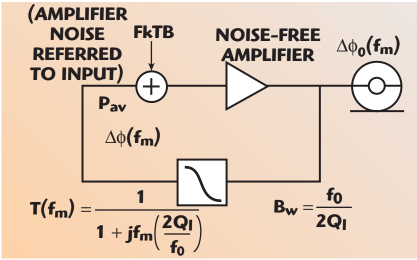
$$s(t) \cong \alpha_c \cos[(2\pi f_o t) - \beta \sin(2\pi f_m t)\sin(2\pi f_o t)] \tag{8}$$



▲ *Fig. 6 Relationship between $\Delta\phi^2_{rms}$ and $\mathcal{L}(f_m)$.*



▲ *Fig. 7 Feedback oscillator phase noise model.*



▲ *Fig. 8 Low pass oscillator phase noise model.*

$$s(t) = \alpha_c \cos(2\pi f_o t)$$

$$-\frac{1}{2}\alpha_c\beta\cos(2\pi f_o t - 2\pi f_m t) + \frac{1}{2}\alpha_c\beta\cos(2\pi f_o t - 2\pi f_m t) \quad (9)$$

The spectral content of the signal is shown in ***Figure 3***, where the carrier, and lower and upper sidebands are represented. Additive noise induces phase modulation sidebands on a signal. To examine and quantify this phenomenon, observe ***Figure 4***, where a signal with available power P_{av} is introduced to an amplifier. The noise (normalized by a 1 Hz bandwidth) generated by the amplifier (FkT) is also referred to the input. The power spectral density of the added noise may be represented by the sum of random variable sinusoidal signals of available power, FkT, and is expressed as

$$e_{n\_rms} = \sqrt{FkT} \quad (10)$$

Similarly,

$$e_{av\_rms} = \sqrt{P_{av}} \quad (11)$$

The reason for this apparent diversion becomes evident when the phasor representation of the signal and added noise are graphically illustrated as in ***Figure 5***. From the previously developed PM theory, the phase deviation engenders two sidebands on the carrier, displaced by the modulation frequency, f_m. The total RMS phase deviation is the sum of the two sidebands, and is represented by

$$\Delta\phi^2_{rms\_tot} = \left(\frac{1}{\sqrt{2}}\sqrt{\frac{FkT}{P_{av}}}\right)^2 + \left(\frac{1}{\sqrt{2}}\sqrt{\frac{FkT}{P_{av}}}\right)^2 \quad (12)$$

$$\Delta\phi^2_{rms\_tot} = \frac{FkT}{P_{av}} \quad (13)$$

In the following descriptions, the total RMS phase deviation will not include the specific reference to 'total'. In addition to the thermal noise with a constant power characteristic versus frequency, active devices are also characterized by a low frequency noise component, often referred to as 'flicker' or 1/f noise, due to the increase in noise power density as the frequency decreases. Mathematically, the 1/f noise may be accounted for by including a frequency dependent term. Accounting for the 1/f noise term, the total phase modulation may now be written as

$$\Delta\phi^2_{rms} = \frac{FkT}{P_{av}}\left(1 + \frac{f_c}{f_m}\right) \quad (14)$$

Note that although the equation indicates an increase in noise below the cut-off frequency f_c of 6 dB/octave, some devices may have a greater exponential characteristic, such as f_c^2, with 12 dB/octave or greater increase in noise density below the cut-off frequency. Bipolar junction transistors (BJT) and heterojunction bipolar transistors (HBT) are characterized by the 6 dB/octave slope and have lower cut-off frequencies than GaAs FET or PHEMT devices.

While the total phase noise-to-carrier power ratio has been mathematically represented by the double sideband symbol $\Delta\phi r^2_{rms}$, phase noise is more commonly characterized using the single sideband noise-to-power ratio at a specified offset frequency, f_m. The symbol $\mathcal{L}(f_m)$ represents the ratio of the single sideband power of phase noise in a 1 Hz bandwidth at fm Hz from the carrier, to the carrier power; the units are dBc/Hz. The mathematical relationship between $\Delta\phi r^2_{rms}$ and $\mathcal{L}(f_m)$ is simply

$$\mathcal{L}(f_m) = \frac{\Delta\phi^2_{rms}}{2} \quad (15)$$

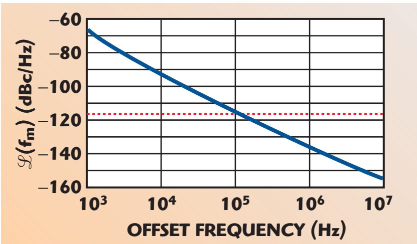
The graphic of ***Figure 6*** is more descriptive and offers a more intuitive definition.

OSCILLATOR PHASE NOISE MODEL

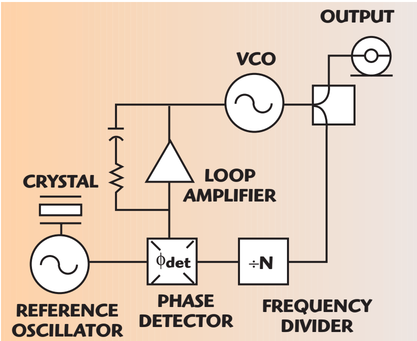
The phase noise model for the phase feedback oscillator is illustrated in ***Figure 7***, where an amplifier is represented with an equivalent input noise and an explicit feedback loop containing a resonator characterized by the center frequency f_o, the bandwidth B_w and the loaded quality factor Q_l. The output power spectrum of phase noise variation is represented by $\Delta\phi^2{}_0(f_m)$; the output power spectral density is processed by the resonator and produces an input power spectral density of phase noise variations represented by $\Delta\phi^2(f_m)$, where f_m is the offset frequency from the carrier, f_o. In order to work directly with the offset frequency, the bandpass characteristic of the transmission resonator is replaced by the low pass equivalent and the feedback oscillator phase noise model is modified, as shown in ***Figure 8***. The low pass equivalent of the transmission resonator is depicted using the transfer function $T(f_m)$.

The feedback loop equation may be written as

$$\Delta\phi_o(f_m) = T(f_m)\Delta\phi_o(f_m) + \Delta\phi(f_m) \qquad (16)$$



▲ *Fig. 9 Simulated oscillator single sideband phase noise.*



▲ *Fig. 10 Phase-locked loop circuit topology.*

Solving for the output power spectral density yields

$$\Delta\phi_o(f_m) = \frac{\Delta\phi(f_m)}{1 - T(f_m)} \qquad (17)$$

The low pass transfer function may be written as

$$T(f_m) = \frac{1}{1 + jf_m\left(\dfrac{2Q_l}{f_o}\right)} \qquad (18)$$

Upon substitution within the loop equation, one may write

$$\Delta\phi_o(f_m) = \frac{\Delta\phi(f_m)}{1 - \dfrac{1}{1 + jf_m\left(\dfrac{2Q_l}{f_0}\right)}} = \Delta\phi(f_m)\frac{1 + jf_m\left(\dfrac{2Q_l}{f_0}\right)}{jf_m\left(\dfrac{2Q_l}{f_0}\right)} \qquad (19)$$

Simplification of the equation yields

$$\Delta\phi_o(f_m) = \Delta\phi(f_m)\left[1 - j\frac{f_o}{2Q_l f_m}\right] \qquad (20)$$

From Equation 14 developed earlier

$$\Delta\phi^2(f_m) = \frac{FkT}{P_{av}}\left(1 + \frac{f_c}{f_m}\right)$$

where upon further substitution and utilization of the magnitude of the transfer function

$$\Delta\phi_o^2(f_m) = \frac{Fkt}{P_{av}}\left(1 + \frac{f_c}{f_m}\right)\left[1 + \left(\frac{f_o}{2Q_l f_m}\right)^2\right] \qquad (21)$$

Recall that

$$\mathscr{L}(f_m) = \frac{1}{2}\Delta\phi_o^2(f_m)$$

The Scherer equation in final form is written as

$$\mathscr{L}(f_m) = \frac{1}{2}\frac{Fkt}{P_{av}}\left(1 + \frac{f_c}{f_m}\right)\left[1 + \left(\frac{f_o}{2Q_l f_m}\right)^2\right] \qquad (22)$$

The significant parameters of the Scherer equation are summarized below:

- Select devices with low 1/f noise, such as BJT or HBT devices as opposed to GaAs FET devices
- Select large geometry devices to maximize P_{av}
- Maximize the resonator loaded quality factor, Q_l
- Minimize the noise figure, F; this may be done by control of the impedance environment of the active device.

It should be remembered that the Scherer equation does not account for nonlinear conversion of noise sidebands. Notwithstanding this limitation, $\mathscr{L}(f_m)$ prediction is reasonably accurate for those applications where the feedback signal level is controlled in a manner that limits the degree of nonlinear operation. As an example, the predicted phase noise of an oscillator constructed from an InGaP HBT using a resonator with a loaded quality factor, $Q_l = 56$, is shown in ***Figure 9***.

PHASE-LOCKED LOOP OSCILLATOR NOISE MODEL

The phase-locked loop circuit topology is illustrated in ***Figure 10***, where a voltage-controlled oscillator (VCO), frequency divider, phase detector and loop amplifier are exhibited in a classic feedback loop configuration. A crystal oscillator provides a stable reference source from which an error signal is derived. The error signal is generated by the phase detector, which compares the phase difference of the VCO—appropriately divided—and the reference source. The loop amplifier conditions the error signal and corrects the phase of the VCO in accordance with the error signal. The net result of the loop action is to impart the spectral characteristics of the reference source to the VCO consistent with the bandwidth of the loop. The block diagram of the phase-locked loop noise model is shown in ***Figure 11***, where each of the constituent component noise sources are identified in accordance with the following symbols and text:

$\Delta\phi_{out}$ = Output RMS phase noise
$\Delta\phi_{osc}$ = VCO phase noise ($\Delta\phi_{osc} = e_{nosc} K_o/s$)
$\Delta\phi_{ref}$ = Reference phase noise
$\Delta\phi_{div}$ = Frequency divider phase noise
$\Delta\phi_{det}$ = Detector phase noise ($\Delta\phi_{det} = /K\phi$)
K_o = VCO gain constant (Rad/V)

$K\phi$	=	Phase detector gain constant (V/Rad)
A(s)	=	Loop amplifier transfer function
E_{ni}	=	Amplifier equivalent input noise

The loop equation may be written by noting the phase noise at each point around the loop

At A:

$$\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div} \tag{23}$$

At B:

$$\Delta\phi_{ref} - \left(\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div}\right)K_\phi \tag{24}$$

At C:

$$\left[\Delta\phi_{ref} - \left(\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div}\right)\right]K_\phi + e_{ni} + e_{n\,det} \tag{25}$$

At D:

$$\left[\Delta\phi_{ref} - \left(\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div}\right)\right]K_\phi A(s) + e_{ni}A(s) + e_{n\,det}A(s) \tag{26}$$

At E:

$$\left[\Delta\phi_{ref} - \left(\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div}\right)\right]K_\phi A(s) + e_{ni}A(s) + e_{n\,det}A(s) + e_{nosc} \tag{27}$$

At F:

$$\Delta\phi_{out} = \left[\Delta\phi_{ref} - \left(\frac{\Delta\phi_{out}}{N} + \Delta\phi_{div}\right)\right]K_\phi A(s)\frac{K_o}{s} + e_{ni}A(s)\frac{K_o}{s} + e_{n\,det}A(s)\frac{K_o}{s} + e_{nosc}\frac{K_o}{s} \tag{28}$$

Solving for $\Delta\phi_{out}$:

$$\Delta\phi_{out} = \Delta\phi_{ref}\frac{\frac{K_oK_\phi A(s)}{s}}{1+\frac{K_oK_\phi A(s)}{Ns}} - \Delta\phi_{div}\frac{\frac{K_oK_\phi A(s)}{s}}{1+\frac{K_oK_\phi A(s)}{Ns}} + e_{ni}\frac{\frac{K_oA(s)}{s}}{1+\frac{K_oK_\phi A(s)}{Ns}} + e_{n\,det}\frac{\frac{K_oA(s)}{s}}{1+\frac{K_oK_\phi A(s)}{Ns}} + e_{nosc}\frac{K_o}{s}\frac{1}{1+\frac{K_oK_\phi A(s)}{Ns}} \tag{29}$$

Making the following substitutions:

$$G_o(s) = \frac{K_oK_\phi A(s)}{Ns}$$

and

$$\Delta\phi_{osc} = e_{nosc}\frac{K_o}{s} \tag{30}$$

And rewriting, one obtains:

$$\Delta\phi_{out} = \Delta\phi_{ref}\frac{G_o(s)}{1+G_o(s)}N - \Delta\phi_{div}\frac{G_o(s)}{1+G_o(s)}N + e_{ni}\frac{N}{K_\phi}\frac{G_o(s)}{1+G_o(s)} + e_{n\,det}\frac{N}{K_\phi}\frac{G_o(s)}{1+G_o(s)} + \frac{\Delta\phi_{osc}}{1+G_o(s)} \tag{31}$$

At this point, one must recognize that all the identified noise sources are uncorrelated, and therefore, may be added on an RMS basis. The output signal power spectral density may now be written as

$$\Delta\phi_{out}^2 = \left|\frac{G_o(s)}{1+G_o(s)}\right|^2 N^2\Delta\phi_{ref}^2 + \left|\frac{G_o(s)}{1+G_o(s)}\right|^2 N^2\Delta\phi_{div}^2 + \left|\frac{G_o(s)}{1+G_o(s)}\right|^2 N^2\left(\frac{e_{ni}}{K_\phi}\right)^2 + \left|\frac{G_o(s)}{1+G_o(s)}\right|^2 N^2\left(\frac{e_{n\,det}}{K_\phi}\right)^2 + \frac{\Delta\phi_{osc}^2}{\left|1+G_o(s)\right|^2} \tag{32}$$

It should be noted that the closed loop gain is a complex transfer function and the magnitude of the complex transfer function has been used.

The constituent noise contributors may now be identified, as listed in ***Table 1***.

Upon review of the individual noise sources, the following guidelines for the design of low phase noise signal sources may be deduced:

- Minimize reference noise: $\Delta\phi_{ref}$
- Minimize divider modulus: N
- Maximize open loop gain: $G_o(s)$
- Maximize phase detector gain: K_ϕ
- Minimize phase detector noise: e_{ndet}
- Minimize amplifier input noise: e_{ni}

An example of a phase noise prediction using the model developed is offered. Because the phase noise parametric data and measurements are readily available on the data sheet, the phase noise estimate utilizes the Hittite Microwave HMC535 Ku-band phase-locked IC-PLL (frequency divider noise from HMC439 (InGaP)). The HMC535 is a GaAs InGaP heterojunction bipolar transistor (HBT) MMIC PLO. The power output is +9 dBm, typical from a +5 V supply voltage. All functions (VCO, op-amp, PFD and prescaler) are fully integrated with the exception of the off-chip customer specific loop components.

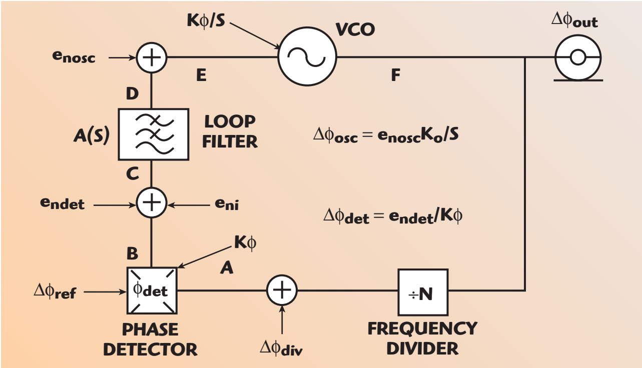
Additional features of the HMC535 are summarized:

- InGaP HBT technology for low 1/f noise
- Low noise Ku-band VCO
- 1/64 prescaler
- Low noise phase detector
- Low noise loop amplifier

A block diagram of the HMC535 IC-PLL configured with external loop components is shown in ***Figure 12***. The following parameters are specified within the HMC535 data sheet:

$K_o = 2\pi 125 \bullet 10^6$ rad/V
$K\phi = 1/\pi$ V/rad
N = 64
$\mathcal{L}_{det}$ = –150 dBc/Hz
$\mathcal{L}_{div}$ = –155 dBc/Hz (at 1 kHz)
$e_{ni} = 2.0\ nV/\sqrt{Hz}$
$\mathcal{L}_{ref}$ = typical VHF crystal oscillator

The results of the phase noise prediction are graphically illustrated in ***Figure 13***. Note the excellent correlation at offset frequencies greater



▲ *Fig. 11 Phase-locked loop noise model.*

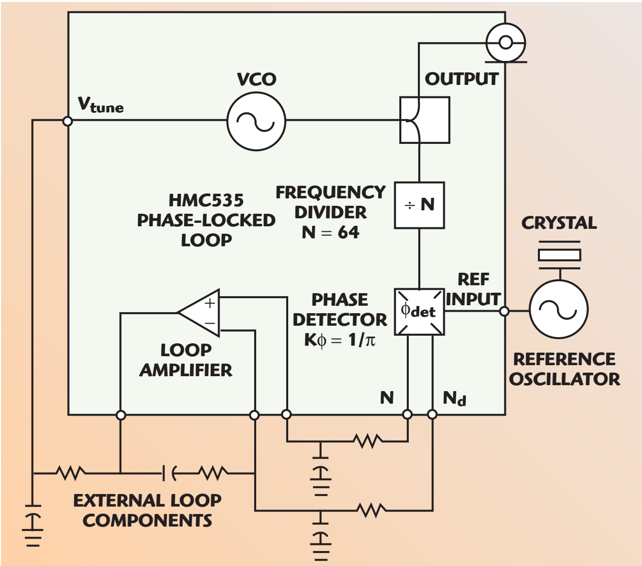
than 1 kHz. The constituent noise source contributions are graphically depicted in ***Figure 14***. As may readily be discerned from the graphic, the principal contribution to the aggregate phase noise at offset frequencies greater than 1 kHz is the divider and phase detector noise; below 1 kHz, multiplied reference noise is the main noise contributor. The phase noise data supplied by Hittite for the HMC535 is more typical of what one would expect of a residual phase noise measurement; that is a measurement of two sources within a source canceling phase bridge. ***Figure 15*** shows the results from a numeric prediction using residual phase noise measurement technique. The residual phase noise estimate is executed with the reference source noise equal to zero, as that is what occurs in a good quality phase bridge. The estimate of phase noise for this example employed a loop amplifier with the controlling elements adjusted to provide a bandwidth equal to that of the Hittite application note.

The strong agreement between prediction and measurement suggests that the oscillator and other loop elements are merely mildly nonlinear.

TABLE I

CONSTITUENT NOISE CONTRIBUTORS

Noise Source	*Contribution*
Reference noise multiplied	$\left\|\frac{G_o(s)}{1+G_o(s)}\right\|^2 N^2 \Delta\phi_{ref}^2$
Divider noise multiplied	$\left\|\frac{G_o(s)}{1+G_o(s)}\right\|^2 N^2 \Delta\phi_{div}^2$
Amplifier input noise multiplied	$\left\|\frac{G_o(s)}{1+G_o(s)}\right\|^2 N^2 \left(\frac{e_{ni}}{K_\phi}\right)^2$
Detector noise multiplied	$\left\|\frac{G_o(s)}{1+G_o(s)}\right\|^2 N^2 \left(\frac{e_{n\,det}}{K_\phi}\right)^2$
VCO noise reduced by open loop gain	$\frac{\Delta\phi_{osc}^2}{\left\|1+G_o(s)\right\|^2}$



▲ *Fig. 12 HMC535 IC-PLL with external loop components.*

PHASE NOISE MEASUREMENT

Phase noise measurements require significant care due to the low measurement levels and possible interference from the electromagnetic environment. In addition, low power supply noise and high isolation within the oscillator and external to the oscillator and measurement equipment are mandatory. There are basically two types of phase noise measurements: absolute and residual. Absolute phase noise measurement is applicable to signal sources while residual phase noise measurement applies to both signal sources and components. In addition, residual phase noise measurement generally implies the removal of the reference source via a well-balanced phase bridge utilized in the measurement.

Absolute Phase Noise Measurement

There are two common techniques employed to execute absolute phase noise measurements: The frequency discriminator method and the phase detector method.

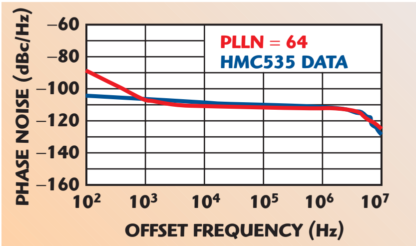
$\mathscr{L}(f_m)$ Measurement Using a Frequency Discriminator

The frequency discriminator method uses the relationship between FM and PM within angle modulation theory. Basically, the relationship between the FM and PM indices may be mathematically described by the equation:

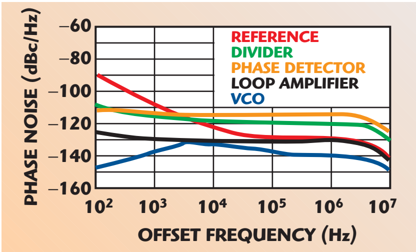
$$\frac{\Delta f}{f_m} = \Delta\phi \tag{33}$$

Therefore, the spectral density of frequency variations may be written

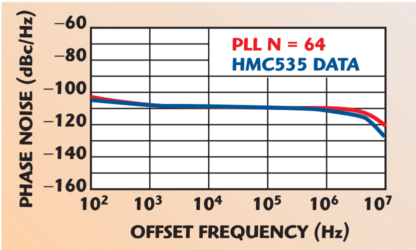
$$\Delta f^2 = f_m^2 \Delta\phi^2 \tag{34}$$



▲ *Fig. 13 HMC535 predicted and measured phase noise.*



▲ *Fig. 14 HMC535 constituent noise sources.*



▲ *Fig. 15 HMC535 residual phase noise estimate.*

Recall that

$$\mathcal{L}(f_m) = \frac{\Delta\phi^2}{2} \quad (35)$$

Now, one may write

$$\Delta f^2 = 2f_m^2 \mathcal{L}(f_m) \quad (36)$$

$$\mathcal{L}(f_m) = \frac{\Delta f^2}{2f_m^2} \quad (37)$$

The output of a frequency discriminator may be written as

$$\Delta V_{rms} = K_f \Delta f_{rms} \quad (38)$$

K_f is the discriminator gain constant. Now one may write

$$\mathcal{L}(f_m) = \frac{1}{2}\frac{\Delta V_{rms}^2 (1\ \text{Hz})}{K_f^2 f_m^2} \quad (39)$$

The test equipment block diagram is shown in ***Figure 16***. Calibration of the frequency discriminator may be accomplished via a source excitation using a frequency synthesizer or other generator capable of precision frequency deviation. An alternate calibration technique requires low level modulation in conjunction with observation of the sideband level; this technique results from the equation

$$\mathcal{L}(f_m) = \left(\frac{\Delta f}{\sqrt{2} f_m}\right) \quad (40)$$

In addition to the resonator implementation of the frequency discriminator, a delay line may also be employed. The delay should be constant versus frequency and must also comply with other restrictions, the principal restriction being

$$f_m << \frac{1}{2\tau_d}$$

where τ_d is the time delay

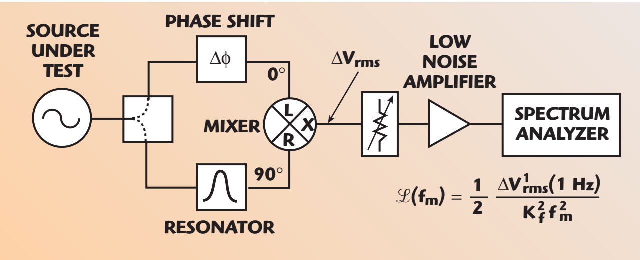


Fig. 16 $\mathcal{L}(f_m)$ measurement using a frequency discriminator.

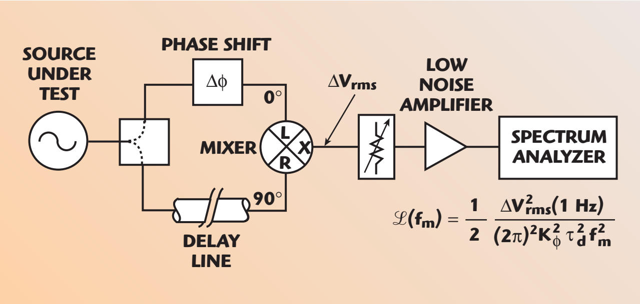


Fig. 17 $\mathcal{L}(f_m)$ measurement using a delay line frequency discriminator.

