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AMF-4B-040080-70-30P	4-8	25	1.5	7	30	2:1	1200
AMF-4B-040080-40-35P	4-8	30	1.5	4	35	2:1	2300
AMF-5B-040080-60-30P	4-8	33	1.5	6	30	2:1	1400
AMF-5B-040080-70-33P	4-8	33	2	7	33	2:1	2200
AMF-6B-040080-60-33P-2 AMF-5B-080120-80-30P AMF-6B-080120-70-30P AMF-6B-080120-50-33P	8–12 8–12 8–12	40 24 30 33	2 1.5 1.5 1.5	6 8 7 5 5	33 30 30 33	2:1 2:1 2:1 2:1	2400 1650 1800 2000
AMF-5B-080120-50-35P	8–12	35	2	5	35	2:1	2800
AMF-5B-060130-50-35P	6–13	35	2		35	2:1	2800
AMF-8B-060180-60-30P-2	6–18	31	2.5		30	2:1	2000
AMF-6B-060180-60-33P	6–18	35	2.5	8	33	2.2:1	2800
AMF-8B-080180-60-30P	8–18	31	2	6	30	2:1	2000
AMF-6B-080180-80-33P	8–18	35	2.5	8	33	2:1	2800
AMF-5B-120180-60-28P	12-18	18	2	6	28	2:1	1600
AMF-6B-120180-50-28P	12-18	24	2	5	28	2:1	1700
AMF-8B-120180-60-30P	12-18	33	2	6	30	2:1	2000
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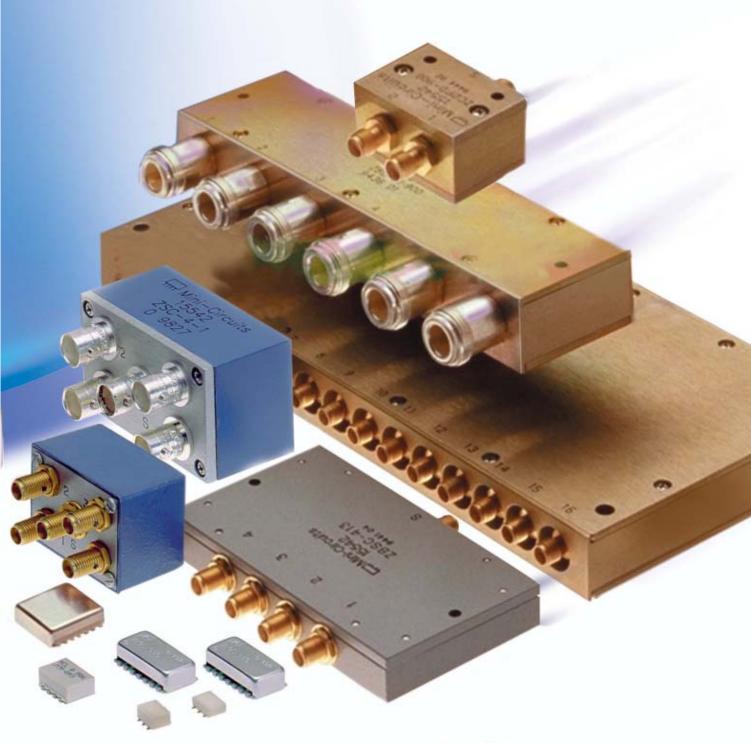
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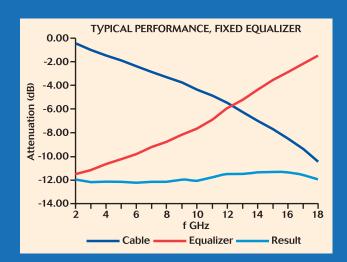


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Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