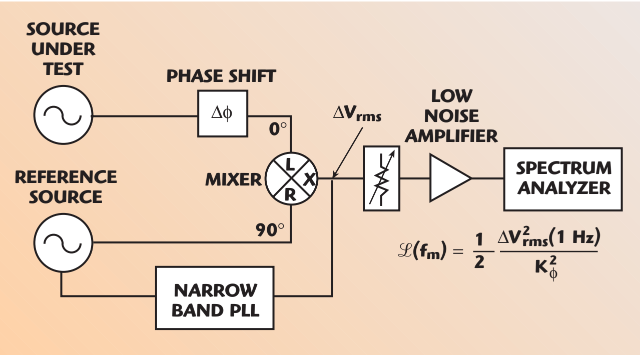


Fig. 18 $\mathcal{L}(f_m)$ measurement using a phase detector.

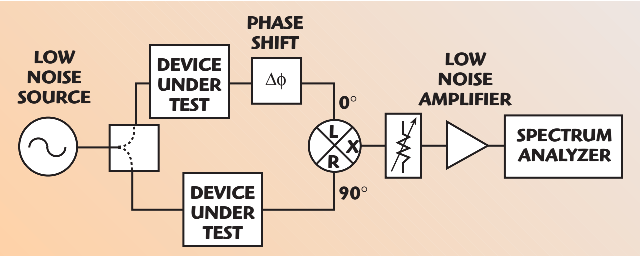


Fig. 19 Residual phase noise measurement set-up.

The governing equation for the delay line frequency discriminator measurement is

$$\mathcal{L}(f_m) = \frac{1}{2}\frac{\Delta V_{rms}^2(1\ \text{Hz})}{\left(2\pi K_\phi \tau_d f_m\right)^2} \qquad (41)$$

As one might expect, this descriptive equation is the same as the prior equation if one recognizes that the discriminator coefficient for the delay line implementation may be written as

$$K_f = 2\pi K_\phi \tau_d \qquad (42)$$

The test equipment block diagram for the phase noise measurement using a delay line frequency discriminator is illustrated in ***Figure 17***. The measurement of $\mathcal{L}(f_m)$ using the frequency discriminator technique is limited close to carrier due to the $1/(f_m)^2$.

$\mathcal{L}$(fm) Measurement Using Phase Detector

The most direct and sensitive method of phase noise measurement utilizes two sources in phase quadrature and a wide dynamic range mixer, as shown in ***Figure 18***. The signals at the RF and LO ports of the mixer should be in phase quadrature to assure maximum sensitivity and AM rejection. If the mixer is operated linearly, the phase detection coefficient is equal to the peak sinusoidal voltage of the mixer output when the two sources are frequency offset. Because the phase noise of each source is measured in this configuration, the phase noise of one of the sources must be known to determine the phase noise of the other source. The governing equation for the phase noise measurement is

$$\mathcal{L}(f_m) = \frac{1}{4}\frac{\Delta V_{rms}^2(1\ \text{Hz})}{K_\phi} \qquad (43)$$

RESIDUAL PHASE NOISE MEASUREMENT

Residual phase noise measurements are employed to determine the degradation in spectral quality of components that are typically used in the generation of low phase noise signals; such components include amplifiers, mixers, frequency dividers and multipliers, and phase detectors. Unlike the absolute measurement of phase noise, residual phase noise measurement typically employs a phase bridge technique and cancellation of the excitation source noise. The block diagram of ***Figure 19*** represents the test equipment configuration utilized for residual phase noise measurement. In the process of executing phase noise measurements, it is prudent to observe the following guidelines:

- When using the phase-lock technique, the offset frequency of the measurement must be much larger than the loop bandwidth.
- Insure that no injection lock phenomenon exists between the two sources.
- Minimize AM detection and maximum detection coefficient by maintenance of quadrature to within ±2°.
- Operation of the mixer in a linear mode is essential to prevent calibration and measurement errors.
- Insure that the calibration of the beat-note signal is sinusoidal.

- Insure that the entire measurement system cascade is operated in the linear range, that is with no compression.
- Impedance interfaces and power levels should remain constant during calibration and measurement.
- Insure that the source cancellation is sufficient when making residual phase noise measurements.
- Use low noise DC power supplies.
- Exercise caution with respect to co-located instrumentation, such as oscilloscopes, computer monitors, DVM and counters.
- Avoid microphonically or acoustically induced noise.
- Utilize a screen room with filtered input power and indirect lighting, when possible. ■

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MEASURING PERFORMANCE IN PULSED SIGNAL DEVICES: A MULTI-FACETED CHALLENGE

This article describes several approaches for generating modulated pulsed signals with signal generators and analyzing devices stimulated with these kinds of signals using vector network analyzers. In particular, it focuses on when an analog signal generator is sufficient and when it is better to use a vector signal generator. It also discusses the capabilities of different techniques used by vector network analyzers.

Measurements with pulsed stimulus signals are undertaken for a number of reasons. For instance, in a wide range of applications, devices under test (DUT) must be characterized by using pulsed signals instead of CW signals. Here, the DUT is stimulated either with a pulsed RF signal or the device is put into pulsed conditions by a pulsed control voltage.

Pulsed measurements require different capabilities of signal detection and signal generation.

For on-wafer measurements of power amplifiers, heat sinks are difficult or even impossible to implement. Using pulsed stimulus signals, S-parameters can be measured at power levels that are used in reality without exceeding the maximum average power that could lead to the destruction of the device. By using an appropriate duty cycle, the average power can be reduced significantly while maintaining a high peak power.

There is also the situation where test devices only operate properly with pulsed stimulus, as is the case for components for the mobile communication market (for the GSM standard, for example). Moreover, power amplifiers in mobile phones or radar output stages often only exhibit their desired performance under pulsed stimulus conditions.

Another consideration is that the DUT behavior often changes during the pulse duration. The amplifiers might show overshoot, ringing, or droop versus time. The pulse widths for these applications vary between some 10 ns for radar applications and several 100 microseconds for GSM applications.

What different kinds of pulses are in use? There are periodical single pulses, double pulses, pulse trains, modulated pulses, Barker pulses and dynamic frequency selection

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(DFS) pulses in accordance with the FCC standard.

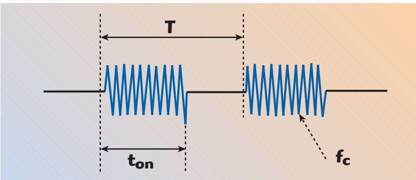
Taking these in turn and starting with periodical single pulses (shown in ***Figure 1***), the most common pulsed stimulus signal is a single pulsed RF signal. A periodical single pulse is defined by the following parameters: carrier frequency f_c, pulse width t_{on} and pulse period T. Some more specific parameters can be derived:

Duty cycle: $D_{cycl} = t_{on}/T$
Pulse repetition frequency (PRF):
$$PRF = 1/T$$

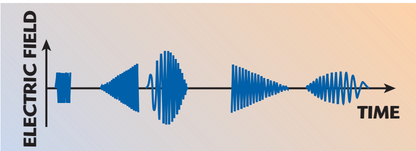
The relationship between peak power (P_{pk}) and average power (P_{avg}) of an RF pulse is defined by its duty cycle

$$P_{avg} = P_{pk} \times D_{cycl} = P_{pk} \times (t_{on}/T)$$

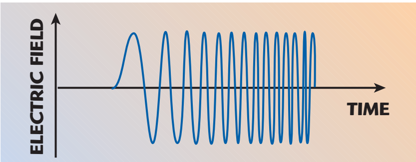
Using periodical single pulses reduces the average power while maintaining the peak power by selecting an appropriate duty cycle. Thus, the average power of the DUT can be reduced to a tolerable value to avoid thermal destruction. Other important parameters describing pulsed RF signals are on-off ratio, rise/fall time (typically 5 ns) and pulse width (down to 20 ns).



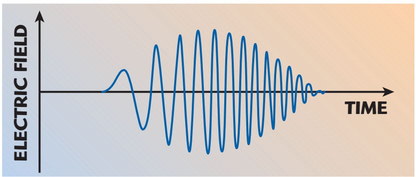
▲ *Fig. 1 Single pulses.*



▲ *Fig. 2 Example of a pulse train.*



▲ *Fig. 3 Pulse with frequency change over time (chirped pulse).*



▲ *Fig. 4 Pulse with frequency change over time and Gaussian shaping.*

Double pulses are used in weather, target tracking or astronomical Doppler-radar applications. The double pulse leads to a double echo and these echoes go through signal processing that efficiently eliminates most noise and other interferers. This ensures high measurement accuracy. With double pulses, parameters are the same as for periodical single pulses.

Pulse trains are commonly used for radar applications. An example of a pulse train is shown in ***Figure 2***. In contrast to single or double pulses, 'pulse trains' are a combination of different kinds of pulses, which can be a periodical or non-periodical set of pulses. In addition, different modulations can be applied to each pulse or ramp, and the overall pulse shape can be configured freely.

FM modulated pulses, in principle, vary their frequency over time. In an analogy to bird sounds, they are called 'chirped' pulses. They can be linearly or nonlinearly chirped. These pulses can also have a specific shape, for example Gaussian, and they can be described mathematically as

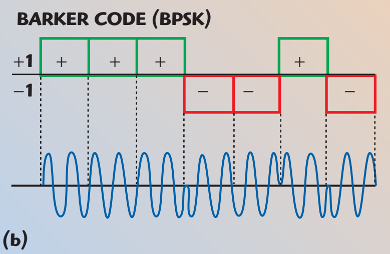
$$E(t) = \mathrm{Re}E_0 \exp[-(t/\tau_G)^2] \exp[i(\omega_0 t + \beta t^2)]$$

$\exp[-(t/\tau_G)^2]$: Gaussian amplitude
ω_0: carrier frequency
βt^2: chirp

Figure 3 shows the pulse with frequency change over time (chirped pulse), while ***Figure 4*** shows the pulse with frequency change over time and Gaussian shaping.

LENGTH	CODES	
2	+1–1	+1+1
3	+1+1–1	
4	+1–1+1+1	+1–1–1–1
5	+1+1+1–1+1	
7	+1+1+1–1–1+1–1	
11	+1+1+1–1–1–1+1–1–1+1–1	
13	+1+1+1+1+1–1–1+1+1–1+1–1+1	

(a)



(b)

▲ *Fig. 5 Barker codes (a) and an example of a 7-bit Barker code (b).*

The next pulse type to be considered is the Barker pulse, which is basically a binary phase shift keying (BPSK) modulated pulsed RF signal. The BPSK modulation is derived from the Barker codes. A bit value of one sets the phase to π, whereas zero bits leave the phase at zero. An additional phase offset may be specified to rotate the constellation points.

This is one signal processing technique used for pulse compression (pulses with inherent modulation applied). In contrast to the analog chirp signal, this signal is digitally modulated. For a high distance resolution, small pulses are normally used. The bottleneck here is the decreasing signal-to-noise ratio. To overcome this problem pulse compression is used for getting wider pulses with a good signal-to-noise ratio. ***Figure 5*** illustrates Barker codes, and gives an example of a seven-bit Barker code.

There are also dynamic frequency selection pulses in accordance with the FCC standard. For license free data transmission, the 5.25 to 5.35 GHz and 5.47 to 5.725 GHz frequency bands are used, for example, for WLAN applications. According to the FCC standard, Unlicensed National Information Infrastructure (U-NII) devices operating in these bands shall employ a DFS radar detection mechanism to detect the presence of radar systems and to avoid co-channel operation with radar systems. Currently, two sets of requirements exist regarding the DFS radar detection:

- FCC Part 15 Subpart E
- ETSI EN 301893 V 3.1

Table 1 shows one example of FCC requirements for Radar Type 6. This waveform type uses a fixed pulse

TABLE I

FCC REQUIREMENTS FOR RADAR TYPE 6

Radar type	6
Pulse width (μs)	1
PRI (μs)	333
Waveform duration (ms)	300
Pulses per hop	9
Hop rate (Hz)	333

sequence that hops across a wide range of frequencies. It is defined that 100 frequencies are taken within the range of 5.25 to 5.724 GHz. It is not permitted to reuse a frequency. The frequency changes every 3 ms and on each frequency a pulse sequence containing nine pulses is generated. It must be ensured that at least one of the random frequencies falls into the receiver bandwidth of the DUT.

Next, consider how a network analyzer measures under pulsed conditions. The following section describes how DUTs can be analyzed with network analyzers using rectangular pulsed signals.

POINT-IN-PULSE MEASUREMENT

Using the point-in-pulse measurement technique, the pulse is only monitored during the on-phase of the RF bursts. Therefore, it is necessary that the sampling time (T_{spl}) to acquire the raw data of a wave quantity or an S-parameter is shorter than the pulse width t_{on} (see ***Figure 6***).

The sampling time is mainly determined by the receiver's measurement bandwidth (IFBw). Theoretically, the relationship between minimum sampling time and measurement bandwidth is

$$T_{spl} \geq 1/\text{IFBw}$$

This means that with increasing measurement bandwidth, sampling time decreases and shorter pulses can be analyzed. For VNAs, the IF filters are implemented as digital filters. Typical VNAs offer measurement bandwidths up to 600 kHz, so that the sampling time is more than 2 µs. Some high end network analyzers that are designed for pulsed measurements offer IF bandwidths up to 5 MHz or more. This results in theoretical sampling times down to 200 ns at 5 MHz bandwidth.

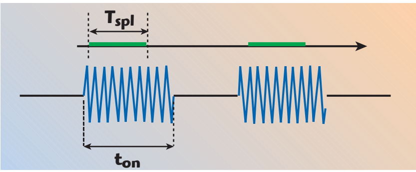


Fig. 6 Sampling time for point-in-pulse measurements.

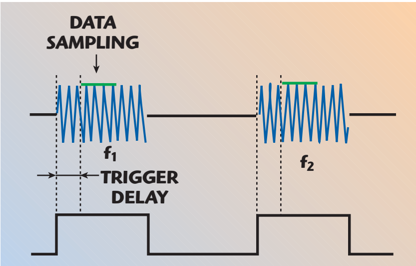


Fig. 7 Trigger delay.

Because the sampling process should only happen during the on-phase of the pulse, a trigger signal synchronous to the RF pulse is necessary to synchronize the data acquisition of the VNA with the on-period of the pulse. The VNA is used in a so called point trigger mode, which means that the data sampling for every single measurement point starts after the detection of a trigger event.

Active devices such as amplifiers often show settling or ringing effects at the beginning of the pulse. Typically the user is not interested in the behavior during this settling time, only when the DUT is settled. By selecting a suitable trigger delay (see ***Figure 7***), the start of the sampling process can be shifted to the quiet pulse roof of the amplifier.

Dynamic range and sensitivity using the point-in-pulse method only depend on the measurement bandwidth of the receivers; they are independent of the duty cycle of the RF pulse. Therefore, the dynamic range depends on the pulse width itself, because the pulse width determines the sampling time and thus the measurement bandwidth that has to be used. To increase the dynamic range by maintaining the measurement bandwidth, averaging can be applied. Ten times averaging in the IQ domain for example increases the dynamic range by a factor of 10.

Round-up

Advantages

- The point-in-pulse measurement allows accurate S-parameter and power measurements
- The moment of data acquisition within the pulse can be shifted freely
- The dynamic range does not depend on the duty cycle

Disadvantages

- A VNA with a wide measurement bandwidth is required

AVERAGE PULSE MEASUREMENT

Because the point-in-pulse measurement demands a VNA with a bandwidth that is equal or higher than $1/t_{on}$, mid-range VNAs do not support this method for applications with short pulse widths. Here, the average pulse measurement technique (also called narrow band or high PRF technique) is recommended. This method places lower demands on the VNA's performance, but requires more knowledge to configure the set ups properly, dependent on the pulse and VNA parameters.

The basic principle is that a pulse signal is generated by multiplying a periodical rectangular signal (pulse envelope or NF signal) that varies between 0 and 1 with a CW signal. The multiplication in the time domain is a convolution of the spectra of both signals in the frequency domain. Signals in the time and frequency domain are shown in ***Figure 8***.

The spectrum of the pulse envelope (NF signal) is shifted by the convolution to the frequency f_c. Because $S_{21} = b_2/a_1$ (a_1 is the incident wave into a DUT, b_2 is the transmitted wave through a DUT) it is then sufficient for S_{21} measurements to measure the ratio between one specific spectral line of a_1 and the equivalent spectral line of b_2. Thus, all S-parameters can be measured. To get the maximum dynamic range, the strongest spectrum line (that is, the main carrier) at f_c is selected:

$S_{21} = b_2(f_c)/a_1(f_c)$
$S_{11} = b_1(f_c)/a_1(f_c)$, etc.

Figure 9 shows the S-parameters of a two-port DUT. For average pulse measurements, it is not necessary to have a very wide measurement bandwidth as required for point-in-pulse measurements, but rather a bandwidth that is 'narrow enough' to capture only the main carrier. The frequency spacing between the carriers is equal

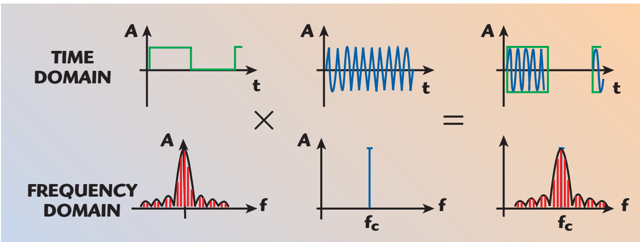


Fig. 8 Signals in the time and frequency domains.

to the pulse repetition frequency (PRF = 1/T) (see ***Figure 10***).

For a good performance with respect to good trace noise, it is important that the adjacent carriers are suppressed by 40 dB or more. Typically, a measurement bandwidth that is roughly 10 times narrower than the carrier spacing with respect to the pulse repetition frequency is selected. Decreasing the measurement bandwidth means an increase of measurement time:

$$\text{IFBw} < \text{PRF}/10$$

where

$$\text{PRF} = 1/T$$
$$\text{IFBw} = 1/T_{spl}$$
$$1/T_{spl} < 1/(T \times 10)$$

and

$$T_{spl} > 10 \times T$$

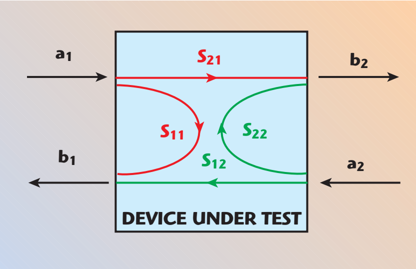


Fig. 9 S-parameters of a two-port DUT.

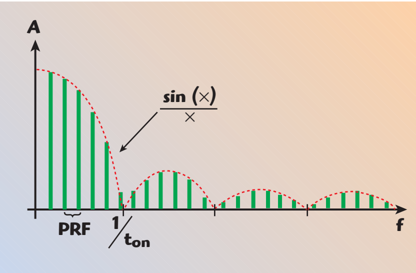


Fig. 10 Spectrum of the NF pulse.

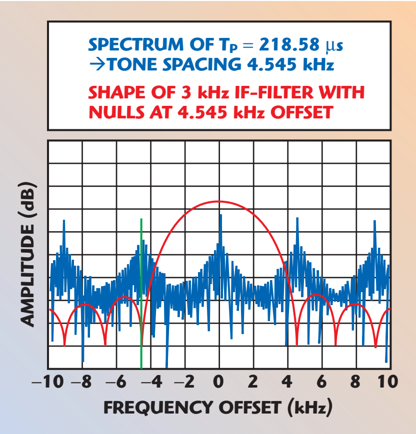


Fig. 11 Spectral nulling.

During several pulses, the VNA samples and measures the average value of the pulse; it is therefore called average pulse measurement. This also becomes clear looking at the frequency domain. With the average pulse measurement method, only the main carrier is detected, which is the convoluted carrier of the NF signal at frequency 0. The carrier at frequency 0 represents the 'DC value' of the NF pulse, which is nothing other than the average value of the NF signal.

A typical problem for this kind of measurement is the filter shape of the digital IF filters of the VNAs, which typically stimulate the DUTs with non-modulated CW signals. The IF filters are designed for fast settling and not for high side lobe suppression, which is often only 20 dB or even less. This can cause problems as soon as one of the adjacent tones falls into one of the maximums of one of these side lobes.

To overcome this problem, two different procedures can be used. Some mid-range instruments use what is called spectral nulling, shown in ***Figure 11***. Depending on the period of the pulse, IF filters can be selected in a way that the nulls of the filter are exactly where the tones to be suppressed are expected.

In contrast, other VNAs use high selective filters without side lobes, so no spectral nulling is required. ***Figure 12*** shows digital IF filters of VNAs/high selective IF filters of a high end VNA.

Average pulse measurements can be done in a swept mode, too. The set up is the same as for point-in-pulse measurements, but no trigger is required. Because the average pulse measurement technique measures the average values of the wave quantities, an absolute power measurement is influenced by the duty cycle. The measured power is

$$P_{meas} = P \times D_{cycl}^2$$

For a duty cycle of 1 percent, the measured power of the main carrier is 40 dB lower then the peak power. This phenomenon is called pulse desensitization. The power reduction in dB is

$$\Delta[\text{dB}] = 20 \log \frac{(\text{pulse width})}{(\text{pulse period})}$$

For very low duty cycles, the signal-to-noise ratio becomes very low and limits the dynamic range of the measurement.

Round-up

Advantages

- The average pulse measurement technique can be applied on very short pulses
- The VNA does not require a special bandwidth or special trigger capabilities. It is only necessary to directly access the generator path to apply a modulator or a modulated signal source

Disadvantages

In contrast to the point-in-pulse measurement, the average pulse method requires a periodical pulsed signal

- The results represent only average values and therefore also include ringing or overshoots that might happen at the beginning of a pulse
- The IF filters of the VNA must be able to suppress other signals except the main carrier. This requires IF filters without side lobes, or a suitable selection of IF filter shapes dependent on the pulse repetition frequency of the pulse
- The dynamic range drops by 20 dB as soon as the duty cycle is reduced by a factor of 10, which can result in poor performance for low duty cycles. In these cases a point-in-pulse measurement is recommended

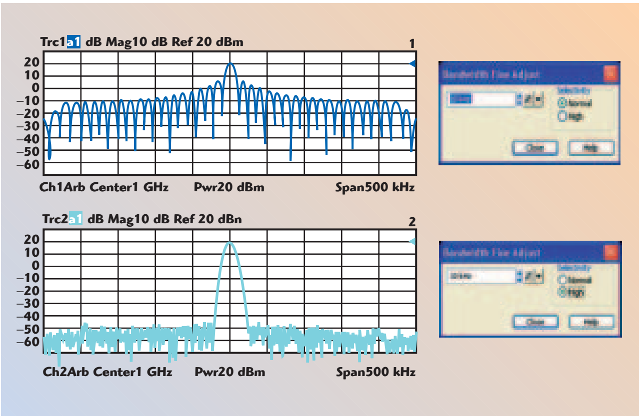


Fig. 12 Digital IF filters of VNAs/high selctive IF filters of a high end VNA.

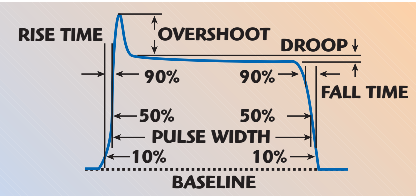
PULSE PROFILE

To analyze the time dependent behavior of a DUT during a burst, the VNA has to perform a so-called pulse profile measurement. Typical parameters to characterize the time dependent behavior are rise time, overshoot and droop.

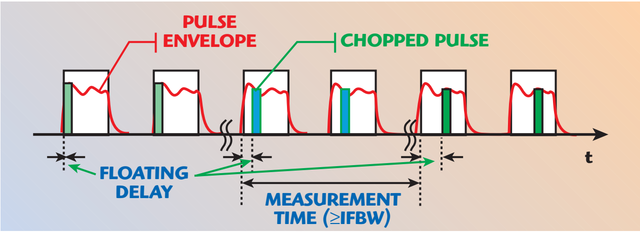
For this measurement, the VNA must feature a time resolution that is significantly higher than the pulse duration. A typical VNA's time resolution ranges from 3 to 20 µs for measurements in the frequency or time domain. That is not high enough to analyze the behavior versus time with sufficient resolution. ***Figure 13*** shows a representative pulse waveform.

CHOPPING PRINCIPLE

Most VNAs have a measurement bandwidth of 600 kHz or less, which is the limitation factor for high time resolution of pulse widths of 1 µs or below. To achieve resolutions of 100 ns and below, additional external hardware and software can be used to 'chop up' the pulsed signal into slices with different timing positions within the pulse (see ***Figure 14***).



▲ *Fig. 13 Representative pulse waveform.*



▲ *Fig. 14 Chopped pulses.*

The magnitude of these pulse slices with regard to a certain delay is measured and calculated off-line in accordance with the average pulse method. The delay is then increased and the next 'slices' are measured until the desired duration of the pulse is analyzed. The chopping can happen either in the receiver paths on the RF frequency or directly inside the instrument on the IF path. If the IF is chopped, the losses of the necessary switches can be minimized.