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PART NUMBER		LENGTH	+/-	WEIGHT	MA	V MUMIX	SWR 1 A	FREQUE	NCY (IN C	Hz.)	MAXIM	UM INSE	RTION LOS	SS IN dB A	T FREQ. (IN GHz.)	NOM	LENGT
		INCHES	LENGTH	OUNCES	UP TO 1	1TO 2	2104	4106	8 TO 12	12 TO 18	UP TO 1	1102	2104	4106	6 TO 12	12 TO 18	DELAY	CM
1-3636-600- 5202	D	2.0	0.05	0.2	1.06	1.10	1.14	1.17	1.20	1.30	0.10	0.13	0.18	0.22	0.31	0.40	0.24	5.1
1-3636-600- 5203	D	3.0	0.05	0.2	1.06	1.10	1.14	1.17	1.20	1.30	0.12	0.16	0.22	0.27	0.38	0.50	0.36	7.6
1-3636-600- 5204	D	4.0	0.05	0.2	1.06	1.10	1.14	1.17	1.20	1.30	0.14	0.18	0.26	0.32	0.46	0.60	0.48	10.2
1-3636-600- 5205	D	5.0	0.10	0.3	1.08	1.10	1.14	1,17	1.20	1.30	0.16	0.21	0.30	0.37	0.53	0.69	0.60	12.7
1-3636-600- 5206	D	6.0	0.10	0.3	1.06	1.10	1.14	1.17	1.20	1.30	0.17	0.24	0.34	0.42	0.61	0.79	0.72	15.2
1-3636-600- 5207		7.0	0.10	0.3	1.08	1.10	1.14	1.17	1.20	1.30	0.19	0.27	0.38	0.47	0.69	0.89	0.84	17.8
1-3635-600- 5208	D	8.0	0.10	0.3	1.06	1.10	1.14	1.17	1.20	1.30	0.21	0.29	0.42	0.52	0.76	0.99	0.96	20.3
1-3636-600- 5209		9.0	0.10	0.3	1.06	1.10	1.14	1.17	1.20	1.30	0.23	0.32	0.46	0.57	0.84	1.08	1.08	22.9
-3636-600- 5210		10.0	0.10	0.3	1.06	1.10	1.14	1.17	1.20	1.30	0.25	0.35	0.50	0.62	0.92	1.18	1.20	25
-3636-600- 5211		11.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.27	0.38	0.55	0.67	0.99	1.28	1.32	27
-3636-600- 5212	D	12.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.29	0.40	0.59	0.72	1.07	1.38	1.44	30.
-3636-600- 5213		13.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.31	0.43	0.63	0.77	1.14	1.47	1.58	33.
1-3636-600- 5214		14.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.33	0.46	0.67	0.83	1.22	1.57	1.68	35.
-3636-600- 5215		15.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.35	0.49	0.71	0.88	1.30	1.67	1.80	38.
-3636-600- 5216		16.0	0.15	0.4	1.06	1.10	1.14	1.17	1.20	1.30	0.36	0.51	0.75	0.93	1.37	1.77	1.92	40.
-3636-600- 5217		17.0	0.15	0.5	1.06	1.10	1.14	1.17	1.20	1.30	0.38	0.54	0.79	0.98	1.45	1.86	2.04	43.
-3636-600- 5218	D	18.0	0.15	0.5	1.06	1.10	1.14	1.17	1.20	1.30	0.40	0.57	0.83	1.03	1.52	1.96	2.16	45.
-3636-600- 5219		19.0	0.15	0.5	1.06	1.10	1.14	1.17	1.20	1.30	0.42	0.60	0.87	1.08	1.60	2.06	2.28	48.
-3636-600- 5220		20.0	0.15	0.5	1.06	1.10	1.14	1.17	1.20	1.30	0.44	0.62	0.91	1.13	1.68	2.15	2.40	50.8
-3636-600- 5221		21.0	0.15	0.5	1.08	1.10	1.14	1.17	1.20	1.30	0.46	0.65	0.95	1.18	1.75	2.25	2.52	53.
-3636-600- 5222		22.0	0.15	0.5	1.06	1.10	1.14	1.17	1.20	1.30	0.48	0.68	0.99	1.23	1.83	2.35	2.64	55.
1-3636-600- 5223		23.0	0.15	0.6	1.06	1.10	1.14	1.17	1.20	1.30	0.50	0.71	1.03	1.28	1.91	2.45	2.76	58.4
1-3636-600- 5224	D	24.0	0.15	0.6	1.06	1.10	1.14	1.17	1.20	1.30	0.52	0.74	1.07	1.33	1.98	2.54	2.88	61.0
-3636-600- 5225		25.0	0.15	0.6	1.06	1.10	1.14	1.17	1.20	1.30	0.54	0.76	1.11	1.39	2.06	2.64	3.00	63.
-3636-600- 5226		26.0	0.15	0.6	1.06	1.10	1.14	1.17	1.20	1.30	0.56	0.79	1.15	1.44	2.13	2.74	3.12	66.0
-3636-600- 5227		27.0	0.15	0.6	1.06	1.10	1.14	1.17	1.20	1.30	0.57	0.82	1.19	1.49	2.21	2.84	3.24	68.
0000 000 5000		200	OFE		1 100	-	-	4.67	4.00	400	0.00	0.85	1.23	1.54	2.29	2.93	3.36	71.
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International Wireless Communications Expo (IWCE) April 4-8, 2005 Las Vegas, NV

This show plays host to more than 300 exhibiting companies in the mobile communications industry. The IWCE conference program features the latest developments in business, regulatory/policy, interoperability, transportation and utility applications, public safety and homeland security. For more information, visit www.iwceexpo.com.

IEEE Wireless and Microwave Technology Conference April 7-8, 2005

The 7th annual IEEE Wireless and Microwave Technology (WAMI) Conference will address up-to-date multidisciplinary research needs and interdisciplinary aspects of wireless and RF technology. Topics: next generation (3G/4G) wireless communication systems, 802.11/HiperLAN2 wireless LAN systems (OFDM and multi-carrier), Bluetooth/personal area networks (PAN)/wide area networks (WAN), spread spectrum wireless systems, smart antennas, adaptive antenna arrays, MIMO and space-time processing. For more information, visit www.wamicon.org.

IEEE International Reliability Physics Symposium (IRPS) April 17–21, 2005

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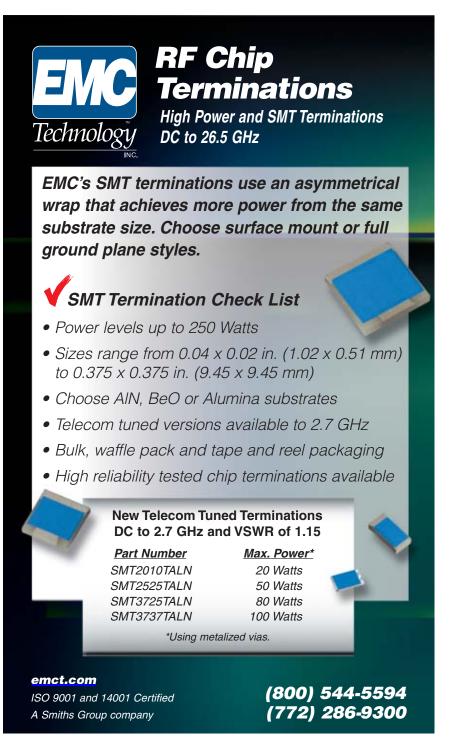
The 2005 IRPS will present the latest developments in microelectronics reliability at its 43rd annual conference. This symposium provides researchers a forum to participate in technical sessions, tutorials, workshops, hands-on equipment demonstrations, poster sessions and reliability year in review, which brings attendees up to date on the latest developments in the microelectronics field. The latest developments in memory, MEMS, assembly and packaging,

MICROWAVE JOURNAL **MARCH 2005**

COMING EVENTS

failure analysis, device and processes, transistor hot-carrier reliability, and ESD and latch-up will be featured. For more information, visit www.irps.org or contact Timothy A. Rost, IRPS 2005 general chair (972) 995-9035 or e-mail: t-rost@ti.com.

IEEE MTT-S International Microwave Symposium and Exhibition June 12-17, 2005 Long Beach, CA This symposium will serve as the centerpiece of Microwave Week 2005. Topics: research, development and application of RF and microwave theory and techniques. In addition to IMS2005, a microwave exhibition, a historical exhibit, the RFIC symposium and the ARFTG conference will be held during Microwave Week 2005. The technical sessions will run Tuesday through Thursday of Microwave Week. Workshops will be held Sunday through Tuesday, and the ARFTG Microwave Measurements Conference will be held on Thurs-









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day and Friday. For further information, visit www.ims2005.org or contact Charlie Jackson, general chair, Raytheon SAS (310) 291-3329 or e-mail: c.jackson@ieee.org. For exhibition information, contact Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750 or e-mail: kdednah @mwjournal.com.