Round-up

Advantage

- Can be done with most VNAs in conjunction with external setup for pulse profile measurements

Disadvantages

- No analysis of non-periodical pulses, double pulses, pulse trains or complex modulated pulsed signals
- Low dynamic range for low duty cycles and high resolution
- Low measurement speed
- Change of duty cycle requires recalibration
- Difficult to operate

WIDEBAND DETECTION

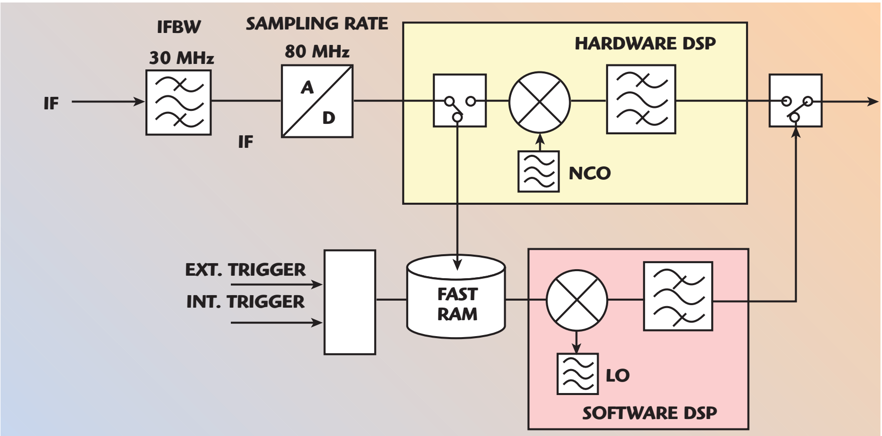
A new approach is wideband detection with fast data recording. The performance for pulse profile analysis of pulsed signals or S-parameters with pulsed stimulus is limited by the sampling rate of the A/D converter, the processing time between two data points and the available bandwidth; sampling rate and data processing time between two data points limit the time resolution, while the measurement bandwidth determines the minimum rise and fall time of the pulse that can be analyzed.

The bandwidth limiting factors are the analog bandwidth of the receivers and the capabilities of the digital signal processors (DSP) for digital filtering. A high end VNA has an analog bandwidth of 15 MHz (with some performance degradation of 30 MHz), but the DSP's IF filters only offer adequate performance for normal CW or time sweeps with 5 MHz bandwidth. The VNA samples down converted IF signals at a sampling rate of 80 MHz, which results in a time resolution of 12.5 ns.

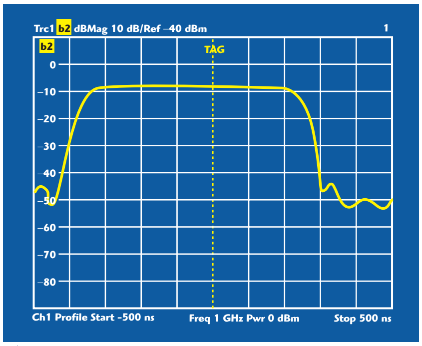
In addition to the sampling time, there is a data processing time between two measurement points, which is a bottleneck when it comes to high resolution measurements in the time domain. The limitations are the IF filtering by the DSPs with maximum rise and fall times of 1/(5 MHz) = 200 ns, and the data processing time limiting the time resolution to 1.5 µs + sampling time.

With a new approach, performance for pulse profile measurements is dramatically improved. The sampled raw data is directly stored without filtering. Instead of the DSP, the instrument's software performs digital down conversion and digital filtering after recording. ***Figure 15*** illustrates fast data recording.

The A/D converter continuously digitalizes the data with a sampling rate of 80 MHz and writes them into fast RAM. This ensures that no delay occurs between the samples of individual measurement points. Because of the high sampling rate, a measure-



▲ *Fig. 15 Fast data recording.*



▲ *Fig. 16 Pulse profile of a wave quantity with trigger signal.*

ment point is output every 12.5 ns, that is, the time resolution is 12.5 ns.

The trigger signal, usually derived from the rising edge of the pulse, determines the zero point in time. Thus, the exact time relationship between the trigger detection and the incoming RF pulse can be measured too. This relationship is especially important for determining the correct trigger delay in point-in-pulse measurements versus frequency or level (see ***Figure 16***).

Owing to such a progressive method, a VNA is able to perform extremely fast-pulsed measurements. With more than 10 sweeps/s at 1001 test points, DUTs can easily be adjusted during the pulse profile measurement. In addition to periodical single pulsed signals, this new technique handles double pulses as well as user-defined pulse trains. DUTs stimulated with pulses that have frequency and magnitude modulation, for example, chirps, can also be analyzed.

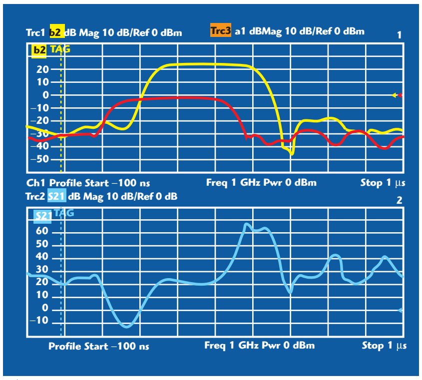


Fig. 17 Wave quantities and S-parameters with a group delay of 100 ns.

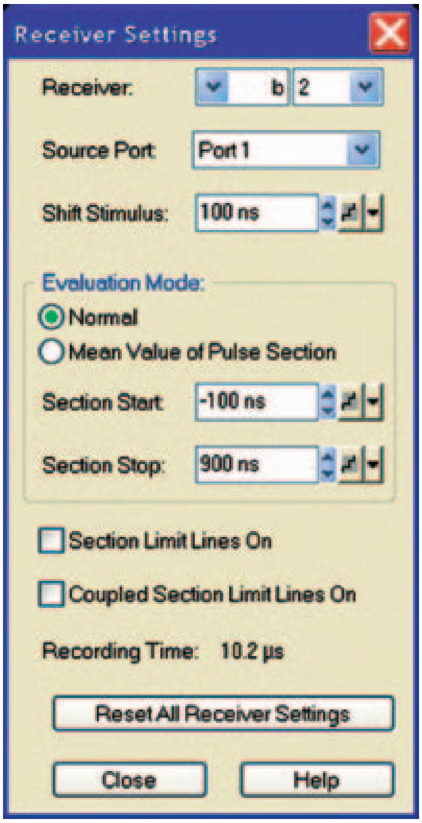


Fig. 18 Assignment of a specific time delay to a wave quantity, depending on the measurement direction.

GROUP DELAYS

Measuring the S-parameters of DUTs with group delays in the range of the pulse width is often difficult or even impossible. The stimulated RF signal may no longer be present at the DUT's input by the time the VNA receives the transmitted RF signal from the output. A correct S_{21} parameter can only be measured with temporal signal overlapping. ***Figure 17*** shows a measurement of wave quantities and S-parameters of a DUT with a group delay of 100 ns.

A VNA solves this problem by applying a time offset to the wave quantities: before calculating the S-parameters, it mathematically shifts the wave quantities by the DUT's group delay. A specific time delay can be assigned to each wave quantity, depending on the measurement direction (see ***Figure 18***), so the VNA correctly displays the gain S_{21} versus the entire pulse duration (as shown in ***Figure 19***).

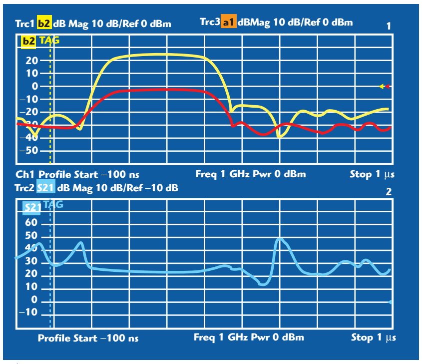


Fig. 19 Gain S_{21} vs. the entire pulse duration.

Round-up

Advantages

- Analysis of single non-periodical pulses
- Analysis of pulse trains and double pulses
- Analysis of pulses with modulation
- High time resolution

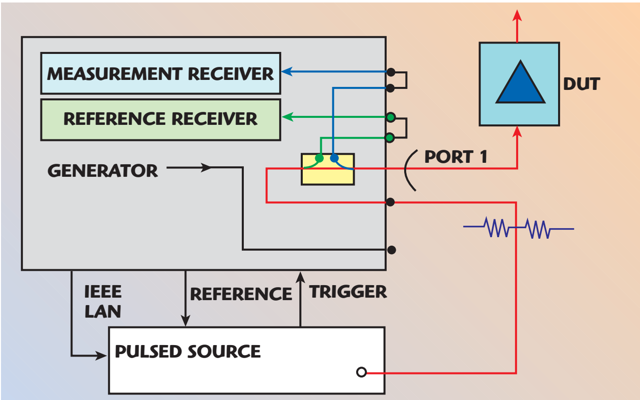


Fig. 20 Test set up with modulated signal source.

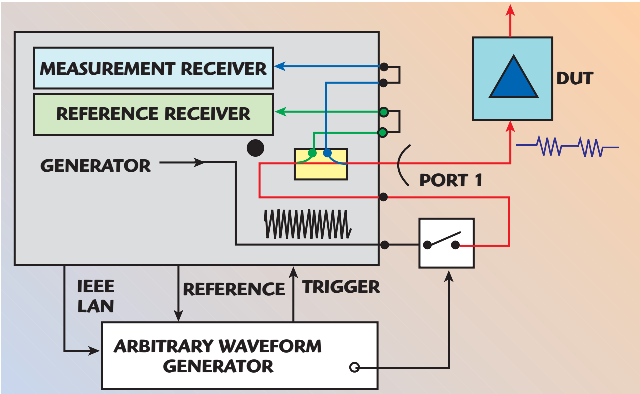


Fig. 21 Test set up with external pulse modulator.

SIGNAL GENERATION

Most VNAs cannot modulate the internal generator with sufficient performance. It is therefore more convenient and versatile to use external modulation sources, especially for very complex pulse scenarios. In most cases, pulses range from less than a microsecond to several hundred microseconds and carry data in various modulation schemes. Additionally, a limited spectral bandwidth may call for dedicated pulse shaping and often requires high on-off ratios.

The generation of these pulse signals is therefore not a trivial task, and simple CW pulses from analog microwave sources are sometimes not sufficient to fulfill testing needs. Today's powerful vector signal generators are generally the best choice for the generation of arbitrary pulses containing digitally modulated data content. The arbitrary waveform (ARB) mode of these instruments provides enough memory and high resolution for complex and long pulse trains.

With flexible software for vector signal and baseband generators, the generation of complex pulse patterns used in communication or military applications can be dramatically simplified. In addition, the precalculated results (for example, FFT) can be displayed on a screen and directly compared with real measurements on a VNA.

The following section compares the capabilities of analog microwave generators with those of vector signal generators. An analog source contains a pulse modulator and a pulse generator. The pulse modulator is driven by the pulse generator with a square signal. In principle the pulse modulator is a simple switch that activates and deactivates the RF. The main advantage of this concept is the capability of generating very short pulses in the range of nanoseconds with an excellent on/off ratio. The bottleneck is that the capability to apply specific shaping of pulses or to modulate them is missing (for example, Chirp, Barker).

Aimed at a specific modulation in a pulse or a user defined pulse train, a vector signal generator is the only choice for generating those kinds of signals. It takes a precalculated pulse waveform, which is stored in the internal arbitrary waveform generator and generates this waveform cyclically. The waveform is then up-converted to the desired RF frequency by an internal IQ modulator. In contrast to a normal pulse modulator/generator solution, this concept offers great variety and flexibility in setting up pulse scenarios or pulse trains.

By using external software the complete pulse scenario set up is simplified. Pulse parameters can be set in a versatile way and the settings can be controlled on FFT, vector plane or time plan displays. This becomes important especially for the previously described FCC pulse scenarios. The DFS-FCC radar types can be directly selected so the failure probability of a wrong set up is negligible. Limitations of a vector signal generator can be the limited on/off ratio and the minimum pulse width, depending on the internal IQ bandwidth.

At a Glance Comparisons

Analog Signal Generator with Pulse Generator and Pulse Modulator

Advantages

- High pulse on-off ratios (> 80 dB)
- Very short rise and fall times (< 5 ns typical)
- Very short pulse widths (> 20 ns)
- RF frequencies up to the microwave range

Disadvantages

- Limited pulse shaping
- Generation of modulated pulses is not possible (e.g., Chirp, Barker, etc.)
- Generation of complex pulse trains is not possible

Vector Signal Generator

Advantages

- Customized pulse shaping and modulation
- Arbitrary pulse trains

Disadvantages

- Limited on-off ratio (limited by the ARB dynamic). The full dynamic range of a vector signal generator's ARBs provides a total of 16 bits for both I and Q signals. The theoretical dynamic range is 96 dBc. In practice, however, the dynamic range is limited to approximately –65 dBc. To overcome this problem, an internal marker signal can directly drive the pulse modulator of the vector signal generator. This gives a dynamic range of more than 80 dBc.
- Longer rise and fall times and pulse widths (limited by the IQ bandwidth). The minimum pulse width is determined by the IQ bandwidth of the instrument. For a given IQ bandwidth of 100 MHz, for example, the minimum pulse width should be at least $1/(3 \times 100$ MHz$)$, which equals 3.3 ns.

TEST SET UPS

For applications where the DUT requires a pulse-modulated input signal, a generator with pulse modulation or a vector signal generator for complex waveforms can be used. The modulated RF signal of the generator is directly injected into the generator path of the VNA instead of using the non-modulated internal VNA generator (as shown in ***Figure 20***).

Because the modulated signal is also measured by the reference receiver when it passes the internal coupler, system error correction can be applied on S_{11} and S_{21} measurements. A system error or level calibration recorded under CW conditions thus applies under pulsed conditions and needs not be repeated when the duty cycle is changed. As the VNA controls power and frequency of the external generator via LAN or IEC/IEEE bus, this set up is suitable for pulsed measurements versus frequency and level.

For measurements with simple RF pulses, a pulse modulator can be inserted into the generator path enabling bidirectional measurements and thus also two-port calibrations. With a modulator applied in the generator path of port 1, the forward parameters S_{11} and S_{21} are measured under pulsed stimulus conditions and the reverse parameters S_{12} and S_{22} under non-pulsed stimulus conditions. Only an additional arbitrary waveform generator is required for a pulsed DUT (as shown in ***Figure 21***).

Neither the set up with external pulsed signal generator nor with external modulator requires recalibration if the duty cycle is changed. A calibration performed in CW mode is also valid under pulsed conditions. This set up allows an accurate, calibrated measurement of S-parameters as well as accurate calibrated measurements of absolute power levels.

CONCLUSION

Pulsed measurements require different capabilities of signal detection and signal generation. For simple tasks, for instance when measuring the S-parameters of a DUT that has no influence on the shape of the pulse, an average pulse measurement with a standard network analyzer and the capability to modulate the source may be sufficient. However, if the user has to measure the S-parameters and absolute power levels with very low duty cycles, or if the pulse shape is influenced by the DUT, he or she requires a point-in-pulse measurement with a network analyzer with high measurement bandwidth and short sampling times.

Measuring the time dependent behavior of a DUT during the pulse requires pulse profile measurements with a high end network analyzer. Ideally, the instrument provides a very wide measurement bandwidth, a high sampling rate and special features for continuous data recording. To generate periodical pulse modulated RF signals, a simple switch driven by a suitable pulse generator is sufficient. An off-the-shelf solution would consist of a microwave generator with inbuilt pulse capabilities that can also be controlled directly by the network analyzer for swept measurements versus frequency or power.

Pulse trains with additional modulation besides the pulse modulation require a vector signal generator with internal I/Q modulator. For generating pulse trains, a high performance vector signal generator must be used. Therefore, a high clock rate and a large memory in the baseband, as well as a wide I/Q modulator bandwidth, are essential. ■

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Thilo Bednorz *received his master's degree in electrical engineering from the Technical University of Munich. From 1990 to 1993, he worked in the spectrum analyzer group of Rohde & Schwarz. Since 1994, he has been working in the network analyzer group.*

LAYOUT-DRIVEN HIGH FREQUENCY DESIGN GETS BOOST FROM NEW EM TECHNOLOGY

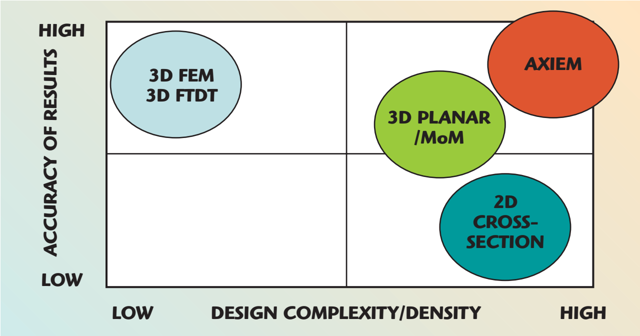
Competition to attract consumers in the wireless communications market is driving incredible innovation in the design of feature-rich devices in compact packages. Geometries are shrinking and integrated circuit (IC) densities are expanding, while at the same time application frequency and bandwidth grows. In order to reduce size and weight, and to improve the cost-effectiveness of the module, it has become necessary to migrate to fully integrated monolithic microwave ICs (MMIC) that include most or all of the above RF functions. These MMICs must be optimized for size and electrical performance simultaneously. This requires high frequency electrical design to progress concurrently with physical layout. Therefore, engineers need to know the electrical behavior of these densely packed components in "real-time." This challenge calls for an evolution in the electromagnetic EM technology used to characterize passive structures and interconnects. To fully support layout-driven electrical design, EM technology must solve large and small geometries rapidly within a well-defined yet flexible design flow without sacrificing accuracy.

EXECUTIVE INTERVIEW SERIES

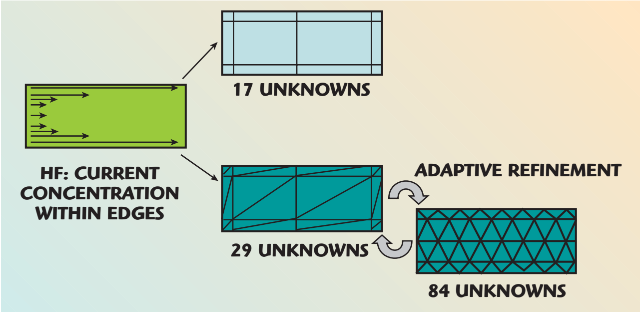
***MWJ* SPEAKS WITH SHERRY HESS, VP OF MARKETING, AWR. VISIT WWW.MWJOURNAL.COM TO READ THIS IN-DEPTH INTERVIEW.**

AWR, an innovative company founded by microwave engineers committed to providing a better way to design, has been developing a completely new approach to fast, high capacity EM simulation. The results of this R&D effort is a new product called AXIEM,™ a breakthrough, pioneering EM technology that delivers speed, capacity and accuracy to the designers of microwave/RF products. AXIEM now enables EM analysis to be an integral part of the entire design flow and decision-making process, start to finish. By addressing long simulation run times and design flow inefficiencies, AXIEM is a practical design tool that goes beyond being a time-consuming, back-end verification step in a final go/no-go loop.

APPLIED WAVE RESEARCH INC.
El Segundo, CA



▲ *Fig. 1 The EM technology landscape.*



▲ *Fig. 2 Rectangles vs. triangles for equivalent accuracy prior to "AWR-hybrid" meshing.*

WHAT IS UNIQUE ABOUT AXIEM?

Today's EM tools as used for high frequency IC design fall into one of three camps: two-dimensional (2D) cross-section, three-dimensional (3D) planar, or general purpose 3D.

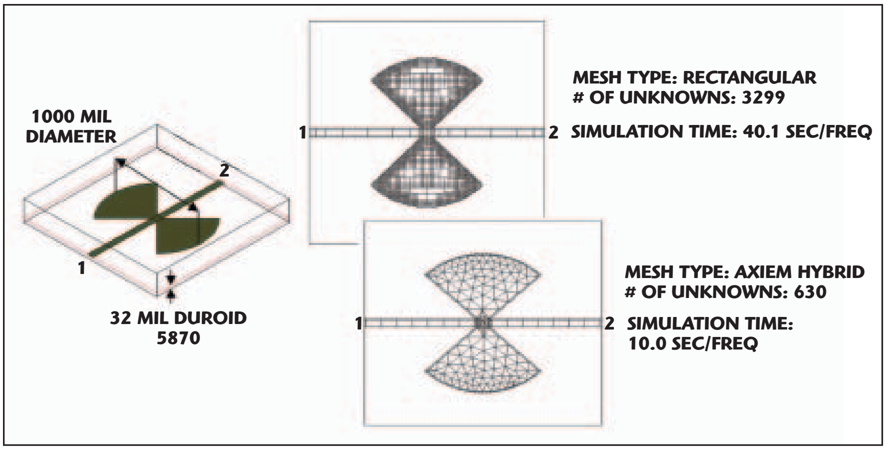
- 2D cross-sectional-based codes rely on either the method-of-moments (MoM) or the finite element method (FEM) to derive per-unit-length properties of conductor systems, including coupling, loss and characteristic impedance. They are extremely fast but are of limited use, especially for lines that are electrically long.
- 3D planar codes are optimized to the IC/planar nature of the device/circuit. Typical formulations are either closed-boundary, using a fixed "Manhattan" mesh and a fast Fourier transform to generate Green's functions; or open-boundary, using a triangular mesh and numerical integration techniques. Three-dimensional planar methods capture currents in three dimensions, where 2D solvers cannot, and can therefore be used to fully characterize most circuit problems, but at the expense of simulation time and computer memory.
- 3D FEM or finite difference time-domain (FDTD) tools, which attempt to provide a vehicle for solving all EM problems from antenna to motors and biological effects to EMI compliance, sacrifice computer run times and memory utilization when used by circuit designers for their IC designs.

Figure 1 conveys the choices available among EM technologies for designs for their fit (structure complexity and timeliness of results) versus accuracy of results.

To elevate EM simulation from verification tool to true design diagnostic tool, AWR developers focused on advancing the state-of-the-art in meshing technology, solver technology and the overall workflow. By starting from the ground up and implementing numerous technical innovations in these areas, AXIEM is able to achieve unprecedented simulation speed and accuracy for a wide range of microwave circuit structures. This powerful EM technology is then integrated into an AWR exclusive MMIC design flow that offers the users control and flexibility over passive circuit extraction.

AWR recently introduced the ACE™ technology, which provides interconnect model extraction in seconds as opposed to hours, and, more importantly, provides users with a "design tool" that encapsulates EM within it. The company now follows up this innovative capability with the industry's first EM technology that is able to keep pace with the rapid changes in IC design—a tool that no longer requires that designers make trade-offs across speed, accuracy and capacity, enabling them for the first time to use EM as a tool of standard adoption throughout the design flow and not just at the final stages.

EM solvers themselves are actually complex beasts that are combinations of complex mathematical techniques: meshing, a Green's function generator and the actual matrix solver algorithm. The speed and accuracy trade-off really comes down to what is the weakest link. The AXIEM technology was developed to tackle the problems of speed and accuracy by looking at each of the constituent pieces, and making each best-in-class.

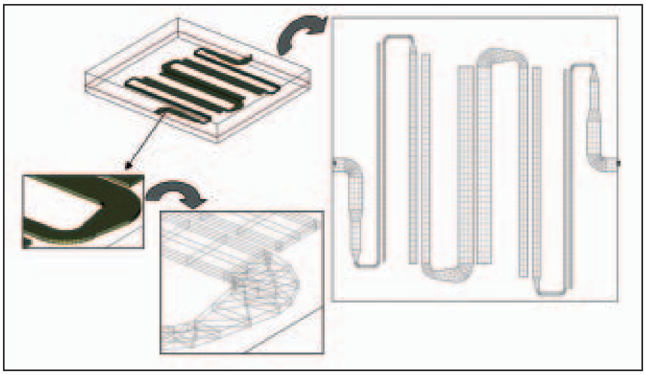


▲ *Fig. 3 AXIEM produces 5X fewer unknowns as demonstrated with a Nera radial stub example.*

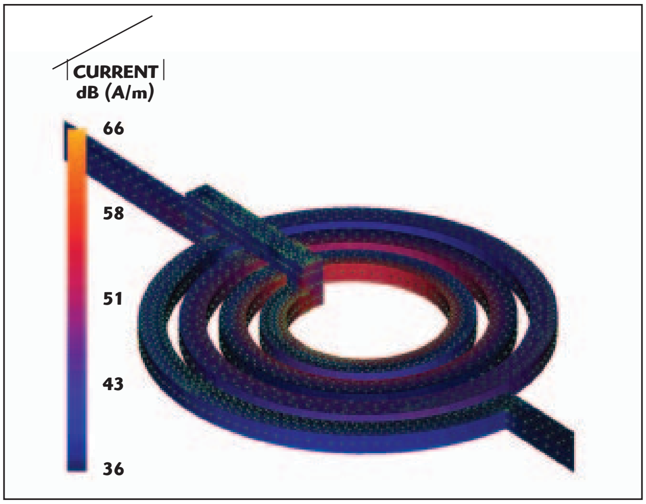
MESHING TECHNOLOGY

Hybrid Meshing

The AXIEM product employs a unique, AWR-pioneered, intelligent hybrid surface mesh consisting of rectangles and triangles. By applying the optimum mesh type to a given surface, a hybrid mesh provides significant advantages to using a purely rectangular mesh or a triangular mesh. For instance, it is not possible to create an efficient rectangular mesh for arbitrary geometries such as curved or tapered metal traces. The hybrid approach uses rectangles where most effective and efficient,



▲ *Fig. 4 Nera filter example reveals metal thickness and AXIEM hybrid mesh.*



▲ *Fig. 5 Current flow for a thick metal spiral at 20 GHz.*

and then embraces triangular elements in regions where a rectangular mesh is an ill-conditioned choice.