Wireless Communications Association 2005 June 28-July 1, 2005 Washington, DC

This 18th annual event will convene 2000 broadband wireless executives from 40 nations, and feature 200 speakers and 75 exhibitors who will showcase product solutions from 2 to 90 GHz, as well as FSO and SDR solutions. For more information, visit www.wcai.com or contact Tim Sheetz at (202) 452-7823 or e-mail: tim@wcai.com.

Antenna Systems 2005 September 22–23, 2005 Santa Clara, CA

Antenna Systems 2005 is a two-day international conference focused on the latest and most important advancements in antenna systems technology. The technical conference will serve OEM developers of products that utilize antennas and antenna systems, systems operators, antenna integrators and manufacturers, and component and material suppliers interested in learning the latest capabilities and best practices in this rapidly changing field. Antenna Systems 2005 is an opportunity to network with peers, professionals and potential business partners involved in technology solutions serving a variety of applications. See the latest products, services and systems available, and discover what's coming next. Learn the latest business and application developments in antenna markets worldwide. For more information, visit www.antennasonline.com/ast conf2005 index.htm or contact Jeremy Martin at (720) 528-3770 or e-mail: jeremym@infowebcom.com.

European Microwave Week 2005 October 3-7, 2005 Paris, France

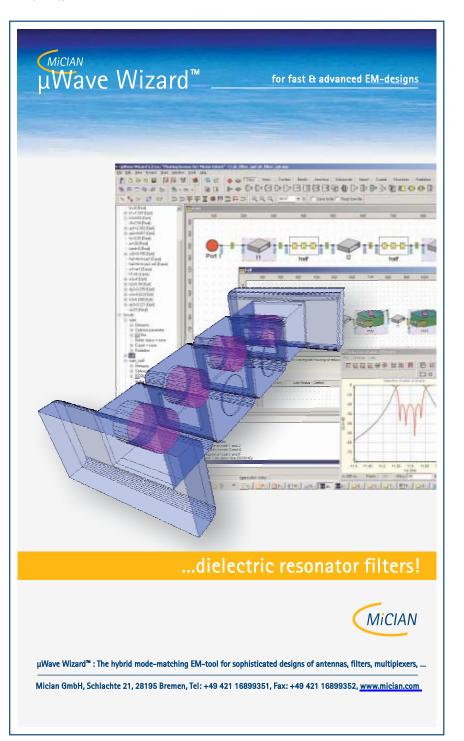
European Microwave Week 2005 (EuMW) features four major conferences, a three-day commercial exhibition that attracts international players, alongside technical workshops and short courses. GAAS 2005 – The 13th Gallium Arsenide and other Compound Semiconductors Application Symposium (October 3–4); ECWT 2005 – The European Conference on Wireless Technology (October 3–4); EuMC 2005 – The 35th European Microwave Conference (October 4–6); EuRAD 2005 – The 2nd European Radar Conference (October 6–7); and the European Microwave Exhibition (October 4–6). For more information on the event, visit www.eumw2005.com.

COMING EVENTS

MTT Wireless
January 15–20, 2006
San Diego, CA

This inaugural symposium will encompass a combination of events all geared to wireless systems and technologies. A three-day exhibition will take place the same week as three technical conferences. The centerpiece of the week is the *IEEE Radio and Wireless Symposium* (RWS), which continues the evolution of

the successful Radio and Wireless Conference. Also participating are the established *Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems* (SiRF) and the *IEEE Topical Workshop on Power Amplifiers for Wireless Communications* (PA Workshop). For more information, visit www.mttwireless.org. Companies interested in the exhibition or in sponsorships should contact Kristen Dednah at (781) 769-9750. Technical attendees and perspective authors should contact Fred Schindler at (978) 670-2230.

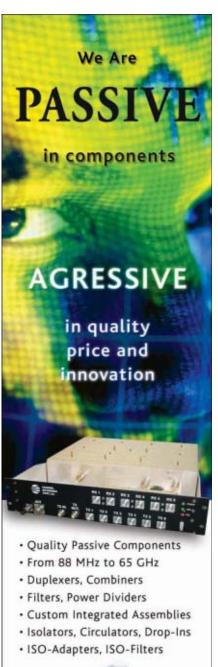


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Workshops & Courses

RF Device Characterization and Modeling

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Site: Vienna, Austria

■ **Dates:** March 29–April 1, 2005

Contact: Vienna University of Technology, Gusshausstrasse 25/360, 1040 Vienna, Austria +43 1 58801 36001 or e-mail: erasmus.langer@tuwien.ac.at.

Antennas: Principles, Design and Measurements

■ **Topics:** This course will cover antenna fundamentals, arrays, wire antennas, broadband antennas, horns, reflectors, antennas in systems, antennas for wireless communications and measurements. For more information, visit www.antennacourse.com.

■ **Site:** Dulles, VA

■ **Dates:** April 19–22, 2005

Contact: Leanne Traver, Northeast Consortium for Engineering Education, PO Box 68, Port Royal, VA 22535–0068 (804) 742-5611 or e-mail: ed-pub@crosslink.net.

CST OF AMERICA'S USER GROUP MEETING

■ **Topics:** Join engineers using CST MICROWAVE STUDIO® (CST MWS) software and those interested in learning more about the technology, exchange ideas and talk with CST engineers and developers about future developments. Featured keynote speaker is Dr. Peter Thoma, head of research and development and managing director of CST. For more information, visit www.cst.com.

Site: Monterey, CA

■ **Dates:** April 21–22, 2005

Contact: CST of America Inc., 10 Laurel Avenue, Suite 300, Wellesley, MA 02481 (781) 416-2782.

ANTENNA ENGINEERING

Topics: This course presents the theory and practice of antenna engineering, covering the range of antenna properties and types from basic to state-of-the-art. The antennas presented in the course cover a wide spectrum of frequency, up to and including the millimeter wavelengths and a wide range of applications. For more information, visit www.pe.gatech.edu.

Site: Atlanta, GA

■ **Dates:** April 25–29, 2005

Contact: Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

MICROWAVE MEASUREMENTS TRAINING COURSE

■ **Topics:** This five-day course is a unique opportunity for recent graduates or those new to the field to gain the most up-to-date understanding of modern measurements. The course will provide a thorough understanding of the essential, theoretical and practical background of microwave measurements. Delegates will be able to hear from experts in the field of measurements and have the chance to visit the National Physical Laboratory's facilities during the course. For more information, visit www.iee.org.

■ Site: Middlesex, UK

■ **Dates:** May 9–13, 2005

Contact: Carilyn Clements, IEE, +44 (0) 1438 765631, fax: +44 (0) 1438 767305 or e-mail: <u>cclements@iee.org.uk</u>.

MICROWAVE/RF CIRCUIT DESIGN AND ANALYSIS

■ **Topics:** This four-day course is designed for engineers, technicians and managers who are involved in developing microwave and RF active and passive device models for use in CAE tools to simulate circuit performance before building the hardware.

■ Site: Beltsville, MD

Dates: May 23–26, 2005

■ Contact: Lisa Hardy, course registrar, (ATI) (888) 501-2100, www.aticourses.com.