The AXIEM meshing process is fully automated. Its intelligent meshing process uses heuristic knowledge of the solution to automatically create a mesh that is optimized to provide the greatest accuracy while minimizing the number of unknowns required, thereby delivering speed of solution coupled with unprecedented accuracy at a touch of the button. ***Figure 2*** illustrates the advantage of rectangles over triangles for a quasi-TEM microstrip transmission line.

Generally speaking then, rectangles are the preferred element choice when the structure for analysis is friendly to rectangles; however, as designers know, this is often not the case. With AXIEM's hybrid meshing technology, the efficiency of rectangular elements is wed to triangles for their flexibility of fit to arbitrary shapes (that is, non rectangular) that is so often the case with today's microwave/RF IC designs.

As shown in ***Figure 3*** (supplied by Nera ASA, Bergen, Norway), a radial stub is 5X more efficient in terms of mesh production/population when the AXIEM technology is employed versus a typical rectangular meshing approach.

True 3D Metal

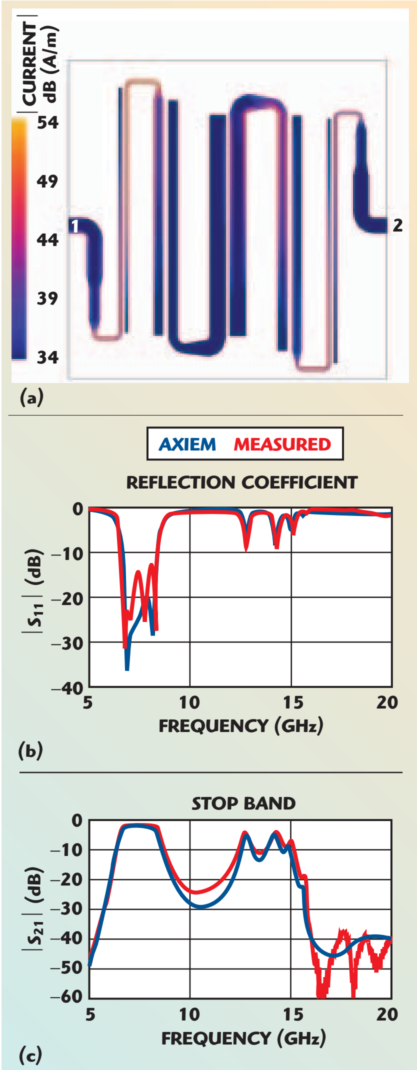
Additionally, the AXIEM product also differs from other planar solvers on the market in that the AXIEM mesher accurately and efficiently creates true 3D meshes of extruded planar geometries, and the final solution includes all x, y and z directed currents on all surfaces—making it an excellent fit for today's high frequency microwave/RF IC designs. ***Figure 4***, also from Nera, illustrates both the thick metal capability and the hybrid mesh technology of AXIEM, whereas ***Figure 5*** shows the results of AXIEM for a curved spiral inductor where the metal width is of the same dimension as its thickness.

Solver Technology

While 3D planar EM technology is not news in and of itself, what is new and groundbreaking about the AXIEM technology is that it has been expressly pioneered to overcome the limitations of existing 3D planar formulations that rely on the Sommerfeld integral (or similar) for delivering speed of simulation, yet at the cost of accuracy and a decrease in dynamic range. AXIEM obtains a full-wave EM solution by employing an AWR-innovated method of moments (MoM) technology as its solver engine. Its solution methodology uses a proprietary technique that is similar to the fast multipole method, yet adapted for full-wave analysis.

As a result, the AXIEM solver scales similarly to the fast multipole method, which is the order of Nlog(N), as opposed to the order N^3 as is the case with most existing MoM solvers. The AXIEM solver is therefore orders of magnitude faster for its simulation speed than conventional MoM codes. As an example, ***Figure 6*** shows the results from AXIEM for the Nera filter design of Figure 4, including both passband shaded current display and $|S_{11}|$ and $|S_{21}|$ measured and simulated data. For this example, the simulation time was well under a minute for approximately 2000 hybrid mesh elements (or unknowns). Furthermore, given that the results of AXIEM will normally be employed by a nonlinear circuit simulator, accurate DC solutions are also a given.

It is also worth noting that the AXIEM technology is coupled to ad-



▲ *Fig. 6 Passband current (a), and $|S_{11}|$ (b) and $|S_{21}|$ (c) simulated vs. measured data.*

vances in computer architectures: it delivers even faster simulation time as the core solver was designed from its inception to enable parallel implementation on both multi-central processing unit (CPU) computers and/or distributed clusters. The parallel implementation enables designers to realistically solve very large designs in as little time as possible by dividing the computation (frequency data points or matrix computations) across multiple CPUs or computers.

DESIGN FLOW

As a stand-alone EM solver, AXIEM is a powerful addition to any designer's stable of tools. The meshing technology enables complexity by delivering robust representations of the currents with fewer unknowns. The solver provides accuracy regardless of complexity, and does so efficiently across the entire frequency range. The true value of AXIEM, however, lies in its integration into the overall AWR design flow, where it contributes significantly to AWR's commitment to accelerating GHz design.

While delivering innovations in its meshing and solver algorithms, the AXIEM technology also takes to a new level the AWR automated design flow philosophy. By employing features that automatically determine and set user options, the requirement of a super-user with years of EM design expertise to run the product is not necessary nor a prerequisite. In addition, AXIEM is tied to circuit and system simulation, layout and verification through the proprietary AWR unified data model (UDM). The UDM provides features such as extraction directly from simulation without having to perform explicit layout and EM setup steps, thereby incorporating EM directly and seamlessly into circuit simulation.

When used in conjunction with AWR's ACE technology, the same EM structures can be mapped back into circuit models in a matter of a few seconds, providing a window into the critical interconnects and couplings, and can be modified and designed accordingly, and then more accurately modeled or verified within the mainstream design flow with the AXIEM tool. The AWR UDM and ACE innovations, now combined with AXIEM as an integral part of the overall flow, compliment each other to further cut design time and iterations from the overall project.

CONCLUSION

Until recently, EM effects were second-, third- or even fourth-order effects to consider for successful IC design. With the increase in wireless and RF/microwave products in both military and consumer markets, and the effect of Moore's law in shrinking overall footprint size and increasing complexity/frequency/bandwidth, EM effects have become first- and second-order effects that must be accounted for. Today, every design requires some sort of EM analysis, but the technology has not kept pace with the demands of users who now must employ EM analysis as a design process diagnostic utility rather than the traditional back-end verification tool.

The breakthrough AXIEM technology delivers an industry-first design tool that meets today's advanced design requirements for an EM analysis tool that is fully integrated into the design flow—at the front end where it can help identify problems early in the process.

The pervasive miniaturization and complexity in nearly every next-generation wireless product has pushed the envelope on not only this technology, but the development technologies behind it as well—from tools, to foundry processes, to packaging, etc. The one constant is that time-to-market windows continue to shrink and the winners are those who can get working products to market in the shortest period of time.

AXIEM (www.axiem3d.com) is currently in beta test with existing customers and the commercial release is scheduled for Q1 2008. The product is priced at US$30,000 for locked licenses and supports Windows 2000, XP and Vista, and Linux. Additional information may be obtained via e-mail at info@appwave.com. In addition, AXIEM can be seen at the AWR booth no. 912 at the European Microwave Conference, October 9–12, in Munich, Germany.

Applied Wave Research Inc., El Segundo, CA (310) 726-3000, www.appwave.com.

RS No. 304

Premier Planar EM Tool Integrated into Budget-conscious RF EDA Environment

As traditional RF and microwave component designs move higher in frequency, the accuracy of physical design verification is a key enabling factor. EM solvers play an important role in the accuracy that drives high performance, small size and faster time to market for today's designs.

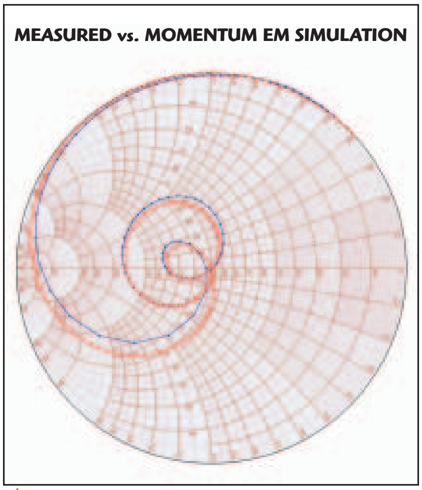
The Agilent Genesys environment now has this EM accuracy built into the platform, delivering a powerful combination of a compact, general-purpose EDA environment, with the performance needed to achieve first-pass success at traditional high frequency design. The innovation is that first-pass success in a proven RF design can be obtained for around $15K US, including the industry's premier planar EM tool, as well as a full environment with linear, layout, Yield/Optimization, SMT libraries and more (see ***Figure 1***).

While the majority of RF EDA environments have been racing to embrace IC and multi-technology corporate design, they have left behind individuals and self-directed workgroups who work in smaller budgets, and support themselves without the benefit of corporate staffing and infrastructure for sophisticated design flows. Genesys, formerly of Eagleware-Elanix, satisfies this need. It integrates linear, layout, harmonic balance, Spice, RF system and synthesis into a multi-lingual environment, but does so in an affordable platform. Now with an accurate planar EM tool tightly integrated inside, the Genesys environment has been re-energized for microwave component and subsystem design up to 100 GHz, and can do so at a price that enables the whole RF community, not just major companies.

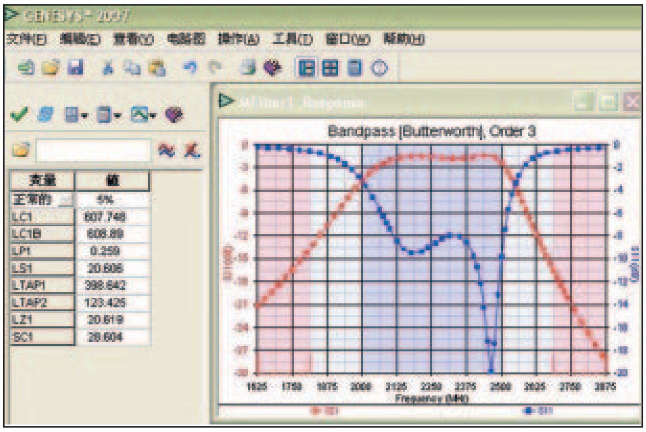
This article explores some of the possibilities enabled by having Momentum within the Genesys platform. The Genesys 2007.08 release delivers other capabilities that are also of interest to self-supporting designers:

Agilent EEsof
Santa Rosa, CA

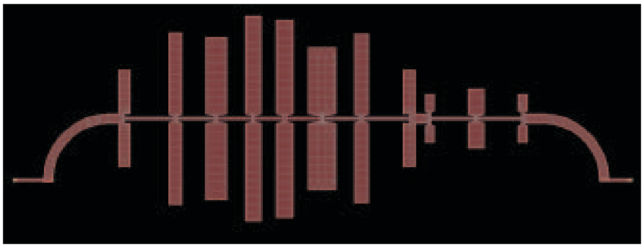
- New histograms and additional statistical capability for design-for-yield techniques
- Enhanced vendor parts libraries, now exceeding 30,000 parts
- Quick-start licensing, allowing users to be enabled worldwide, in minutes
- User Interface available in six languages (English, Russian, Japanese, Korean, and both Traditional and Simplified Chinese). Genesys is fast becoming the personal choice of RF designers worldwide (see **Figure 2**)



▲ *Fig. 1 Measured vs. modeled impedance for a typical microwave low pass filter.*



▲ *Fig. 2 Genesys 2007.08 available in six languages.*



▲ *Fig. 3 This high rejection low pass filter simulates easily on a laptop in minutes using Momentum GX, while Empower fails due to memory (>2GB).*

APPLICATIONS

Genesys has a long tradition in the Eagleware-Elanix company for linear circuit synthesis and design. Genesys then added nonlinear simulation, transient, RF system simulation and more. With highly accurate planar EM, Genesys is now an attractive platform for a wider variety of design endeavors, such as:

- High performance passive structures
- Active physical designs with SMT commercial parts
- RF system design, incorporating layout-oriented parasitics
- Planar antennas

PROVEN METHOD OF MOMENTS ENGINE

Genesys Momentum GX is based on the Agilent Momentum planar EM engine, proven over a decade of use by thousands of engineers using MDS, Series IV, ADS, RFDE and now GoldenGate platforms. While there are a variety of planar EM simulators on the market, each has its advantages and disadvantages. Whereas these standalone planar EM solutions optimize either performance, price, or integration, only Momentum GX simultaneously leads in all three categories, and it does this by targeting specific RF and microwave applications. Momentum GX packages the accuracy of the finest EM techniques and makes them financially and functionally accessible to a wide audience of designers in a personal design package.

PASSIVE STRUCTURES

Like all major RF EDA platforms, Genesys includes physical transmission line models with discontinuities, end effects and dispersion. These circuit models may be adequate for many circuit and IC designs, but even EM-based discontinuity models do not couple to each other, nor do they allow for novel structures and high performance component design.

A literature search of high performance design techniques reveals structures for which there are no models, which leads to intensive use of EM field solvers. Momentum GX with its conformal mesh, variety of boundary conditions, and unlimited number of layers and vias allows for creative approaches to high performance, high quality passive structures (see ***Figure 3***).

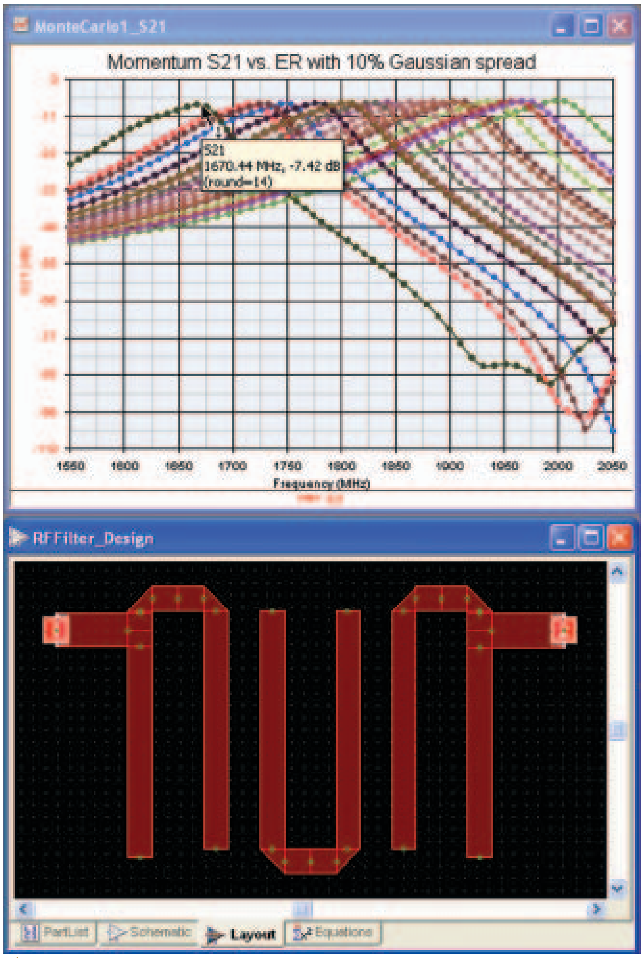
Examples of such passive structures are filters, diplexers, resonators, launches, transitions, interstage matching networks, baluns, couplers, splitters and many more. Genesys provides inexpensive synthesis modules that automate the creation of such structures, and these become a great starting point for more unique designs, if desired. Using the schematic, layout and linear simulation needed for a physical design, passive structures can then be optimized, tuned and statistical techniques applied, even with high performance EM (see ***Figure 4***). The Momentum GX planar EM solver gives passive physical designers confidence that the result will be accurate, even though the Genesys platform may operate more intuitively than IC design platforms.

ACTIVE CIRCUIT DESIGNS

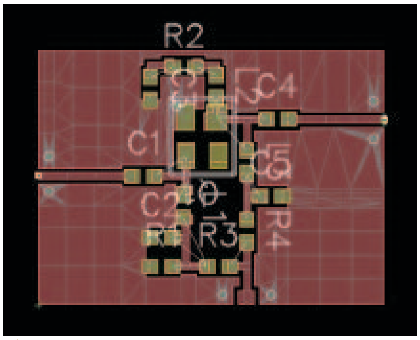
Designers of multi-stage amplifiers, RF transceivers, and other components and subsystems also benefit from the accuracy and convenience of the Momentum GX simulator. For many years, Genesys users have had access to a Method of Lines planar EM solver called "Empower". As a square-grid mesh EM solver, Empower is less suited for complex designs, that is, designs with curved structures, open boundaries, and designs needing a critical accuracy for DC bias and skin effect loss than EM solvers with more sophisticated meshing technology. Despite these limitations, the Genesys Empower module allows a seamless co-simulation between the electrical design with many surface-mount parts and the EM simulation of the passive metal interconnects. It does not require the placement of dozens of internal ports in the layout and handles the connection of the underlying S-parameter data automatically. Momentum GX continues this attractive Use Model (see ***Figure 5***).

Users of Empower and similar industry EM simulators will benefit in a number of ways from adopting Momentum GX. Momentum GX preserves Empower's seamless co-simulation model and extends performance to new levels. Momentum GX is nearly an order of magnitude faster than Empower, and uses far less memory for realistically-sized RF designs, allowing for greater complexity. It provides a direct DC solution for highly accurate bias, and superior loss prediction for thick metal and vias, which are needed by active circuits such as power amps. The "Automatic Frequency Sweep" (AFS) function and the RF (quasi-static) mode allow for even faster simulations relative to Empower.

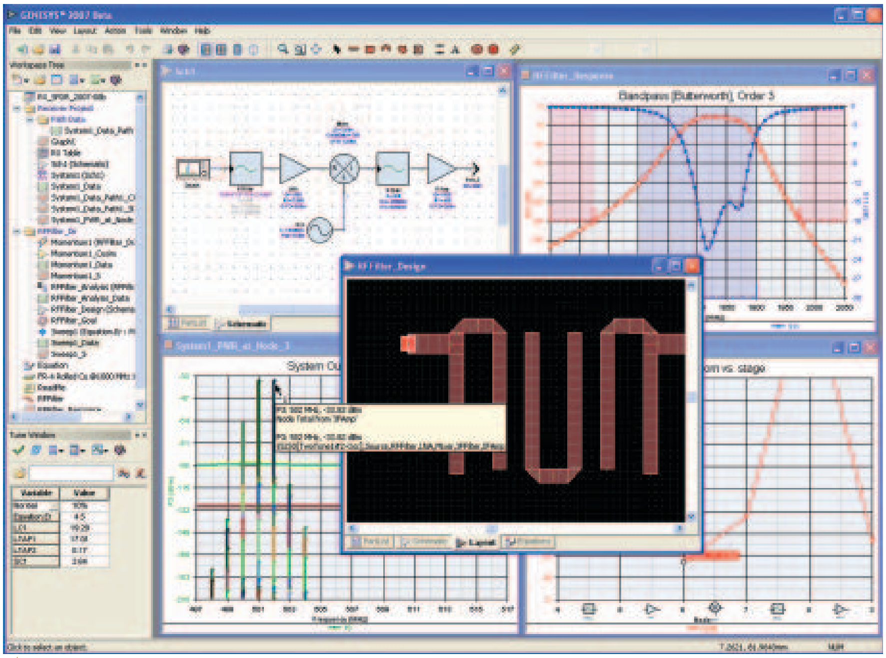
Finally, the ability to interact with external RF Board drafting systems allows drawings to be imported and schematic parts with electrical connectivity to be placed on top of the artwork to be co-simulated with EM parasitics. This verifies critical areas of the final board layout and maintains closure of the RF design process with a minimum of organizational investment. While some RF EDA systems highlight a real-time 1:1 mapping between schematic and IC layout elements in the RF environment, this is impractical for designers constrained by real-world mechanical design flows, as well as design teams without the admin, library and integration support staff needed to maintain high levels of automation. Having a premier planar EM simulator and several input/output graphics translators, Genesys supports a variety of planar "back-ends" tying its schematic environment with verification and manufacturing. This also includes a direct path to rapid-prototyping machines. The Genesys environment provides a solid foundation for self-supporting, independent RF



▲ *Fig. 4 The effect of the variation of the dielectric constant on a microstrip filter.*



▲ *Fig. 5 User-placed internal ports and separate artwork are not needed to perform nonlinear EM co-simulation because of tight EM integration.*



▲ *Fig. 6 Planar EM effects and physical circuit synthesis integrated up to the RF system architecture level.*

designers to create working design flows within a minimum cost envelope. Momentum GX further minimizes prototyping within those design flows.

The net benefit of having accurate physical simulations for arbitrary planar structures is creative confidence. Designers using Genesys can enjoy many of the same benefits for medium-sized RF component design as users of larger IC design systems, but because of its moderate cost, Genesys pays for itself in a matter of months, not years, without compromising the performance of the RF designs.

PHYSICAL RF SYSTEM DESIGN

Genesys is somewhat unique in that it allows the filters and passive structures of an RF system block diagram to be synthesized in place at the RF system level. Those filters and interconnect parasitics can now be rolled up to the RF system level with EM accuracy. Momentum GX will co-simulate with the Genesys Spectrasys and the Genesys linear simulator, allowing RF system architects to see the effects of physical design on spurs, mismatch, imperfect filtering and more, right at the RF system level (see **Figure 6**).

PLANAR ANTENNAS

Antenna designers also benefit from Momentum GX by creating matching networks and feed structures to their planar designs, as well as identifying higher order resonances and radiation efficiency. The next release of Genesys will include additional capability for planar antenna design.

CONCLUSION

Agilent Genesys has always had a reputation for fast, easy circuit synthesis and linear design. With this sixth Agilent release within 25 months, Agilent is investing in Genesys to be the design platform of choice for self-supporting designers and small workgroups doing traditional RF and microwave design. With local language support in six different languages, and a full physical environment complete with a premier planar EM simulator under $15K (US list), Genesys opens a set of new possibilities for the entire RF design community.

Agilent EEsof,
Santa Rosa, CA (800) 829-4444,
www.agilent.com.

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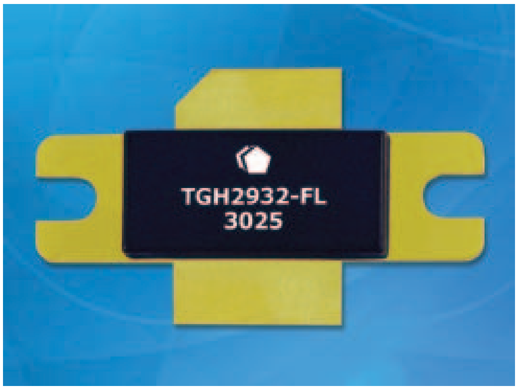


HIGH VOLTAGE, HIGH EFFICIENCY HBTs FOR 3G AND 4G AMPLIFIERS

The search for more efficient power amplifier technologies to address needs of the 3G and 4G base station market is a continuous one. Put simply, the efficiency of a power amplifier can be thought of as the amount of RF power it transmits divided by the amount of DC power it consumes in order to generate the RF signal. The difference between consumed DC and transmitted RF power is left as the waste product enemy of all things electronic—heat. Heat must be removed, so large and heavy heatsinks are used in base station superstructures, cooling fans run continuously and air conditioning systems strain to keep up with the thermal load.

Operators of GSM-based systems were accustomed to the high efficiencies of a saturated power amplifier design, so the 10 percent efficiencies of early 3G power amplifier products were a rude awakening, and they had the electric bills to prove it. In response, base station OEMs have been working to optimize their designs and have turned towards techniques such as digital pre-distortion and advanced circuit topologies to help improve the state-of-the-art in power amplifier efficiency.

Semiconductor device designers have also been hard at work to make advances in realized power efficiencies within power amplifier transistors. This combination of better semiconductor devices and more sophisticated amplifier designs have today produced power amplifiers that are on the order of 30 percent efficient—a lot better than the early days of 3G deployments, but still not where system operators want efficiency to be. For example: one major system operator has set a goal of 50 percent overall amplifier efficiency for its 3G system; now base station OEMs and RF power device providers are scrambling to find ways to meet this challenge. With 4G deployments and their more difficult signal environments looming on the immediate horizon, it is clear that some revolutionary new design techniques and device technologies will be needed to satisfy operator and radio manufacturer expectations.

LDMOS has an established reputation for handling linear signal amplification needs in base station applications where 30 percent overall PA efficiency is considered today's state-of-the-art. Contrast this to the handset market, where GaAs amplifiers are the norm due to the much higher power-added efficiency (PAE) of GaAs. With handset battery life a crucial consideration, GaAs HBT has dominated the landscape. Could a high voltage GaAs process be developed that would allow similar efficiency gains to be realized in a linear base station application?

TRIQUINT SEMICONDUCTOR INC.
Richardson, TX and Orlando, FL

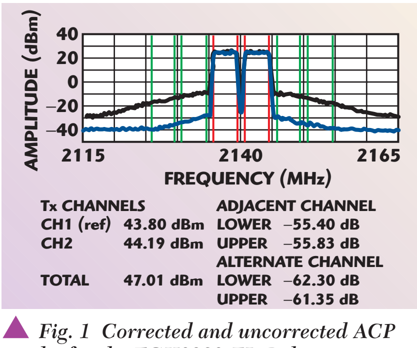
As a major GaAs, SAW and BAW manufacturer, as well as a lead researcher for a multi-year GaN development process through DARPA, TriQuint Semiconductor had a wealth of experience in high efficiency product development, design and manufacturing from which to address the need for a high voltage, high efficiency power amplifier for 3G and 4G base stations. TriQuint compared the capability of GaAs and GaN processes in terms of performance, ruggedness and cost structure, and selected its proprietary InGaP GaAs High Voltage HBT (HV-HBT) technology as the best option for improving the efficiency of 3G and 4G power amplifier applications.

TriQuint had previously announced results of its HV-HBT process technology research in the form of efficient but relatively low power transistors for the base station market. More recently, the company has worked to improve the semiconductor processes, device designs and assembly steps needed to realize a new generation of even higher performance devices with correspondingly higher power levels. Results demonstrated by preproduction devices show the most recent design iterations to be extremely well suited for use in advanced circuit topologies being implemented by base station OEMs, which will in turn help drive the next leap forward in 3G and 4G base station amplifier efficiencies.

The initial device created to demonstrate the capabilities of the process was designated TGH2932-FL. Housed in an industry-standard ceramic package, it was designed as a 140 W peak power device optimized for the 2110 to 2170 MHz WCDMA band. In a typical one-carrier WCDMA signal environment that exhibits 7.4 dB PAR (peak-to-average ratio) at 0.01 percent CCDF (complementary cumulative distribution function), the TGH2932-FL delivers 25 W of average power with 14.5 dB of gain and a collector efficiency of 34 percent. The TGH2932-FL is highly pre-distortable, exhibiting low memory effects, and well-behaved AM-AM and AM-PM characteristics.

Using commercially available digital pre-distortion correction and crest-factor reductions, adjacent channel power products in this stimulus case are better than –60 dBc. The collector efficiency of 34 percent is impressive by itself, but when the TGH2932-FL is used in a Doherty amplifier configuration, the performance truly excels. In a Doherty amplifier, two devices are used together to form a single amplifier output stage. One of the devices is used as the main amplifier, biased in a conventional class AB mode. The second device is used as a peaking amplifier, and is biased towards class C operation. Since 3G and 4G signals have a very high PAR, the peaking amplifier is available to deliver power during those instantaneous peaks, but is turned off (consuming no DC power) when the signal peaks are absent. Because the peaking amplifier handles the peak power demands, the main amplifier can be operated much closer to compression; at this point collector efficiency climbs markedly.

Additionally, the two devices in a Doherty configuration (main and peaking) are combined in such a way that the main amplifier "sees" different impedances when the peaking amplifier is on or off. Due to this impedance change, the main amplifier is able to operate more efficiently than when it is used as a normal class AB amplifier. To achieve this load modulation at the carrier amplifier output reference plane, it is important to have the correct phase offset between the output match of the carrier amplifier and the signal combiner. Equally important for good Doherty performance is to ensure the peaking amplifier does not load the carrier amplifier when the power level is below the desired threshold. This is achieved with an optimized phase offset in the peaking amplifier path. The target impedance for the carrier amplifier used in a Doherty configuration is twice the impedance that would be used in a class AB implementation. In the case of the HV-HBT Doherty design, the evaluation board was designed to provide an impedance of 4-j2Ω to the carrier amplifier when the peaking amplifier is turned off.

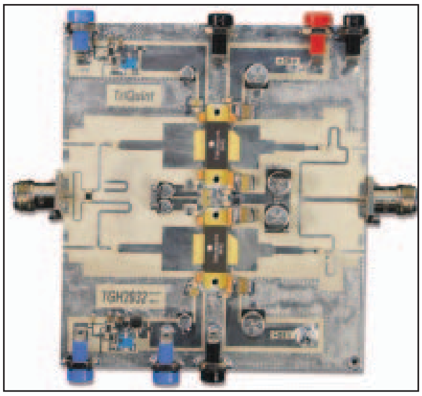


▲ *Fig. 1 Corrected and uncorrected ACP results for the TGH2932-FL Doherty configuration.*

In such a Doherty configuration, a pair of TGH2932-FL devices can deliver RF power with unrivaled efficiency. In one instance, the devices were tested in a more demanding multi-carrier environment, with a signal stimulus of two adjacent WCDMA carriers with 6.5 dB PAR at 0.01 percent CCDF. The un-corrected and predistortion linearized carriers can be seen in ***Figure 1***.

The TGH2932-FL Doherty amplifier delivered approximately 250 W of peak power and 50 W of average power with a gain of 11.5 dB. For a predistortion corrected ACPR of –55 and –60 dBc in the adjacent and alternate channels, respectively, this implementation delivered an unprecedented 57 percent collector efficiency. This means that to produce 50 W of RF power, the amplifier consumed only 88 W of DC power, leaving 38 W to be dissipated as heat—much less than that of a standard household light bulb. (The TGH2932-FL is shown in its Doherty evaluation board in ***Figure 2***.) A direct comparison of these results to published data for equivalent LDMOS or GaN devices used in a Doherty configuration is difficult to accomplish. However, a survey of the literature suggests that the HV-HBT-based Doherty holds an efficiency advantage over LDMOS of at least 10 percentage points, and over the more expensive GaN by approximately five points.[1,2]

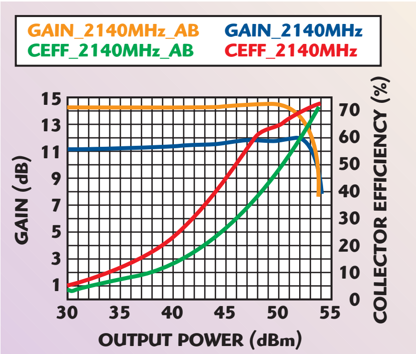
The inherent design advantages of an HV-HBT device are particularly well suited to reap the benefits of the Doherty circuit topology. As can be



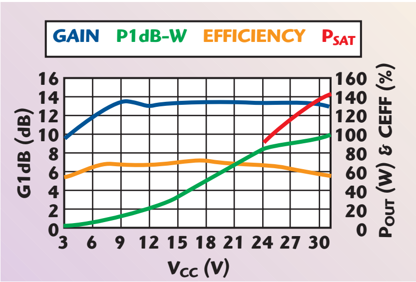
▲ *Fig. 2 The TGH2932-FL Doherty evaluation board.*

seen in ***Figure 3***, the TGH2932-FL Doherty collector efficiencies are achieved over a wide range of power levels, which makes the approach highly advantageous for the very dynamic signal environments present in 3G and 4G systems. Comparing collector efficiencies in Doherty (57%) and Class AB (34%) operation at the 47 dBm point, the HV-HBT devices dissipate 59 W less heat when used as a Doherty, more than a 60 percent savings compared to Class AB.

The truly impressive results in ongoing developmental research represent the culmination of lengthy and highly focused efforts by members of a cross-functional team of process, design and application engineers. Together they modified the basic design of the HV-HBT unit cell to deliver higher efficiency, linearity and peak power. One of the principal challenges that the team faced was an early breakdown phenomenon that was dubbed "flicker". The breakdown would occur at voltages far below where the device needs to operate given a 28 V DC rail with a high power AC waveform riding upon it. However, the breakdown was transitory in nature, and highly unpredictable, even on a given device. By careful design and experimentation the problem of "flicker" was resolved through modification of device structures, coating layers and etch processes.



▲ *Fig. 3 TGH2932-FL Doherty and class-AB comparisons.*



▲ *Fig. 4 The TGH2932-FL performance vs. supply voltage.*

The results achieved by these demonstration HV-HBT devices indicate that they are poised to become an integral part of next-generation high efficiency power amplifier designs that utilize envelope tracking (ET) techniques to boost efficiency even further. In an ET amplifier design, RF power devices have their DC supply voltage modulated to follow the peaks and valleys of the RF signal. In other words, when the RF signal requires a high peak power, the DC supply voltage is increased to allow the peak signal to pass. When the RF signal is closer to the average power level, the DC supply voltage is lowered by a corresponding amount. By modulating the supply voltage in this fashion, circuit designers can tailor the amount of DC power available at any given instant in time to the amount of RF power that needs to be delivered, vastly improving amplifier efficiency and reducing DC power consumption. The TGH2932-FL device is very well suited for ET amplifier design applications because the gain, efficiency and linearity of the HV-HBT device remain nearly constant over a wide range of supply voltages. This allows designers more latitude in adjusting the supply voltage to match RF power demands, maximizing the resulting efficiency gains (see ***Figure 4***).

OEM base station amplifier designers looking to unlock the potential of an ET design should consider the benefits of adopting a HV-HBT device technology. It is anticipated that efficiencies obtained using ET techniques will outstrip those achieved when utilizing a Doherty configuration.

Several design and production enhancements contributed to the success of the demonstration HV-HBT device and its ensuing product line. For example, the design employs thermal shunts to effectively remove heat from the active region of the transistor. Devices are 100 percent screened to a minimum 72 V breakdown and are compatible with existing 28 to 32 V base station power supply voltages. To ease the design burden, packages incorporate a proprietary input pre-match circuit and output-matching element. This approach allows the designer to more readily achieve excellent input and output return losses while improving manufacturability compared to conventional chip and wire solutions.

Performance was the goal when research began on a new generation of base station power amplifiers, but reliability must be assured given the inherent demands of base station manufacturing and field deployment. The intrinsically robust nature of the GaAs material, along with all-gold metallization, results in an extremely rugged device. The TGH series HBT die are treated with a surface passivation to ensure reliable operation in non-hermetic environments. Measured endurance of InGaP HBT devices exceeds 10^6 hours mean-time-to-failure (MTTF) at 170°C junction temperature and 10,000 hours MTTF at a 250°C junction.

The challenges in developing highly linear, reliable and efficient power amplifiers for 3G and 4G base station applications are formidable. To overcome those challenges, semiconductor device and base station design engineers will have to work together to create the next generation of devices optimized for use in more sophisticated topologies. Documented efficiencies show an advantage over competing device technologies that are available today.

Results achieved by this new generation of HV-HBT InGaP GaAs power transistors are an important first step in the quest to deliver a highly efficient, reliable power amplifier that system operators are demanding. As 4G systems are deployed across the world in 2500 and 3500 MHz bands, underlying HV-HBT transistor technology can extend the realized benefits and performance into higher and higher frequencies. TriQuint is working with lead customers to define a family of HV-HBT devices covering a variety of frequency bands and power levels that will harness the capability of new and improved HV-HBT process technology, pushing the boundaries of device performance into commercially realizable designs that can be used by base station OEM amplifier manufacturers to meet challenging performance requirements head-on.

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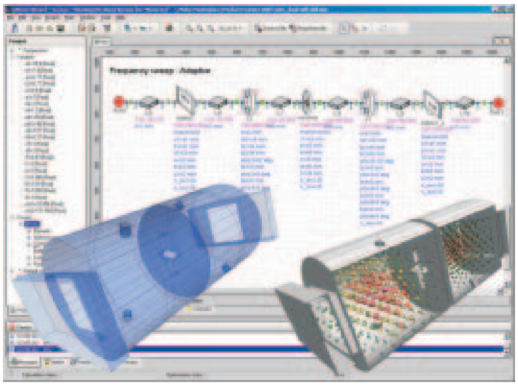


MODE-MATCHING SOFTWARE ACCELERATED BY ADAPTIVE FREQUENCY SWEEP

RF application engineers and component designers throughout the world are constantly striving to find fast and accurate design tools to enable them to reduce design cycles and speed up the development process, and thus minimize customer return times. As design engineers' needs advance, so too must the software that they use and rely on. It is vital that software developers keep ahead of the game and improve on every new release. Mician's latest version of the µWave Wizard™ CAD tool, version 6.5, demonstrates that fact.

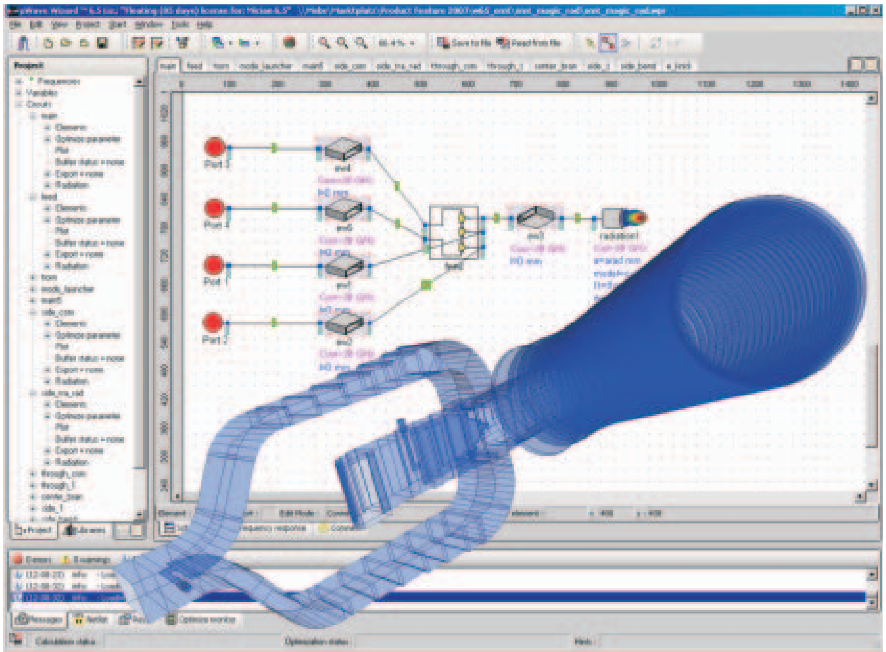
Before examining the specifics of the new version consider the general attributes of the µWave Wizard. It is a CAD tool for the design of passive microwave systems and components based on the well-known fast and accurate mode matching (MM) method. This technique is particularly suitable for fast simulation and optimization of many kinds of waveguide components, including combline and dielectric resonator filters and horn antennas, as well as entire antenna feed networks. The mode matching method and its derivatives such as the hybrid boundary contour mode matching (BCMM) method and the 2D finite element/mode matching are the only techniques capable of offering fast processing speed with very high accuracy.

The secret for achieving very high speed is to avoid the use of time-consuming full 3D solvers wherever possible and to apply the MM method and its derivatives instead. This should even be the case for structures that at first glance seem to be suited for 3D solvers only, like combline resonators, OMTs and turnstile junctions, and radiation into free space out of arbitrary apertures.

The basic idea behind the CAD tool is to break down the entire structure into smaller functional segments by using hierarchical subcircuits containing smaller elements such as steps, irises, cavities, obstacles and empty waveguide connections, as shown in ***Figure 1***.

Several element libraries containing more than 250 pre-designed elements for every design purpose are offered. These elements can be placed and connected in a schematic as in a circuit simulator and the properties such as geometries and materials can easily be assigned to each of those elements. Recently, a 3D FEM solver has been integrated for structures with very complex geometries or with features not feasible to be implemented in MM. For full flexibility, some elements also allow the import of user defined geometries from external data files (STL-files, for example).

MICIAN GMBH
Bremen, Germany



▲ *Fig. 1 Breakdown of a complex structure into functional parts.*

Usually the integrated 3D solver is only being used for small segments (single elements) of the structure and has a multi-modal full-wave interface to all other parts of the structure. The result is a speeding up of the computation time since only those not MM feasible elements within the structure are being calculated by 3D FEM while all other elements are being analyzed by the MM method. The set up of all elements, including the necessary surface and 2D or 3D mesh generations, is fully automated, regardless of which solver is actually used.

VERSION 6.5

Besides the addition of new elements like coaxial T-junctions, bends, three- and four-port OMTs with stepped geometry, dielectric resonators and waveguide step elements with various shapes to the element library, with version 6.5 the graphical user interface (GUI) is an improved modern and more user friendly design. The repositioning of the element libraries into the Project window now enables the names and descriptions of the icons to be displayed simultaneously.

Standard elements that are frequently used such as Port, Empty Waveguide, Short and Waveguide Rotate have been placed at the top of the library. Additionally, the optimization monitor within the GUI has been extended to monitor the variables during the optimization and to provide direct access for editing the values and constraints of those variables.

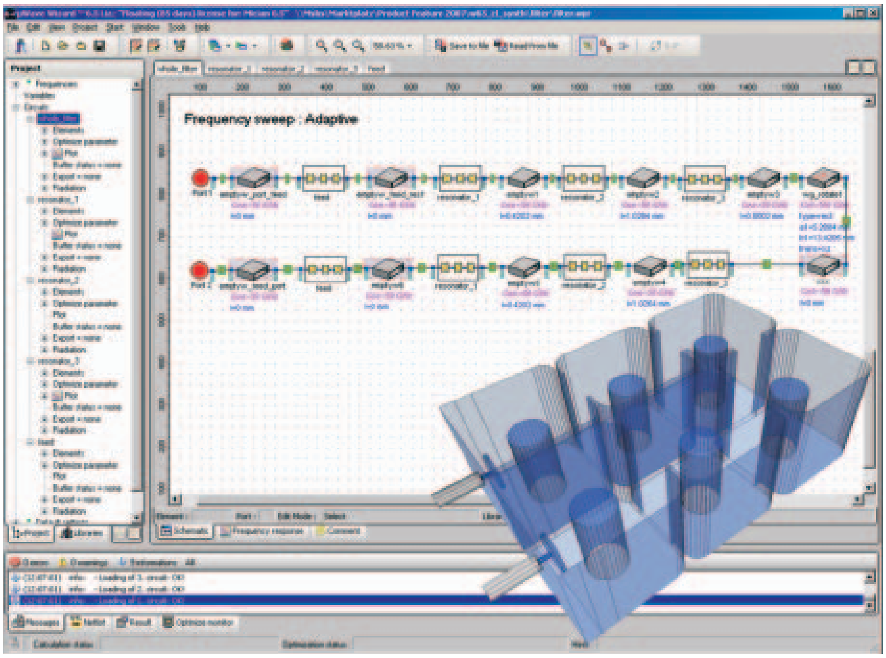
The GUI integrates all components of the CAD tool, comprising circuit schematics, various editors (for variables, optimization goal functions, symmetry, accuracy and material property settings, for example), visualization of 3D geometry, simulation and optimization results, a COM interface for automation with external programs, a macro programming interface Visual Basic and C# (.NET) languages, and a tool for yield analysis. CAD export to common 3D formats like DXF, STL, STEP and VRML for manufacturing is also included.

A key new feature of version 6.5 is the inclusion of finite wall conductivity losses directly into the mode matching method and its derivatives (BCMM), as well as in the 2D FEM method. This is achieved by using a surface impedance model and suitable approximations, which reduce the computational overhead to a minimum. Previously, all wall losses had to be included to switch the solver of each element to 3D FEM.

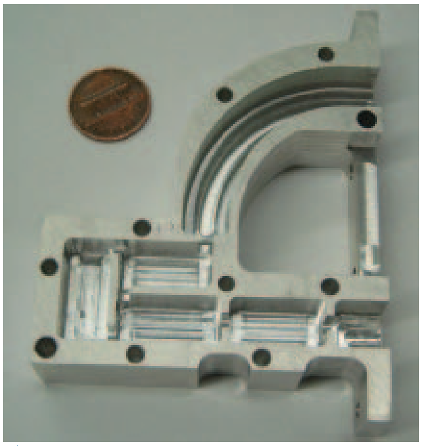
However, this new method maintains the original advantage of MM of both speed and accuracy. The overhead for lossy calculations is typically about 10 to 70 percent, which is mostly caused by switching from real to complex arithmetic and mostly depends on the type of element and the number of modes taken into account.

Another new feature is a fast frequency sweep (FFS) based on adaptive rational function interpolation. This technique enables 'smooth' S-parameter plots to be obtained over a broad frequency range with only few samples being calculated. This saves a lot of CPU time, especially when analyzing or optimizing resonant structures over a broader frequency range. A typical reduction of 5 to 10 times in the number of frequency samples is achieved.

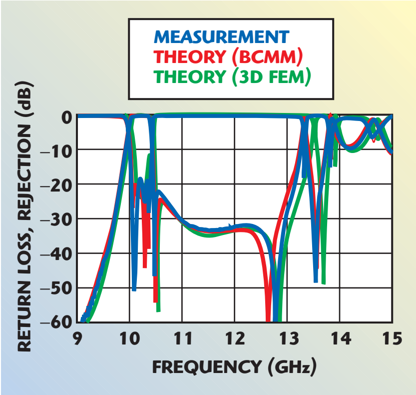
The interpolation includes all higher order mode interactions and is applica-



▲ *Fig. 2 Adaptive frequency sweep.*



▲ *Fig. 3 A 10 GHz bandpass filter in integrated waveguide technology.*



▲ *Fig. 4 Theoretical and measured performance of the 10 GHz bandpass filter.*

ble to any n-port circuit during analysis, optimization and field calculation, which means that the adaptive frequency sweep can be used for all frequency dependent calculations, including optimization, tuning, yield analysis, field calculations and calculation of radiation patterns, incorporating import and export of saved S-parameter files. When converged, differences between responses obtained from conventional and adaptive frequency sweeps are not distinguishable. An example of an adaptive frequency sweep is shown in ***Figure 2***.

SPEED AND ACCURACY

The advantage of the MM method can be demonstrated using the example of an asymmetric four-pole bandpass filter in integrated waveguide technology (see ***Figure 3***). To achieve full convergence of the results, it is necessary to include all modes up to a cut-off frequency of 200 GHz for the application of the BCMM method. This leads to a CPU time of about three seconds per frequency. The result of this computation is shown in ***Figure 4***. Excellent correlation to measurements is achieved.

Using a conventional frequency sweep, 400 samples are needed for reproduction of the curves, leading to a total CPU time of 20 minutes. Using the new, adaptive frequency interpolation, the same results are obtained with the computation of 30 frequencies only, leading to a reduction of a factor of 13 in CPU time.

Also included in Figure 4 are the results of the 3D FEM simulation of the filter carried out by the new integrated 3D FEM simulation feature. Although a similar reduction can be achieved in the number of frequency samples, in this case the CPU time for a single frequency is approximately 22 seconds, although the match of the results is not as good as obtained with the BCMM method due to a small frequency shift and distortion in return loss.

For this computation the same breakdown of the structure into single elements has been used as with the BCMM method, and each element has been analyzed separately using the 3D FEM method, which involved about 125,000 unknowns in total. This scenario is comparable to the case when a circuit is analyzed with the µWave Wizard, but no parts of the circuit are suitable for the MM method. Even so, these CPU time ratio results are better than can be achieved when the 3D FEM calculation is being executed in one single step for the entire structure as occurs in conventional 3D EM simulators.

CONCLUSION

The new µWave Wizard version 6.5 delivers good performance and accuracy to the engineers designing passive microwave and RF circuits. It achieves this goal through the combination of fast EM solvers based on the mode matching method in combination with fast adaptive frequency interpolation. Furthermore, Mician offers support and software updates that incorporate new features and design elements. Additional information can be obtained via e-mail at sales@mician.com.