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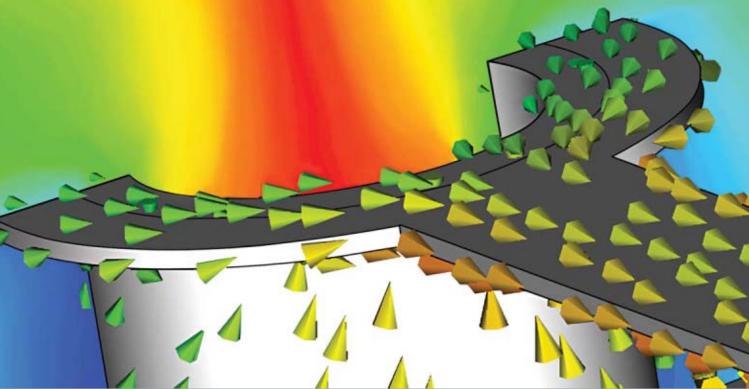
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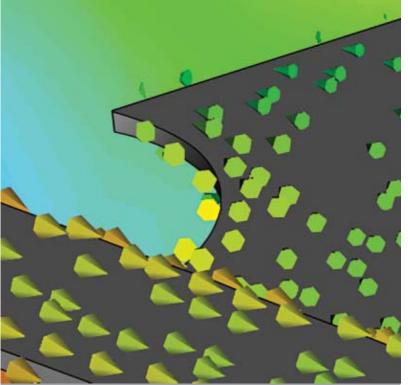
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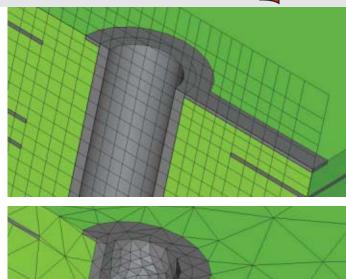












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COVER FEATURE

Planar Electromagnetic Software — Personal Reflections

first realized there was a major problem in 1982 when I moved from GE Valley Forge Space Division to GE Electronics Laboratory (E-Lab) in Syracuse to design some of the first GaAs monolithic microwave integrated circuits (MMIC). I took over the design of a C-band low noise amplifier (LNA). I was told that my first design had to work; there was no budget or time left for any more wafer fabrications. The previous design was compact and made extensive use of spiral inductors. However, the spiral inductors were almost complete unknowns and as a result the previous design did not work.

Fortunately, I could make the chip as large as I wanted to. So I changed all the inductors to equivalent transmission lines and made sure they were spread out so there was very little stray coupling. The design worked the first time. However, the chip area was about 3 mm by 6 mm, and it used only two transistors. This was acceptable for a first of its kind, but it was clear we had to do something so that we could reliably design compact MMICs in the future.

Making this problem even clearer was effort on other, size constrained MMIC designs.

We were doing multiple iterations on these chips. At US \$50,000 and three to six months per wafer fabrication, the situation had to change or GaAs MMICs would end up in the technological trash bin of history, just another blue-sky research project that

no one could reduce to practice. This is when I, and several other researchers, turned to numerical electromagnetics for the answer.

EARLY MICROWAVE DESIGN

In the early 1980s the main microwave design tool was the Smith chart. The IBM-PC was introduced in 1981 (4.77 MHz, 16 kb RAM, no hard drive), and it would be several years before serious microwave design software would be available, and then even longer before it was widely accepted. The most significant commercial circuit theory tool seeing active development at this time was on mainframe computers, although it too had not yet realized widespread acceptance. At E-Lab, we used circuit theory software I had written at Space Division; it ran on a VAX computer that occupied a large air-conditioned room. (I understand that the software was actually still in use in some locations as recently as a few years ago.)

In addition to the circuit theory software I had written on the VAX, I had also, on my own time, written a nice little antenna analysis program, Annie, on an AppleTM computer (see *Figure I*). Lacking a compiler, I wrote the entire program in assembly language, including a full set of floating point arithmetic routines (no floating point coprocessor). I sold over 250 copies of that program to radio amateurs. A friend sold another 250 copies in Japan. The PC version of the program still works and is still available.

Fig. 1 The author developing antenna analysis software on an Apple computer in 1983.



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COVER FEATURE

Given that simple circuit theory microwave software was not yet well accepted and computers were very limited, it was quite a jump to go all the way to numerical electromagnetics. Electromagnetics was viewed by microwave designers as a totally useless academic exercise yielding lots of PhDs, but little or nothing in the way of timely applied solutions. The Smith chart and the Exacto knife were far superior. At that time, microwave designers were completely

Of course, the Exacto knife did not work for GaAs MMICs. Several farsighted researchers, myself included, saw this and proceeded to explore potential solutions, especially for planar circuits. One such technique is the method of moments. I was fortunate in that the originator of the method of moments, Professor Roger Harrington, taught at Syracuse University, just a 10-

minute drive from E-Lab. I wasn't sure exactly how, but I had a feeling that the method of moments had some possibilities. I decided it was time to go for my PhD degree under Professor Harrington. My future was set.