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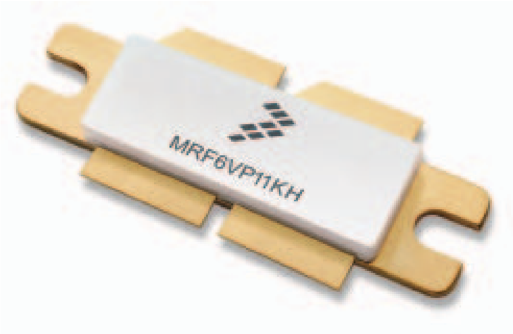


LDMOS FETs with 1 kW Peak Power to 150 MHz

Most applications requiring the generation of RF power depend on silicon and GaAs power transistors with typical outputs ranging from milliwatts to tens of watts. However, less visible but equally important are the wide array of industrial, scientific and medical applications that demand extremely high RF power levels to achieve their intended goals. To serve these applications, Freescale Semiconductor has introduced the MRF6VP11KH delivering peak RF output power of 1 kW at 130 MHz. The benefits of achieving this level of peak RF power are considerable from the perspectives of manufacturing, reliability and operating cost.

The MRF6VP11KH operates from 10 to 150 MHz, is fabricated using Freescale's sixth-generation, very high voltage (VHV6) 50 V LDMOS technology and is the latest transistor in a growing portfolio of devices the company is developing for applications operating up to 450 MHz. It operates in push-pull configuration and provides higher performance than bipolar and other MOSFET devices that are available for these applications. For signals with a pulse width of 100 µs and a 20 percent duty cycle, the MRF6VP11KH produces more than 1 kW at 1 dB gain compression with 65 percent efficiency and 27 dB power gain at 130 MHz. It will produce 1.3 kW output power at the 3 dB compression point with 70 percent efficiency (see ***Figure 1***). Additional specifications are contained in ***Table 1***.

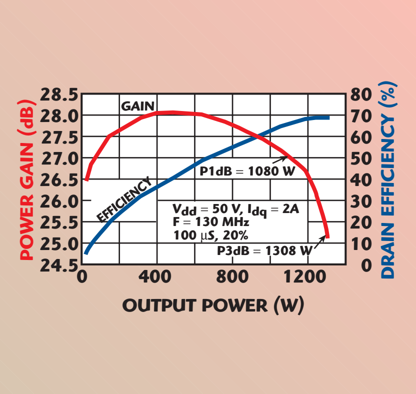
Typical applications for the MRF6VP11KH include medical and industrial magnetic resonance imaging (MRI), CO_2 laser drivers for marking and cutting, industrial heat sealing, range-finding light detection and ranging (LIDAR), plasma generators for thin-film semiconductor processing, as well as broadcast transmitters and HF/VHF communications systems. Many of these applications require tens of kilowatts of RF output power. MRI systems, for example, employ power amplifiers that deliver 20 kW of peak RF power

Freescale Semiconductor,
RF Division
Tempe, AZ

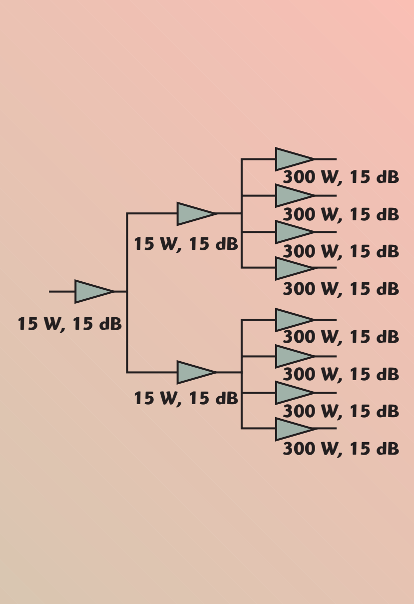
or more. To achieve these high power levels, the transmitters rely on amplifiers that have multiple stages, each stage employing one or more RF power transistors. With the levels of efficiency, gain and output power provided by the MRF6VP11KH, such a line-up is drastically reduced by up to 70 percent. This part count reduction significantly decreases board space requirements and manufacturing complexity, ultimately resulting in lower amplifier costs.

AMPLIFIER COMPARISON

The dramatic advantages provided by the MRF6VP11KH can be demonstrated by comparing two amplifiers at the 2 kW level, the first using standard MOSFET or bipolar devices, and the second, the new MRF6VP11KH. In each case, the amplifiers consist of low power drivers and high power amplifiers in several stages. In the first case, the 2 kW building block would typically require a single 15 W predriver, two 15 W drivers and eight final amplifier transistors for a total of three stages and 11 devices (see ***Figure 2***). Peak output power of this configuration would typically be 2.4 kW with power gain of 45 dB. Using the MRF6VP11KH, 2 kW of output power and gain of 50 dB can be achieved with only three devices in two stages: a single 10 W LDMOS driver (Freescale's MRF6V2010N) and two MRF6VP11KH final amplifiers (see ***Figure 3***).



▲ *Fig. 1 Power gain vs. output power and drain efficiency of the MRF6VP11KH at 130 MHz.*



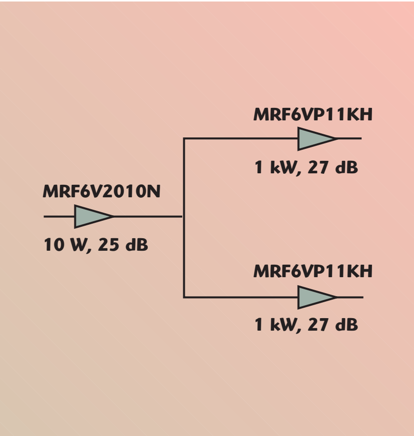
▲ *Fig. 2 The configuration typically required to produce 2.4 kW of peak output power using MOSFET or bipolar devices.*

TABLE I

MRF6VP11KH SPECIFICATIONS AT 130 MHz

Operating frequency (MHz)	10 to 150
Supply voltage (VDC)	50
Peak output power (W)	1000
Pulse width (µs)	100
Duty cycle (%)	20
Typical gain (dB)	27
Typical efficiency (%)	65
Maximum VSWR	10:1
Matching	unmatched
R_{jc} (°C/W)	0.13*
Package type	RoHS-compliant, push-pull ceramic
Other features	integral ESD protection

*simulated results



▲ *Fig. 3 The configuration to produce 2 kW of RF peak output power using two MRF6VP11KH final amplifiers and an inexpensive 10 W driver amplifier.*

RUGGED DESIGN

High power devices such as the MRF6VP11KH require the ability to withstand mismatch conditions well beyond their normal operating range. For example, the MRF6VP11KH can withstand extremely high impedance mismatches, and is rated for VSWRs as high as 10:1 at 50 V and 1 kW output power. It also incorporates electrostatic-discharge (ESD) protection against discharge while handling on the manufacturing floor. This ESD protection provides ample gate voltage swing capability of –6 and +10 V, a very desirable attribute for higher classes of operation. Effective thermal management is essential when generating such high output-power levels from a single device, and considerable effort was spent to reach 0.13°C/W thermal resistant junction-to-case temperature in the design of the MRF6VP11KH.

In addition to the MRF6VP11KH, the company's portfolio of 50 V VHV6 devices ranges from 10 to 450 MHz operation and includes the MRF6V2010N (10 W CW, 23.9 dB gain, 62 percent efficiency), the MRF6V2150N (150 W CW, 25 dB gain, 68.3 percent efficiency) and the MRF6V2300N (300 W CW, 25.5 dB gain, 68 percent efficiency). These devices are currently in production. The MRF6VP11KH is sampling now and production is expected in the fourth quarter of 2007.

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RS No. 301

Acceleration Products

This web site has been redesigned for those interested in bringing the power of a supercomputer to their desktop. The company's Accelerator™ and ClusterInABox™ products harness the parallel processing power of GPUs, delivering unrivalled performance to accelerate electromagnetic simulations up to 35× faster. New additions to the site include: up-to-date product specification pages, case studies, articles, webinars and event listings.

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Calgary, AB, Canada T3C 3P1

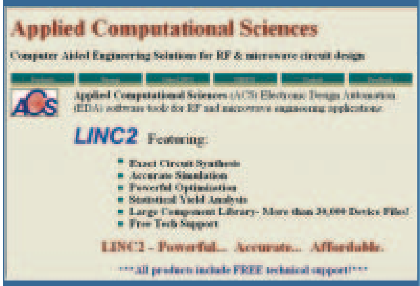
www.acceleware.com

Semiconductor Solutions

This web site highlights the company's semiconductor solutions in the rapidly growing broadband wireless and wireline communications markets. The site was designed to improve performance for its on-line visitors while still delivering valuable information. In addition to the updated contemporary look, a big improvement to the site includes easy-to-navigate selections enabling users to quickly find product information for wireless, cable and broadcast, WLAN and WiMAX, and fiber optic applications.

ANADIGICS Inc.,
141 Mount Bethel Road,
Warren, NJ 07059

www.anadigics.com



EDA Software Tools

This web site highlights new features of the LINC2 RF and microwave circuit design software suite. The LINC2 software package offers high performance RF and microwave circuit design, synthesis, simulation and optimization in a single integrated design environment at an affordable price. LINC2 automates the design of low noise amplifiers, single and multi-stage amplifiers, balanced amplifiers and push-pull amplifiers. LINC2 Filter Pro synthesizes lumped and distributed filters in balanced and single-ended configurations.

Applied Computational Sciences (ACS),
1061 Dragt Place, Escondido, CA 92029

www.appliedmicrowave.com

Mission-critical Solutions

This enhanced and redesigned site features improved navigation, superior search features and a market-driven design. The new site includes a Virtual Factory Tour as well as on-line engineering tools to "Build Your Own" system. "We listened to our customers and stakeholders and redesigned the site with their needs in mind," said Michael Kujawa, VP of sales and marketing for TRAK Microwave.

TRAK Microwave Corp.,
4726 Eisenhower Boulevard,
Tampa, FL 33634

www.trak.com

Tunable Filters and Diplexers

The Coleman Microwave Co. (CMC) site features custom microwave filters in the frequency range of 400 MHz to 40 GHz. Specializing in cavity resonator designs, filters are offered in both coaxial and waveguide modes of operation. Low pass, high pass, bandpass and band reject filters are available and can be configured as single channel, multichannel and diplexers. In addition to fixed tuned versions, CMC specializes in tunable filters and diplexers.

Coleman Microwave Co.,
PO Box 247, Edinburg, VA 22824

www.colemanmw.com

RF and Microwave Products

Crane Aerospace & Electronics, Microwave Systems Solutions (Signal Technology) provides RF and microwave products for the defense, space and communications industries for use in electronic countermeasures, missiles, radar, intelligence and guidance systems. The company specializes in mission critical-harsh environment products for airborne, shipborne, land-based, space and missile applications.

Crane Aerospace & Electronics,
PO Box 97005,
Redmond, WA 98073-9705

www.craneae.com/mw

VCOs and PLL Synthesizers

Visit Crystek's site for innovative frequency control technology. Crystek Microwave offers VCOs and PLL synthesizers in a wide mix of frequency ranges, standard packaging and custom design options. Product highlights include low phase noise, microstrip and coaxial designs, and octave tuning. Since 1958, Crystek has been the industry leader in engineering, manufacturing, support and service.

Crystek Microwave,
12730 Commonwealth Drive,
Fort Myers, FL 33913

www.crystek.com

3D Electromagnetic Field Simulation Software

This recently updated web site features the company's 3D electromagnetic (EM) field simulation software for high frequency applications. New additions to the site include: Web-based videos demonstrating the state-of-the-art 3D EM simulator CST MICROWAVE STUDIO®, applications articles, user forum, technical support area and downloads.

CST of America® Inc.,
10 Laurel Avenue, Suite 300,
Wellesley Hills, MA 02481

www.cst.com

Amplifiers and Subassemblies

CTT's new web site features an easy-to-use navigation covering the company's complete line of solid-state power amplifiers, low noise amplifiers, frequency converters, frequency multipliers, transmitters, transceivers and receivers within the frequency spectrum of 400 MHz to 100 GHz. A page also discusses CTT's CEOs (Custom Engineered Options) that are available on most package formats.

CTT Inc.,
241 East Java Drive,
Sunnyvale, CA 94089

www.cttinc.com

Control Products and Amplifiers

This web site features the company's advanced IF/RF and microwave control products and amplifiers for the defense electronics, aerospace, commercial aircraft, wireless and other high-end commercial industries. From commercial space to advanced wireless applications, the company's custom high reliability products are integral to the complex operations of major satellite, radar, navigation, communications, electronic warfare and missile systems applications.

Daico Industries Inc.,
1070 E. 233rd Street, Carson, CA 90745

www.daico.com

ICs, Modules and Subsystems

This comprehensive, versatile web site has recently added new product pull-down menus and RoHS-compliant component pages. The web site details full specifications for over 480 products, application notes, quality assurance and product support tools, including Product Cross Reference, Parametric Search, PLL Phase Noise and Mixer Spur Chart Calculators, and expanded e-commerce. The company's new Designer's Guide, product selection guide, newsletter and CD can also be requested from the site.

Hittite Microwave Corp.,
20 Alpha Road, Chelmsford, MA 01824

www.hittite.com

Electronic Components

The new web site features detailed information on the company's products, including test data, S-parameters and RoHS/WEEE compliance information. Additionally, new interactive features such as an on-line RFQ form, on-line sample request form and easy rep locator make this site a powerful resource for the design engineer. IMS offers resistors to 1Tohm and 350 W input power, attenuators to 70 dB, low loss dividers to 20 GHz, and low loss, wide rejection filters with passbands from 800 MHz to 8 GHz.

International Manufacturing Services,
50 Schoolhouse Lane,
Portsmouth, RI 02871

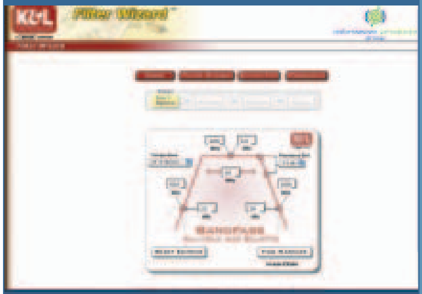
www.ims-resistors.com

Systems and Subsystems

Versatile Power specializes in the design and manufacture of customized power delivery systems, control systems and subsystems. The company's web site will introduce visitors to the company's products, services and ISO 9001-2000 quality. Combining its core competence in power conversion with advanced digital control, Versatile Power provides custom solutions for RF and microwave applications, including telecommunications, aerospace, military, homeland security, test and measurement, and medical.

Versatile Power,
2605 South Winchester Boulevard,
Campbell, CA 95008

www.versatilepower.com



Filter Synthesis and Selection Tool

K&L Microwave's web site features the Filter Wizard^{SM} software. It simplifies the selection of the right filter product from a vast number of designs within the 300 kHz to 40 GHz frequency range. Enter your specifications, and Filter Wizard returns response data, downloadable S-parameter data and outline drawings for matching products. For more information, visit www.klfilterwizard.com.

K&L Microwave,
2250 Northwood Drive,
Salisbury, MD 21801

www.klmicrowave.com

High Power Amplifiers

Xicom Technology is a supplier of antenna-mount and rack-mount high power amplifiers for SATCOM. The company's web site has been expanded to provide complete data sheets with specifications for TWTAs, SSPA, BUCs and KPAs for applications including land, sea, air and SNG. For the demands of SATCOM On-the-Move and SATCOM On-the-Pause, Xicom has introduced the new "Shoebox" family of antenna-mount BUCs for mobile operations in C-, X-, Ku- and extended Ku-bands.

Xicom Technology Inc.,
3550 Bassett Street,
Santa Clara, CA 95054

www.xicomtech.com

Advanced Composite Structures

Ratech is a diversified manufacturer of durable, lightweight, advanced composite structures. CAD/CAM capabilities support the manufacturing of both large and small advanced composite products for applications, such as radomes, antennas, simulation domes and screens. The site offers a comprehensive view of the company's capabilities. A photo library of installations around the world from Anartica to Guam to Chile is available that illustrates the wide variety of climatic conditions that Ratech can design radomes for.

MFG Ratech,
855 East Greg Street, Suite 103,
Sparks, NV 89431

www.mfgratech.com

Microwave Components

MICA's web site features a wide range of products including ferrite products, detector & limiter products, mixer & doubler products, and equalizer products. A page is also devoted to in-stock ferrite products for design engineers looking for fast delivery of some of MICA's standard product offerings. MICA Microwave's advanced capabilities are the result of integrating technological expertise with its unique problem solving techniques to produce the most advanced microwave products available.

MICA Microwave,
1096 Mellon Avenue,
Manteca, CA 95337

www.mica-mw.com

Microwave Test Cable Assemblies

Micro-Coax's web site allows engineers to easily and quickly order flexible microwave test cable assemblies. With its Web Store, Micro-Coax offers a cost-effective alternative that helps engineers who need high frequency cable assemblies for their defense, telecommunications and test instrument designs. The site also features a product selector for one of the largest families of semi-rigid and flexible coaxial products.

Micro-Coax,
206 Jones Boulevard,
Pottstown, PA 19464-3465

www.micro-coax.com

Free Tools for Design Engineers

This web site features even more resources designed to *Accelerate Your Design Success*. Available for immediate download, *Modelithics Select* is a sample of accurate, reliable and scalable models that work with a variety of simulators. Having recognized the value of high quality models in the design process, several component manufacturers are also sponsoring complimentary licenses for high accuracy substrate-scalable models for designer use.

Modelithics Inc.,
3650 Spectrum Boulevard, Suite 170,
Tampa, FL 33612

www.modelithics.com

Filters, Diplexers and Subassemblies

Reactel Inc. has enhanced its web site with a library of data sheets. Accessing information for the company's wireless and custom products has never been easier, and is now just a click away. Additionally, the site includes RoHS-compliant offerings and features Reactel's full-line of RF/microwave filters, diplexers and subassemblies. Reactel's product catalog is also available for download in support of its worldwide customer base.

Reactel Inc.,
8031 Cessna Avenue,
Gaithersburg, MD 20879

www.reactel.com

Microwave Sources

Spinnaker introduces an all-new web site showcasing the company's expanded capabilities in high performance microwave sources for commercial, military and instrumentation applications. The site provides detailed information on Spinnaker's sources, including VCOs, PLOs, frequency synthesizers, DTOs and custom microwave assemblies. Additional features include application notes, design aids, phase noise tutorials, technical papers, employment opportunities and ordering information.

Spinnaker Microwave,
3281 Kifer Road, Santa Clara, CA 95051

www.spinnaker microwave.com

Microwave Equipment

Tampa Microwave is an established supplier of block up and down converters, loop test translators, custom rack-mounted RF assemblies and contract manufacturing for military and commercial SATCOM markets. The company recently acquired the spectrum analyzer, carrier monitoring and Signal Intelligence Receiver (SIGINT) assets of Morrow Technologies Corp. Having recently acquired these assets, visitors can now experience a live demonstration of the Carrier Monitoring products.

Tampa Microwave,
12160 Race Track Road,
Tampa, FL 33626

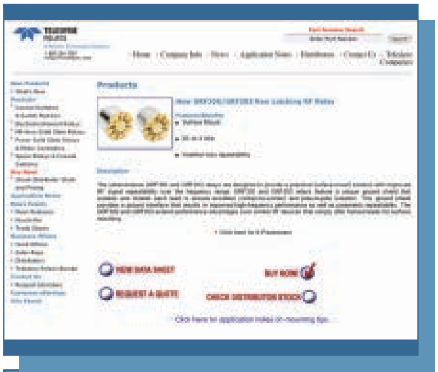
www. tampamicrowave.com

Custom Antenna Systems

TECOM Industries, an ISO-9001 and AS-9100 company, specializes in solving unique antenna problems through custom designs, modifying standard products to meet special requirements and providing build-to-print capabilities for sophisticated antenna systems. TECOM produces complex antennas and antenna systems, developing a comprehensive array of proven products and engineering expertise. The antenna selection guide (www.tecom-ind.com/freq_chart.htm) allows visitors to view available products by frequency range.

TECOM Industries Inc.,
375 Conejo Ridge Avenue,
Thousand Oaks, CA 91361

www.tecom-ind.com



On-line Product Data Sheet

Teledyne Relays announced that improvements to its Series GRF300 and GRF303 high repeatability, broadband TO-5 electromechanical relays now deliver 10 Gbps data rates for digital signal integrity applications. The relays are designed to provide a practical surface-mount solution with improved RF signal repeatability over the frequency range. Improved ground connections provide the 10 Gbps data rates.

Teledyne Relays,
12525 Daphne Avenue,
Hawthorne, CA 90250-3384

www. teledynerelays.com

New Product Slideshow

AR RF/Microwave Instrumentation's home page now features a new product slideshow that features the latest AR products. Currently highlighted is information on its "Subampability" Concept, FM7004 free software upgrade, signal generator offerings and its 4 to 8 GHz amplifier series.

AR RF/Microwave Instrumentation,
160 School House Road,
Souderton, PA 18964

www.ar-worldwide.com

RF Front-end Modules

JMD's new web site showcases its best-in-class performance, highly integrated RF front-end modules. JMD leverages its proprietary multi-layer organic (MLO) substrate technology to integrate filters, baluns, couplers and matching networks. The web site exhibits the technology, the performance of the modules and the advantages versus standard approaches.

Jacket Micro Devices (JMD),
75 5th Street, Suite #700,
Atlanta, GA 30308

www.jacketmicro.com

RF and Microwave Filters

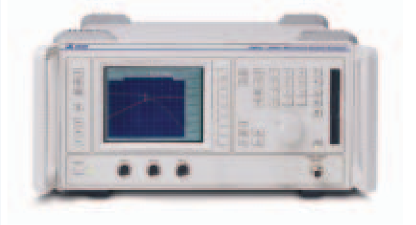
This web site features the company's RF and microwave filters. The company offers an extensive product mix with filters and multiplexers satisfying requirements from 100 kHz to 18 GHz. These products are currently being utilized in major digital and analog wireless communications systems, test equipment and military systems.

Lark Engineering Co.,
27282 Calle Arroyo,
San Juan Capistrano, CA 92675

www.larkengineering.com

The following booth numbers are complete at the time of going to press.

Internal Pulse Modulator

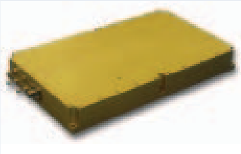


This internal pulse modulator, option 025, is designed for the company's 6800 series of microwave analyzers that operate up to either 18 or 40 GHz. For Aeroflex's 6810 series of microwave sources, this new option offers sensitivity and range measurements for radar receivers, and tests pulsed amplifiers under pulsed conditions. When fitted to Aeroflex's 6820 series of microwave scalar analyzers, this option also offers insertion loss, return loss and fault location (distance-to-fault) measurements on radar systems in both coax and waveguide.

Aeroflex Inc.,
Wichita, KS (316) 522-4981,
www.aeroflex.com.
Booth 111/210 **RS 217**

Solid-state RF Amplifier

The model SSPA 3.0-4.0-20 is a high power, broadband RF amplifier that operates from 3 to 4 GHz. This PA is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a large bandwidth. This amplifier operates with a base plate temperature of 85°C. It is packaged in a modular housing that is approximately 4.5" by 8.0" by 1.0". This amplifier has a typical P1dB of 30 W at room temperature. Saturated output power across the band is typically 32 to 40 W. Noise figure at room temperature is 7 dB typical.



Aethercomm Inc.,
San Marcos, CA (760) 598-4340,
www.aethercomm.com.
Booth 101/200 **RS 218**

Fast Signal Analyzer

The EXA signal analyzer is claimed to be the industry's fastest economy-class signal analyzer. Its speed and accuracy, coupled with its performance and application coverage, provides development and manufacturing engineers with the capabilities to cost-effectively troubleshoot new designs, increase manufacturing throughput, or analyze complex and time-varying signals. It integrates a broad range of standards-based measurements with the company's 89600 vector signal analysis software, all in a single instrument. As well as using an open Windows® XP Professional operating system, the EXA also provides an advanced signal analysis user interface. All measurement features and functions are intuitively grouped and accessible from the front panel or via a USB keyboard and mouse.

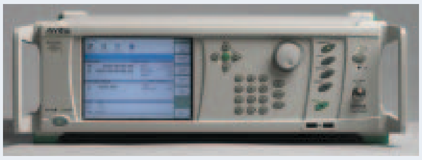
Agilent Technologies Netherlands BV,
Amstelveen, The Netherlands
+31 20547 2111, www.agilent.com.
Booth 908/930 **RS 219**

Pulsed IV/RF System

This pulsed IV/RF measurement system provides a versatile, robust and accurate system. The robustness of this solution has been tested everyday for more than 10 years and the measurement accuracy is guaranteed. Because accurate measurements are essential, this system makes it possible for the user to visualize the true pulses shape, avoiding measurement errors. Typical pulse widths are about 300 ns for power up to 100 V/2A, coupled with pulsed S2P measurements (10 MHz to 40 GHz).

AMCAD Engineering,
Limoges, France +33 (0)555 040 531,
www.amcad-engineering.com.
Booth 212 **RS 220**

Microwave Signal Generator



The MG37020A is a fast-switching microwave signal generator that provides best-in-class frequency switching speed, which makes it well suited for integration into automated test systems used in both commercial and defense applications. The MG37020A features an enhanced Pulse Modulation Burst Mode for radar interference testing of wireless LAN/MAN dynamic frequency selection (DFS) for regulatory compliance, and an Ultra-Stable Phase Track option to interconnect up to four MG37020A generators for applications requiring multiple test signals.

Anritsu EMEA Ltd.,
Luton, Bedfordshire, UK
(+44) 1582 433433, www.eu.anritsu.com.
Booth 914 **RS 221**

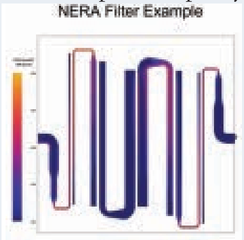
Acceleration Products

These Accelerator™ and ClusterInABox™ products harness the parallel processing power of GPUs, delivering unrivalled performance to accelerate electromagnetic simulations up to 35× faster. Acceleware integrates with leading applications for antenna design & optimization, printed circuit boards, RF circuits & connectors, head/cell phone modeling/SAR, filter design & optimization, and electromagnetic compatibility (EMC).

Acceleware Corp.,
Calgary, AB, Canada (403) 249-9099,
www.acceleware.com.
Booth 602/604 **RS 216**

EM Tool

AXIEM,™ AWR's groundbreaking new EM tool, delivers speed, capacity and accuracy to microwave/RF designers. It provides advancements in meshing technology, solver technology and overall work flow. AXIEM integrates EM analysis for the first time into the front end of the circuit design flow, making it a true design diagnostic tool that enables developers to improve productivity, shorten design cycle time and speed products to market.



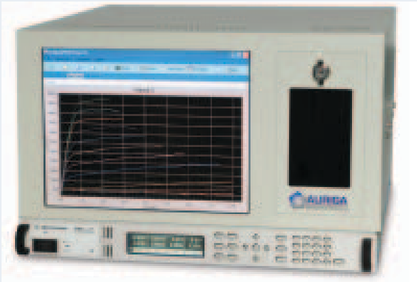
Applied Wave Research Inc.,
El Segundo, CA (310) 726-3000,
www.appwave.com.
Booth 912 **RS 222**

Solid-state Amplifiers

These broadband amplifiers operate in a frequency range from 4 to 8 GHz and include models available in 15, 35, 60, 90 and 120 W. This amplifier family is suitable for wireless test applications and EMC testing for automotive requirements, and also the new IEC 61000-4-3 standard.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181,
www.ar-worldwide.com.
Booth 518 **RS 223**

Pulsed IV/RF Instrument



The new AU4550 Pulsed IV/RF Instrument provides unequalled test accuracy, compact design, and inexpensive options and modular hardware that allow easy, inexpensive upgrading. Pulsed heads set closer to the device-under-test and narrow range pulse heads improve accuracy while a synthetic instrument core eliminates hardware redundancies, reducing the footprint by half, even when fully optioned. The AU4550's interchangeable pulser heads and LXI-compliancy allow adaptability to scale pulsed IV to pulsed IV/RF while meeting changing industry standards.

Auriga Measurement Systems LLC,
Lowell, MA (978) 441-1117,
www.auriga-ms.com.
Booth 1006 **RS 224**

NEW WAVES

Next Generation Amplifiers

The BZ series of next generation amplifiers offers wide bandwidth and low noise figures. The amplifiers fit into one standard housing (as shown). Within the 30 kHz to 70 GHz range, customized power, gain and noise figure combinations are available. With noise temperature of 10 K at cryogenic temperatures, excellent group delay, military specifications and high dynamic range, these RoHS-compliant units may be optimized to achieve up to +30 dBm output power.

B&Z Technologies,
Stony Brook, NY (631) 331-0101,
www.bnztech.com.
Booth 844 **RS 225**

UHF RFID Tag

ECCOPAD® MetalTag is a true read on metal UHF RFID tag, is EPC Gen 2 compatible, and has outstanding read range of 8' (2.5 meters) or more when used directly with metal and liquids. This new product is attractively priced starting at $2.00/MetalTag for evaluation quantities, with quantity discounts available, making it a cost-effective solution for high value asset tracking in today's RFID market. The new small size of the MetalTag (2.5" × 0.625"), a tag and isolator all in one, eliminates the need for larger labels especially for tagging small objects. MetalTag is perfect for small asset tracking applications like laptop computers, tools and electronic components.

Emerson & Cuming Microwave Products,
Randolph, MA (781) 961-9600,
www.eccosorb.com.
Booth 920 **RS 232**

Amplifier Test Equipment

CAP Wireless introduces its broadband rackmount and benchtop microwave power amplifier test equipment. Leveraging its Spatium™ amplifier series with CAPLINE™ technology, these solid-state test and measurement products offer a simultaneous combination of bandwidth and power previously unattainable with traditional solid-state or traveling wave tube technology. Several models offer instantaneous frequency coverage from 2 to 20 GHz, with power levels, depending upon bandwidth, to 150 W. Configured for 1 mW drive level, and available with several options, these amplifiers provide test engineers with additional flexibility for EMI/EMC evaluation, signal distribution, component characterization, antenna range and anechoic chamber instrumentation, as well as laboratory use where signal generator power is insufficient.

CAP Wireless,
Newbury Park, CA (805) 499-1818,
www.capwireless.com.
Booth 202 **RS 226**

Calibration Software

The 16-term calibration technique is an important capability that has been recently added to the WinCal XE calibration software to help semiconductor labs reduce design cycles and time to market. Using WinCal XE for on-wafer measurement helps semiconductor manufacturers create more accurate high frequency RF device models. With the explosion of wireless devices, semiconductor companies are under pressure to get high speed products to market faster than ever before. The 16-term calibration eliminates certain undesired measurement parasitic effects, thus enabling more accurate device models and shorter design cycle times.

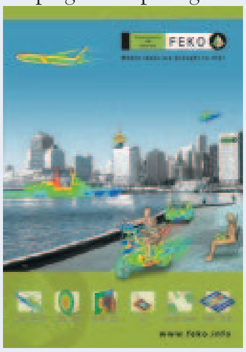
Cascade Microtech Inc.,
Beaverton, OR (503) 601-1000,
www.cmicro.com.
Booth 908/930 **RS 227**

Spiral Antenna

This spiral antenna series operates in a frequency range from 0.5 to 40 GHz, exhibits an excellent impedance match and radiation pattern control over a broad operating band in a compact, lightweight package, designed to operate in harsh environments. Available in RHCP and LHCP.

Chengdu AINFO Inc.,
+86-28-8816-3497, www.ainfoinc.com.
Booth 1010 **RS 228**

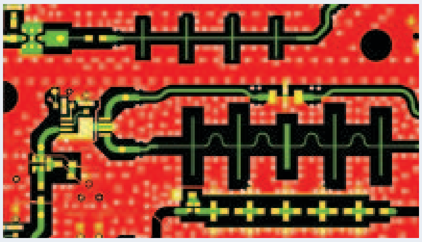
EM Software



EM Software and Systems GmbH distributes the programme package FEKO (www.feko.info), a leading CEM code. FEKO is applied to antenna design (3D and planar antennas), antenna placement on large structures, EMC analysis (including cable harness), SAR computation, RCS analysis and other applications. Consultation, studies and projects for the areas electromagnetic compatibility, antennas as well as general application of computational electromagnetics are provided. Special extensions to numerical electromagnetics software according to customer requirements can be developed.

EM Software & Systems GmbH,
Böblingen, Germany
+49 (0)7031 714 5200, www.emss.de.
Booth 405 **RS 233**

CAD Layout Software



HYDE 12.1 is a CAD layout software that supports the editing of simulated RF structures in the context of the complete RF layout. HYDE can also easily combine any number of microstrip components to one embedded part and place it within the substrate. Through this high flexibility, HYDE supports several technologies like PWB, LTCC, hybrid thick/thin film and PCB.

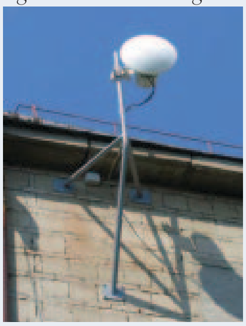
Durst CAD/Consulting GmbH,
Holzgerlingen, Germany +49-7031-7472-0,
www.durst.de.
Booth 313 **RS 229**

SMA-Q Adapter

This SMA-Q adapter offers a quick and safe connection in push-and-pull technology. The SMA-Q adapter range provides a time-saving adapter for standard SMA connectors. Its special feature is the push-and-pull mechanism that enables a tool-free connection with the measuring device. SMA-Q adapter and SMA connectors are connected by means of a thread. SMA-Q adapters are fully compatible with SMA connectors (MIL-STD 348) and are mainly used for test and measurement purposes requiring a higher packing density. The SMA-Q adapter is made of stainless steel and guaranteed for 500 connecting cycles.

elspec GmbH,
Geretsried, Germany
+49 (0) 8171-4357-0, www.elspec.de.
Booth 613 **RS 230**

Gigabit Ethernet Radio Links



The gigabit ElvaLink radio bridge was designed for a wide range of applications such as mobile backhaul, business network, FSO backup, IP network and emergency recovery network. The operating frequencies cover 71 to 76 GHz, 81 to 86 GHz and 92 to 95 GHz. These are FCC licensed bands recently released by the FCC for commercial use in wireless point-to-point communications. ElvaLink PPC-1000 is a full-duplex gigabit point-to-point link especially designed according to FCC requirements. It provides interconnection between remote LAN segments at ultra high speed and utilizes Gigabit Ethernet protocols, which is the evolving standard for switches and routers available from a variety of telecommunication equipment manufacturers.

ELVA-1,
Riga, Latvia +371-7-065100,
www.elva-1.com.
Booth 826 **RS 231**

NEW WAVES

ALC Log Amplifiers

These ALC Log Amplifiers™ are designed for use in early warning radar receiver, threat detection equipment, electronic countermeasures and missile guidance systems. A logarithmic amplifier (or "log amplifier," for short) is a specialty amplifier subsystem that is primarily used as an amplitude detector of input signal strength on the front-end of pulsed radar and other wideband electronic warfare systems. As a log amplifier provides an output voltage proportional to the logarithm of its input voltage (which is mathematically equivalent to the input power in dBm), the amplitude information is converted to a more usable format than other linear detection schemes. In pulse radars, log amplifiers allow the system to process signals with narrow pulse widths and large amplitude variations by effectively compressing a large input dynamic range into smaller, more manageable blocks.

Endwave Corp., San Jose, CA (408) 522-3100, www.endwave.com.
Booth 709/711 **RS 234**

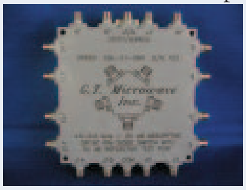
High Linearity Broadband MMIC Amplifier

The model FMA3025SOT89E is a high linearity broadband MMIC amplifier that operates in a frequency range from 250 to 4000 MHz. The FMA3025SOT89E provides a best-in-class combination of noise figure and linearity when compared to alternative competing solutions. Fabricated using high reliability GaAs PHEMT technology this new broadband MMIC is ideally suited for applications where high linearity is required. Features include: high dynamic range, lead-free industry standard SOT-89 package, RoHS-compliant, single 5 V supply, 14 dB gain at 0.9 GHz and 24 dBm P1dB output power at 5 V.

Filtronic Compound Semiconductors, Newton Aycliffe, County Durham, UK +44 1325 30 306880, www.filtronic.com.
Booth 820 **RS 235**

PIN Diode Reflective Switch

The model S9L-51-0BX is a 3 W CW SP17T PIN diode switch that operates from 4.5 to 5 GHz. It has 30 dB of isolation with 3 dB insertion loss and a 1.5:1 VSWR. The device is controlled via 5 bits of TTL compatible logic with a switching speed of 1.0 µsec. The unit requires a power supply of +5/–12 VDC at +500/–200 mA of current. The package measures 3.5" × 3.5" × 0.88".



G.T. Microwave Inc., Randolph, NJ (973) 361-5700, www.gtmicrowave.com.
Booth 826 **RS 236**

Microwave Horn Antennas

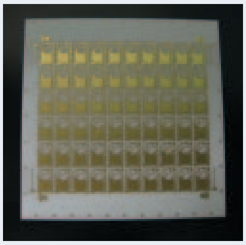
This comprehensive range of standard 20 dB gain microwave horn antennas can be specified in waveguide sizes from WR-650 to WR-28, covering the frequency range from 1.2 to 40 GHz. Available in a choice of aluminium, copper or brass, the horn antennas have a proven track record in demanding military applications and can be supplied with an extensive choice of waveguide-to-coaxial adapters. As well as the standard range of horns, Link offers a custom design service that enables it to accommodate individual requirements for input type and parameters such as gain, beamwidth and frequency coverage.

Link Microtek Ltd., Basingstoke, Hampshire +44 (0)1256 355771, www.linkmicrotek.com.
Booth 404 **RS 242**

New Waves

Foundry Service

Recent mobile phones and wireless communication demand for multi-band, higher frequencies and multi-mode, such as with BT, WLAN, DTV, GPS, etc. have presented new challenges.

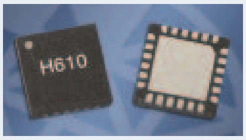


HIRAI SK Corp. provides the foundry service with high Q, high precision and space, and cost-effective multi-layered LTCC substrates. HIRAI ships samples in a week and provides the design support of embedded passive components and test services up to 67 GHz.

HIRAI SK Corp.,
Tokyo, Japan +81-584892394,
www.hirai.co.jp.
Booth 703 **RS 237**

RMS Power Detector

The HMC610LP4E is an RMS power detector that features best-in-class ±1 dB dynamic range in excess of 70 dB at 900 MHz and is ideally suited for the measurement of complex modulated waveforms with large crest factors.



At 2.7 and 3.5 GHz, the HMC610LP4E delivers ±1 dB dynamic ranges of 63 and 46 dB, respectively, with excellent stability of ±0.5 dB error over its –40° to +85°C operating temperature range. The SiGe BiCMOS HMC610LP4E is housed in a 4 × 4 mm QFN package.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.
Booth 938 **RS 238**

Laser-based PCB

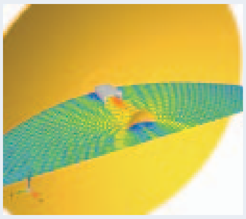
With the LPKF ProtoLaser 200, precise microwave and RF circuits can be manufactured to exact requirements on almost all substrates, ranging from FR-4 to PTFE.

Direct laser structuring is accomplished in just minutes, and without requiring hazardous chemicals. For in-house production of complex prototypes and small series production, LPKF offers the ProtoMat S100. The LPKF ProtoMat S100 is qualified for surface-sensitive and soft and flexible substrates.

LPKF Laser & Electronics AG,
Garbsen, Germany
+49 (0)5131-7095-324, www.lpkf.de.
Booth 836 **RS 243**

EM Field Solver

The new Empire XCcel™ 5.1 3D EM field solver is now supporting full 32 and 64 bit calculations on Windows XP, Vista and Linux operating systems.

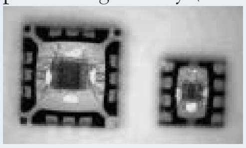


A further speed improvement of up to 900 MCell/s has been obtained by smartly exploiting multi-core processor technology. New features, like healing of imported 3D data, improved GUI speed for complex structures and even more efficient memory management, will be presented by IMST engineers at this year's event.

IMST GmbH,
Kamp-Lintfort, Germany
+49 2842 981 0, www.empire.de.
Booth 207 **RS 239**

Power Amplifier Design Library

The SiGe SBC18 RF power process power amplifier design library (PADL) facilitates power amplifier design.

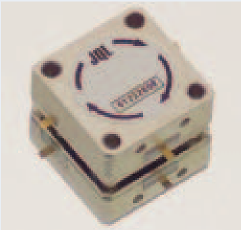


A selection of 10 devices is available with varying compression points (P1dB = 20 to 34 dBm) targeted towards mobile communication and wireless broadband applications. The power cells are modeled and "pre characterized" with multiple modulation formats addressing numerous air interfaces such as WCDMA, CDMA and WiFi 802.11 a/b/g. Excellent linearity vs. efficiency tradeoff can be achieved with margin at nominal bias.

Jazz Semiconductor,
Newport Beach, CA (949) 435-8000,
www.jazzsemi.com.
Booth 924 **RS 240**

Drop-in Circulators

This series of drop-in circulators is designed for 3.5 and 4.9 GHz WiMAX.



These new drop-in circulators measure only 1/2" × 1/2" in size, but cover wide bandwidths of 3.1 to 3.5 GHz, 3.3 to 3.8 GHz and 4.7 to 5.2 GHz, respectively. Typical insertion loss is only 0.35 dB, while isolation and return loss are typically 20 dB.

JQL Electronics,
Buffalo Grove, IL (630) 930-9917,
www.jqlelectronics.com.
Booth 121 **RS 241**

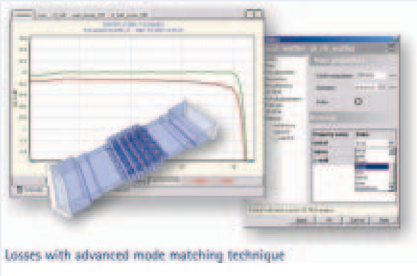
7/16 DIN Loads

This family of 1, 2, 5, 10, 35, 50 and 100 W 7/16 DIN-Male coaxial loads are designed for next generation equipment deployments.

Their rugged construction and excellent performance (VSWR of 1.10) across all wireless bands from DC to 6 GHz makes them ideal for base station and RF/microwave lab applications. Made in the USA—36 month warranty. These coaxial loads are available from stock.

MECA Electronics,
Denville, NJ (973) 625-0661,
www.e-meca.com.
Booth 100/102 **RS 244**

EM-software Tool

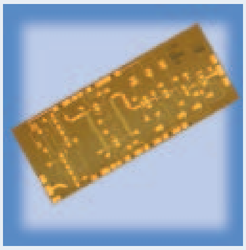


Version 6.5 of the company's EM-software tool µWave Wizard™ offers a GUI with an improved modern and more user friendly design. A key new feature is a fast frequency sweep based on adaptive rational function interpolation. This technique enables 'smooth' S-parameter plots to be obtained over a broad frequency range with only a few samples being calculated. Another new feature of version 6.5 is the inclusion of finite wall conductivity losses directly into the mode matching method and its derivatives (BCMM), as well as in the 2D FEM method. Furthermore, full 3D visualization of electromagnetic fields and a series of new, flexible elements comprising various types of dielectric resonators have been included.

Mician GmbH,
Bremen, Germany
+49 (421) 16899351, www.mician.com.
Booth 300 **RS 245**

GaAs MMIC Transmitter

The model XU1004-BD is a gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) transmitter that delivers +14 dBm OIP3 and 5 dB conversion gain with +4 dBm LO drive level.



Using 0.15 micron gate length GaAs pseudomorphic high electron mobility transistor (PHEMT) device model technology, the transmitter covers the 32 to 45 GHz frequency bands and includes a balanced resistive mixer followed by a distributed amplifier, an LO doubler and an LO buffer amplifier. This device is well suited for point-to-point radio, LMDS, SATCOM or VSAT applications.

Mimix Broadband Inc.,
Houston, TX (281) 988-4600,
www.mimixbroadband.com.
Booth 1004 **RS 247**

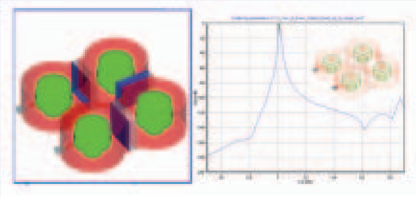
8 to 18 GHz High Power Amplifier

The model AMF-2B-08001800-80-40P is a connectorized high power amplifier, covering octave bandwidths from 8 to 18 GHz and delivering approximately 3 W of power and 2.5 W from 6 to 18 GHz. In the band of 10 to 15 GHz, it

delivers about 7 W of P1dB. The SMA connectorized aluminum housing is 21 × 95 × 60 mm. It is intended for bolting to a flat cooling surface or fins. Housing is environmentally sealed, EMI shielded and a hermetic sealing option is also available. PA includes reverse voltage protection, in addition to full internal regulation. A TTL-control pin is optional.

MITEQ Inc.,
Hauppauge, NY (631) 436-7400,
www.miteq.com.
Booth 204 **RS 248**

Fast EM CAD and Optimization Tool

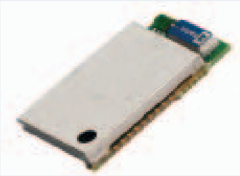


WASP-NET® ends the quest for a new quality of EM CAD and optimization speed. WASP-NET's pioneering hybrid MM/FE/MoM/FD CAD engine uniquely combines the efficiency and flexibility advantages of four solvers in one single tool. Advanced features include: fast optimization of all types of waveguide components and aperture antennas; full-wave direct synthesis of combline, cross-coupled waveguide and LTCC filters; dielectric loaded horns, shaped subreflectors; large slot arrays; multiprocessor and advanced 64-bit options; and increased speed for designing 3D components, for example, tunable dielectric resonator filters.

Microwave Innovation Group (MiG) GmbH & Co. KG,
Bremen, Germany +49-421-223-79660,
www.mig-germany.com.
Booth 411 **RS 246**

ZigBee Solution

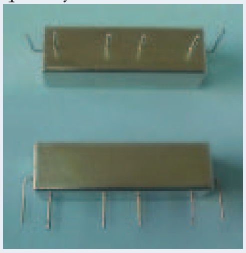
µTiny, a miniature ZigBee module based on the Texas instruments CC2430 SoC, is an ideal low cost ZigBee solution for building automation and wireless sensor networks (WSN). The new miniature ZigBee module will be available in Q3 2007. A ZigBee Certified Platform (ZCP) based on the company's current generation TinyOne ZigBee module, including an in-house ZigBee 2006 stack, is already available for purchase. Being a small-sized SMD component, µTiny occupies only 25 × 15 mm of space and it is about 3 mm high. It has 2 mW output power, –94 dBm sensitivity and it consumes less than 2 µA on stand-by. Soon available with or without an integrated antenna, µTiny offers engineers the optimum choice for low cost ZigBee integration into battery operated applications.



One RF Technology GmbH,
Villach, Austria +43 4242 21234,
www.one-rf.com.
Booth 614 **RS 249**

Crystal Notch Filter

The F9183 is part of OPT's family of high frequency fundamental mode crystal filters. These include both bandpass and notch type filters. Typical product frequencies are above 100 MHz. The packaging is custom and per customer's requirements. Features include high reliability, superior power handling performance compared to overtone crystal filters. Typical applications include tactical radio systems, telecommunications filtering for commercial and defense systems.



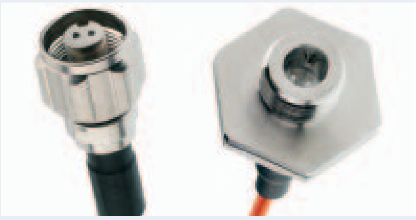
OPT Hellas SA,
Athens, Greece +30-210-602-5072,
www.opthellas.com.
Booth 320 **RS 250**

Integrated Product Solutions

In addition to a full line of coaxial RF connectors and cable assemblies, Phoenix of Chicago offers unique, custom engineered integrated product solutions. By integrating multiple components such as: resistors, filters, switches and bias tees into convenient connectorized packages, system reliability can be improved in a smaller footprint. One of these products is the ruggedized antenna. Starting with a COTS or proprietary antenna, Phoenix will upgrade it to an antenna suitable for the military and use in harsh environments. This is accomplished by a patented transition between the antenna element and the connector, which compensates for different coefficients of thermal expansion. This is added to both internal and external gaskets, resulting in an antenna that meets IP67 and immersion per MIL-STD-810.

The Phoenix Company of Chicago,
Wood Dale, IL +44 (0) 1582 460032,
www.phoenixofchicago.com.
Booth 321/420 **RS 251**

Outdoor Connector



The OutDoor connector (ODC series) is a new Fiber-To-The-Antenna (FTTA) concept. This innovative solution is a fiber optic connection with two or four channels for antenna up and down links between the Remote Radio Unit (RRU) and the Main Unit of the "BTS." In new communication networks (3G and higher generation networks), these multi-mode and single-mode transmission lines allow data to travel at the speed of light with practically no loss. The fast and easy ODC screw-on locking system can withstand harsh environmental conditions and features complete EMI immunity. The ODC series is the ultimate solution for ultra low loss fiber optic links into UMTS networks, WiMAX, W-CDMA, TD-SCDMA, CDMA2000, LTE and many other applications.

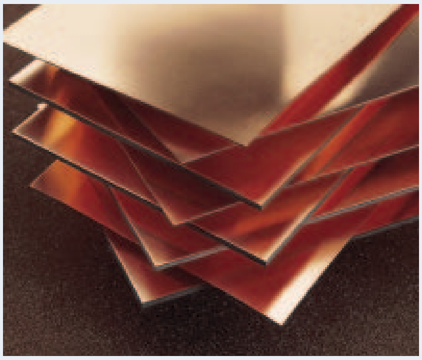
Radiall,
Rosny Sous Bois, France
+33 1 49 35 35 35, www.radiall.com.
Booth 1022 **RS 252**

Ceramic Filters

RFM offers a broad line of high quality, low cost, small size bandpass filters, duplexers and multi-duplexers. The company's rigid process control and thorough quality control system ensure perfect performance and reliability. Applications include (400 MHz to 3.8 GHz): AMPS, PCS, GSM, DCS, WLL, DCS, Wi-Fi and WiMAX applications and UMTS/DMB.

RF Morecom Corea,
Gyeunggi-Do, Korea +82-31-455-3823,
www.rfmorecom.com.
Booth 213 **RS 253**

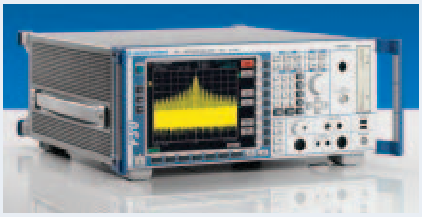
Antenna Grade Laminates



The RO4500™ antenna grade line of materials extend the capabilities of the RO4000® product series. These RO4500 laminates provide controlled dielectric constant, low loss and excellent passive intermodulation response (PIM), all critical to the wireless infrastructure market. RO4500 substrates are compatible with conventional FR-4 and high temperature lead-free solder processing. Unlike traditional PTFE solutions, they do not require special treatment for plated through-hole preparation, offering design engineers an affordable alternative.

Rogers Corp.,
Rogers, CT (860) 774-9605,
www.rogerscorporation.com.
Booth 510/512 **RS 254**

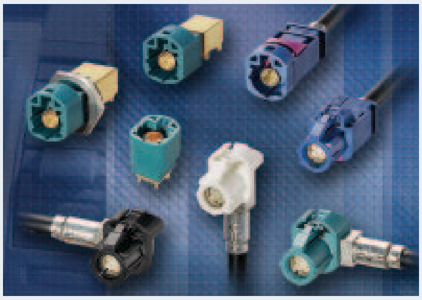
20 Hz to 67 GHz Spectrum Analyzer



NEW WAVES

The R&S FSU67 spectrum analyzer extends the upper frequency limit in spectrum analysis from 50 GHz to 67 GHz, making external waveguide mixers superfluous. In addition, the continuous frequency range starting at 20 Hz simplifies harmonics measurements, for example, since the test set-up does not have to be reconfigured. Developers and manufacturers of microwave components, oscillators and communications equipment thus profit from high measurement accuracy and excellent RF performance due to clear signal display.
Rohde & Schwarz GmbH & Co. KG,
Munich, Germany +49 1805 12 4242,
www.rohde-schwarz.com.
Booth 900/918 **RS 255**

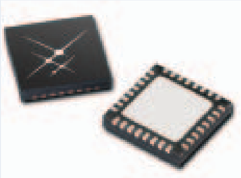
Interconnect System



The new RosenbergerHSD® interconnect system has been developed for HighSpeedData transmission in excellent quality. Rosenberger-HSD is a symmetrical, impedance controlled 100 Ω interconnect system for transmitting data streams at high bit rates. The high performance digital system prevents interference through crosstalk and external sources. Performance is achieved by using an optimized shielding concept with complete braid connection to the outer contact of the connector. The interconnect system enables applications up to 1.6 Gbit/sec. – 800 Mbit/sec. on two differential pairs each at 10 m length.
Rosenberger Hochfrequenztechnik
GmbH & Co. KG,
Fridolfing, Germany
+49 08684 18-263, www.rosenberger.de.
Booth 832 **RS 256**

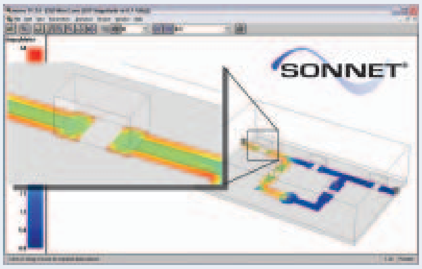
Low Pass Butterworth Filter

The SKY73201-364 is a high performance, programmable, monolithic, clock-referenced low pass filter. It is configured as a sixth-order Butterworth to provide extremely high stopband isolation while maximizing passband flatness and minimizing group delay distortion. The SKY73201-364 is programmable in 1 MHz steps, from 1 to 28 MHz, via the three-wire Serial Port Interface (SPI). Nearly ideal Butterworth performance is maintained over process variations via a proprietary internal calibration circuit, which derives its timing accuracy from a 20 or 40 MHz reference clock. Skyworks offers lead (Pb)-free, RoHS-compliant QFN 32L 5 × 5 mm packaging.



Skyworks Solutions Inc.,
Woburn, MA (781) 376-3000,
www.skyworksinc.com.
Booth 121/321 **RS 257**

High Frequency EM Simulation Software



The newly released Sonnet® Suites Release 11 offers perfectly calibrated internal ports that can be used for highly accurate attachment points for active or passive components. These Co-calibrated™ Ports enable full co-simulation within the EM analysis environment. Release 11 also includes a totally redesigned Agilent ADS Interface with a new GUI interface and a new 64-bit EM analysis engine.
Sonnet Software,
North Syracuse, NY (315) 453-3096,
www.sonnetsoftware.com.
Booth 507 **RS 258**

Push-pull Connectors and Adapters

Spectrum's current most innovative designs are the push-pull connectors and adapters. They mate with standard female connectors of type N and in the near future push-pulls for TNC and 7/16 will follow. The function of the push-pull is easy: It slides onto the mating standard female and locks automatically (push-on). Releasing is simple as well (just pull off). No special instructions have to be followed and no special handling is needed. The new push-pull series add on perfectly to Spectrum's push-on family.

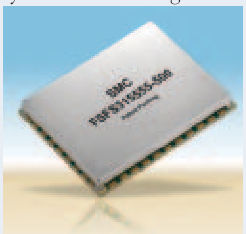
Spectrum Elektrotechnik GmbH,
Munich, Germany +49-89-3548-040,
www.spectrum-et.com.
Booth 1014 **RS 259**

SMP Coaxial Connectors

This line of SMP connectors conform to DSCC 94007, 94008 and MIL-STD-348 specifications. SMP connectors provide microwave performance through 40 GHz and offer 0.170 inch center-to-center spacing for high density, push-on mating to join two RF modules. A typical mating configuration includes two shrouds joined by a bullet adapter. Shrouds with a full detent retain the bullet when modules are separated. The smooth bore (or limited detent) permits the shroud to separate from the bullet for consistent mating alignment.
SV Microwave Inc.,
West Palm Beach, FL (561) 840-1800,
www.svmicrowave.com.
Booth 514 **RS 260**

Fast Settling Synthesizers

The FSFS series of surface-mount, fast settling synthesizers is designed for frequency hopping and jamming applications. The FSFS315555-500 is the first model released in the series providing under 50 µsec of settling time when commanded for start/stop and stop/start frequency jumps. The synthesizer tunes in 5 MHz steps within the tuning band of 3150 to 5550 MHz, having spurious rejection of 75 dBc typical. The phase noise is –80 dBc/Hz up to 100 kHz and –100 dBc/Hz at 1 MHz offset from the carrier. This synthesizer requires +5 and +15 V DC for operation and is packaged in a small surface-mount RoHS compliant package, measuring 1.25" × 1" × 0.3".

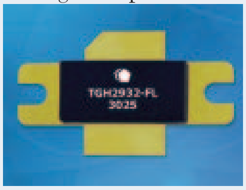


Synergy Microwave Corp.,
Paterson, NJ (973) 881-8800,
www.synergymwave.com.
Booth 103 **RS 261**

NEW WAVES

HV HBT Amplifiers

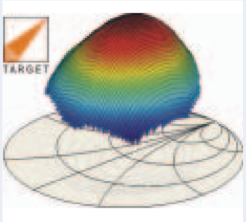
TriQuint Semiconductor has set a new efficiency standard for base station signal amplification with a family of HV HBT amplifiers. The first product, TGH2932-FL, has a collector efficiency of 34 percent and is designed as a 140 W peak power device optimized for the 2140 MHz WCDMA band. TGH2932-FL delivers 25 W of WCDMA average power with 14.5 dB gain. This is the first of a family that will include devices for all major cellular bands at a variety of power levels.



TriQuint Semiconductor Inc., Hillsboro, OR (503) 615-9000, www.triquint.com.
Booth 400/402 **RS 269**

Microwave Power Amplifier Research

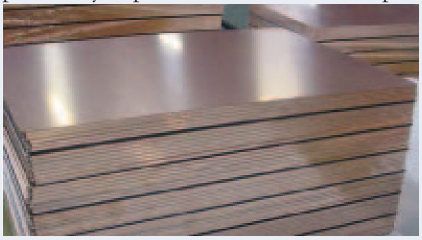
The TARGET Network of Excellence is active in the fields of microwave power amplifier research. TARGET comprises the best researchers in Europe, coming from 49 academic and industry partners. It offers high level trainings and courses in the fields of RF semiconductor materials and devices, RF device characterization, RF device modeling, MW power amplifier design, linearization techniques and TX modeling. TARGET is also a unique point of contact to all those partners for measurements and characterization services.



TARGET, Vienna, Austria +43 (0) 1 50528 30-0, www.target-net.org.
Booth 828 **RS 263**

Base Materials

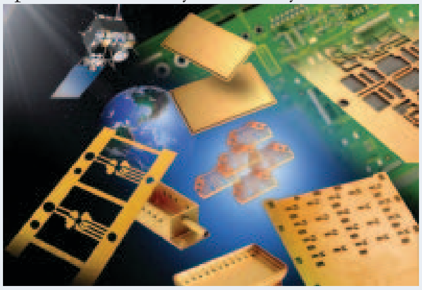
A seamless dielectric-to-metal interface ensures superior RF grounding, particularly important beneath the low impedance drain traces needed to match today's LDMOS transistors for optimum output power. Copper-plate backing offers best thermal dissipation for recessed power-transistors. Taconic has over 12-years manufacturing experience of heavy metal-plate backed PTFE/glass laminates and has become the world's leader for volume work. Copper, brass and aluminum are available in thicknesses of 0.7 mm and above, and are bonded directly to the dielectric substrate. RoHS-compliant.



Taconic Advanced Dielectric Division, Mullingar, Co. Westmeath, Ireland +353 44 93 95600, www.taconic-add.com.
Booth 824 **RS 262**

Gold-based Surface Finish

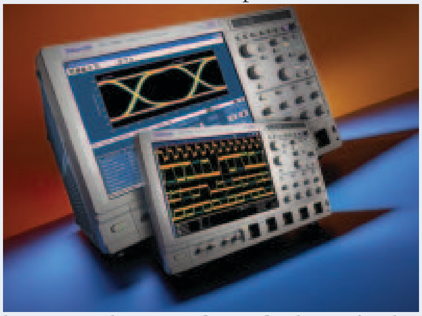
TECfin Connect is a new range of gold-based finishes designed to provide optimum durability, reliability and/or solderability dependent on the application. The finishes have been exclusively developed by Tecan to change surface properties for specific electronics applications from consumer electronics products to aerospace, medical and military needs. Four corrosion resistant finish options are offered allowing the most appropriate to be selected to ensure the best possible performance characteristics for application-specific needs. These include properties such as conductivity, connection, solderability and contact resistance.



Tecan Ltd., Dorset, UK +44 (0) 1305 765432, www.tecan.co.uk.
Booth 119 **RS 264**

Ultra-wideband Software

This Ultra-wideband Software (Tektronix UWB) is designed for DPO/DSA70000 oscilloscopes. Tektronix UWB extends the debug and analysis capabilities of the industry's highest performance real time oscilloscopes that operate up to 20 GHz bandwidth, 200M memory, and 50 GS/s on all four channels, to include real-time analysis of ultra-wideband RF and electrical signals. Tektronix UWB running on these oscilloscopes is the most advanced solution for the test and measurement of digital RF applications such as ultra-wideband communications and ultra-wideband radar and also for high speed serial data.



Tektronix Inc., Beaverton, OR (503) 627-6460, www.tektronix.com.
Booth 904 **RS 265**

Radiating Cable Antennas

This new line of M/A-COM radiating cable antennas is designed to replace conventional antennas in applications that require wide frequency bandwidths (100 to 6000 MHz) and deployment in physical spaces that present extreme challenges to traditional antenna solutions. The M/A-COM radiating cable antenna series is ideal for cellular, Bluetooth and WLAN frequency band installations, as well as airborne, vehicular and ground-based applications.

NEW WAVES

Tyco Electronics M/A-COM,
Milton Keynes, UK +44 1908 574200, www.macom.com.
Booth 519 **RS 270**

Waveform Software Package

RFXpress™ is an advanced new software package that performs RF/IF/IQ waveform creation and editing of digitally modulated signals for AWG5000 and AWG7000 arbitrary waveform generators. RFXpress provides a user interface that makes creation and management of general-purpose digital RF waveforms far more intuitive. It also provides specialized UWB-WiMedia plug-ins and a library of waveforms for thoroughly testing new designs. With RFXpress software, the AWG5000 and AWG-7000 are the easiest to use, most powerful and comprehensive IF/RF and I/Q signal generators – transforming the testing of emerging digital RF applications including UWB-WiMedia.

Tektronix Inc.,
Beaverton, OR (800) 833-9200, www.tektronix.com.
Booth 904 **RS 266**

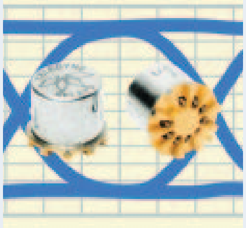
X-band Pulse Transmitter

The model NSX-880 is a pulse transmitter of a modern design and may be used in various types of X-band radars that include: airborne radars, airport surface monitoring radars, battlefield radars and sea surface surveillance radars. The transmitter is provided with BITE and control unit. The NSX-880 transmitter has modular architecture to ensure maximum reliability and to facilitate servicing. Mechanical construction of the unit enables users easy servicing upgrading of the system. The NSX-880 transmitter is equipped with effective forced air-cooling system. High TWT efficiency and high electrical efficiency of the power supply requires minimum cooling and provides high reliability over a wide temperature range.

PIT Telecommunications
Research Institute (PIT),
Warsaw, Poland +48 22 4865 325, www.pit.edu.pl.
Booth 215 **RS 267**

Electromechanical Relays

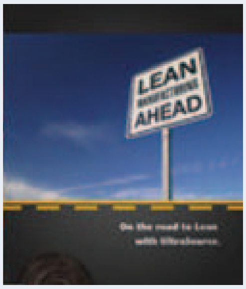
Teledyne Relays announced that improvements to its Series GRF300 and GRF303 high repeatability, broadband TO-5 electromechanical relays now deliver 10 Gbps data rates for digital signal integrity applications. The relays are designed to provide a practical surface-mount solution with improved RF signal repeatability over the frequency range. Improved ground connections provide the 10 Gbps data rates. Compared with competitive relays used in test and measurement equipment, the GRF300 and GRF303 deliver better performance at a lower cost.



Teledyne Relays,
Quickborn, Germany +49 (0) 4106 7684-0,
www.teledyne-europe.com.
Booth 1012 **RS 268**

Lean Manufacturing

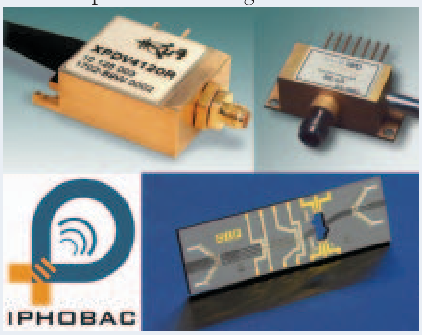
This brochure details the company's road to Lean Manufacturing. Anyone with an interest in Lean Manufacturing principles, and the challenges and rewards in implementing them, will find this informative four-page brochure a handy reference. In it, UltraSource reviews the personal journey towards Lean and outlines some key achievements along the way, including a 475 percent increase in a critical productivity metric. Readers will also learn how documented operational procedures are leveling workloads and visual communication boards and "Kaizen" meetings are revolutionizing the operational culture of the facility. A list of valuable reference books on Lean and TPS (Toyota Production System) is also provided.



UltraSource Inc.,
Hollis, NH (603) 881-7799, www.ultrasource.com.
Booth 219 **RS 271**

Components and Subsystems

The European IST project IPHOBAC is developing pre-commercial photonic components and integrated functional subsystems for millimetre-wave applications. Among the different components developed in IPHOBAC are broadband 110 GHz photodiodes (coaxial w1-package), high output power photodiodes (> mW at 100 GHz), 30 to 300 GHz photomixers, 110 GHz EA modulators and tunable millimetre-wave lasers (DFB, DBR). The pro-



ject recently developed a compact photonic synthesizer allowing tuneable millimetre-wave generation from DC to 110 GHz with output power levels in the mW range.
University of Duisburg-Essen, Duisburg, Germany +49 203 379-2825, www.ist-iphobac.org/iphobac/contact/index.asp.
Booth 520 **RS 272**

Foundry Services

These dedicated foundry services are advanced 6" HBT and HEMT MMIC technologies that support RF applications from 100 MHz up to 100 GHz. The company's current customers cover various applications including mobile communications, satellite and auto radar.
WIN Semiconductors Corp., Tao Yuan Shien, Taiwan 886-3-397-5999, www.winfoundry.com.
Booth 406 **RS 273**

Fractional-N Synthesizer

The PSA1450F-LF is a wideband (1050 to 1850 MHz) Fractional-N synthesizer that achieves spurious levels as low as –80 dBc in a small surface-mount package (0.866" × 0.630"). The PSA1450F-LF has a fine resolution of 8 kHz with a PDF of 32 MHz and operates at Vcc 5/15 V, Icc 25/40 mA with an output power of +8 dBm ±2 dB. The PSA1450F-LF also provides excellent phase noise of –100 dBc/Hz at 10 kHz offset and has a fast switching speed of < 6 µs for a 40 MHz frequency hop.

Z-Communications Inc., San Diego, CA (858) 621-2700, www.zcomm.com.
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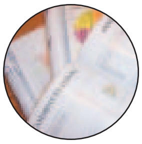

NEW LITERATURE

TECHNICAL SOLUTIONS BROCHURE

This 20-page, full-color technical brochure provides an overview of LTE and demonstrates how Agilent solutions can help you introduce quality LTE 3GPP devices and products. Topics covered include an overview of the technology, a discussion of the physical layer as well as in-depth information on designing LTE systems and circuits, generating LTE signals and performing LTE signal analysis. Several detailed technical diagrams help to further explain this technology.

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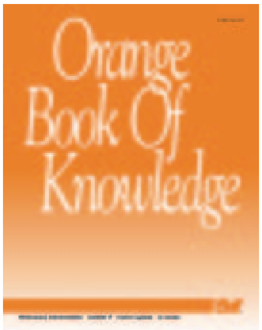

The AR Orange Book of Knowledge contains articles and application notes on a wide range of topics and applications, from the importance of mismatch capability to testing beyond specs and everything in between. The book represents the cumulative knowledge of all AR companies, making it perhaps the most comprehensive resource in the industry.

AR,
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www.ar-worldwide.com.

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SHORT FORM CATALOG

The 2007 short form catalog highlights the company's latest products and product upgrades in 2007. EM Research designs and manufactures high performance frequency sources for hi-rel and military applications. The company specializes in surface-mount and modular phase-locked oscillators and synthesizers from 4 MHz to 18 GHz.

EM Research Inc.,
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www.emresearch.com.

RS No. 202

COMPONENTS GUIDE

The 2007 IF/RF Microwave Signal Processing Components Guide is available for free from Mini-Circuits. The 144-page catalog offers the RF/microwave industry's most comprehensive listings of RF, IF and microwave components with essential performance specifications for each product. In addition, the catalog also provides a listing of Mini-Circuits' patents and the product model numbers to which they apply.

Mini-Circuits,
Brooklyn, NY (718) 934-4500,
www.minicircuits.com.

RS No. 203

COMPONENT CD CATALOG

The Spring 2007 full-line CD Components Catalog offers a comprehensive display of standard and custom capabilities. The CD includes thousands of pages of product specifications, outline drawings, test data, manufacturing flow diagrams and a wide assortment of technical application notes. MITEQ designs and manufactures state-of-the-art microwave components. Emphasis is on high performance, custom engineering driven applications.

MITEQ Inc.,
Hauppauge, NY (631) 436-7400,
www.miteq.com.

RS No. 204

CATALOGS, CALCULATORS, INSTRUCTIONAL VIDEOS

The 12th edition of the company's CD-ROM includes several new and updated brochures and catalogs including the newest edition of the LMR® Wireless Products Catalog. The CD-ROM features a menu for navigation within each catalog. Also included are 'how-to' installation videos to assist users of LMR low loss coaxial cable products and two calculators for determining both coaxial cable attenuation and conversion of VSWR-to-return loss.

Times Microwave Systems,
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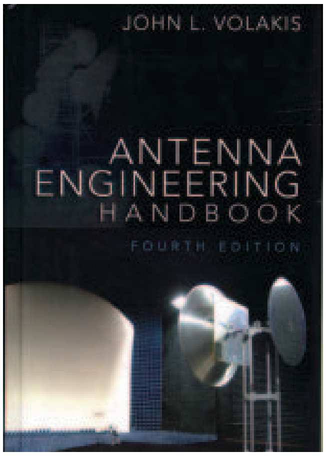
RS No. 205

Antenna Engineering Handbook: Fourth Edition



John L. Volakis, Editor
McGraw-Hill • 1775 pages; $175
ISBN: 978-0-07-147574-7

In this fourth edition of the handbook, the content and chapters have been expanded and updated, taking into account the unprecedented developments over the past 10 to 15 years. Twenty-one new chapters have been added and five chapters have been significantly modified. In fact, 50 percent of the current edition is totally new. The introductory chapters have been completely rewritten with a focus on new applications, such as mobile and cellular technologies. Several new topics, such as smart and adaptive antennas, wideband arrays, low profile antennas, ultra-wideband antennas, millimeter-wave and terahertz antennas, dielectric resonator antennas, wideband patch antennas, fractal antennas and antennas on electromagnetic band gap (EBG) ground plane are well covered in the current edition. New or significantly updated topics include base station antennas, reconfigurable antennas, handset (cellular)/terminal phone antennas, portable TV antennas, biomedical antennas, antennas for miniature sensors (including RFIDs), reflect arrays and radiometer antennas. Topics such as those on transmission lines and matching circuits were authoritatively covered in the previous edition and were only updated. However, some key and sorely missing topics are now well covered by expert authors. These include measurement techniques and facilities, propagation, frequency selective surfaces and volumes and computational methods with a listing on commonly used packages for antenna design and propagation studies. Chapters on MIMO and multipath techniques have been added, as these are important topics in wireless system developments.

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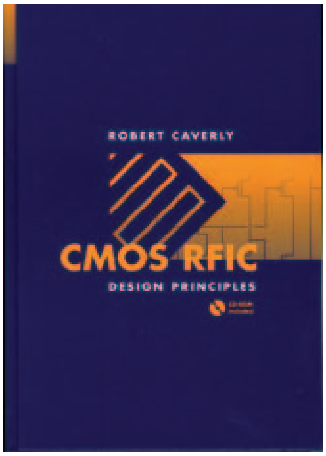
CMOS RFIC Design Principles



Robert Caverly
Artech House • 450 pages; $129, £72
ISBN: 978-1-59693-132-9

The purpose of this book is to address the needs of the RF, wireless and microwave circuit designers, both professional and students, to the design issues associated with CMOS RF integrated circuits. The book is divided into three major sections of roughly three chapters each. The first portion of the book is a review of RF system fundamentals and includes terminology and definitions widely used to describe these circuits. Chapters on CMOS active device and passive element fundamentals are included as a means to introduce the reader to the use of these design equations and their limitations for "first-path" designs. The second portion of the book covers elemental CMOS circuits, such as low noise amplifiers, general gain amplifiers, mixers and oscillators. Ideal circuit topologies are discussed first and then merged with the non-ideal CMOS circuit elements to provide insight into circuit modifications needed to achieve design specifications. Behavioral models for these elements are introduced for future use in later portions of the book. The third portion of the book covers more advanced CMOS RF integrated circuits, such as voltage-controlled oscillators, phase-locked loops, frequency synthesizers and power amplifier architectures. In addition to coverage of the fundamentals, numerous references are made to current literature on these circuits. All three sections of the book include a number of examples to aid in understanding of the principles discussed. Where feasible, simulations are performed (and illustrated) with CAD tools widely used in industry and academia.

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