Figure 2 shows the open forum paper (IMS 1987, Las Vegas, NV) where I first presented the method of moments approach I eventually commercialized. That was an especially hectic time for me, as I was also the open forum chairman.

Other researchers doing planar EM work at this time included Rolf Jansen, Achim Hill, Larry Dunleavy, Jian-X Zheng, Joseph Pekarek, Y.L. Chow, Niels Fache, Juan Mosig, Robert Jackson and others. Work from all of these researchers influenced the entire field, and some actually made the very considerable jump to commercial products.

By the end of the 1980s, circuit theory was well embedded in the microwave design flow and EM was just getting started. By the end of the 1990s, EM analysis was firmly embedded, too. Thus, we refer to the 1980s as the decade of circuit theory microwave design, and the 1990s as the decade of EM-based microwave design.

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COMMERCIALIZATION

Making the jump from academic research to successful commercial product deserves discussion. In my own case, having grown up as a farm boy pitching hay and a driving tractor, I could not even spell entrepreneur, much less consider becoming one. So I tried everything I could short of commercializing the software myself. I went to all the major EDA vendors and actually had strong interest from two of them, but both eventually turned me down. I went to the companies that had funded my PhD



Fig. 2 The author's first publication in 1987 of the EM technique that he commercialized.

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COVER FEATURE

research; it was not in their overall corporate strategy, a reasonable objection. So, I either had to commercialize it myself, or drop it and get on with life.



🛕 Fig. 3 An EM seminar in Tokyo in 1995 captures a large audience.

From selling the Annie program, I knew commercialization was going to be way too much work, so I decided to drop it and get on with life. I decided to pursue an academic career. Maybe I could do more development as part of my research and eventually someone might pick up the software. I did successfully obtain a temporary position at Syracuse for two years, but serious attempts applying for tenure track positions at both Syracuse and Cornell

failed. So, in between teaching courses, I spent those two years preparing software for applied use and then I would "quit my day job." It was like I was being forced to become an entrepreneur.

Looking back on the effort to commercialize the software, I subjectively estimate about 10 percent of my total effort has been in doing the underlying EM theory and numerical software. Another 30 percent was spent doing productization, putting the software into a form that could be used in applied work. This includes setting up substantial automated testing, writing documentation and developing a good user interface. About 60 percent of the total effort has been in marketing and sales.

A portion of the marketing and sales was simply traveling all over the world to tell skeptical microwave designers about the wonders of numerical electromagnetics. *Figure 3* shows the strong interest my seminars generated, this one in Tokyo, Japan, in 1995.

Occasionally I hear researchers complaining that they publish research and someone else gets rich. My reply is that if they want to get rich, just do the productization, marketing and sales as described above and you too will become wealthy... maybe. I chose (or perhaps was forced) to take the commercialization route. This turned out to be successful, but I fully realize that in doing so I have not experienced research and publishing in more depth and in a wider variety of topics. I sometimes wonder what my life course would have been if I had been successful in one of my tenure track applications, but that I will never know.

Also, I occasionally get enquires like, "I have this really neat EM code, it's 90 percent done and only 10 percent is left to do, would you like to sell it?" I reply that they have the right numbers, but in the wrong order. Most researchers leave it there (just like I tried to do), but every now and then one takes up the challenge and puts in the extra 90 percent required to commercialize. I have heard essentially this same story from several microwave software vendors.

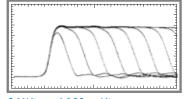
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Cover Feature

get a simple, equation-free, high level understanding.

There are two basic approaches to the method of moments as applied to planar circuits. In the approach I use, we place the problem in a rectangular, shielding box. When we work the equations, we view the sidewalls of the box as a rectangular waveguide propagating in the vertical direction. The top cover and bottom ground plane are just waveguide terminations. Recall that the M and N, TE and TM waveguide modes all have cosine and sine terms in them. In applying the method of moments, we write the fields as a sum of these waveguide modes. This is a sum (over all M and N modes) of cosines and sines. What is a sum of cosines and sines? It's a Fourier series. Thus, we can use a 2-D fast Fourier transform (FFT) to sum all these cosines and sines. *Figure 4* shows a portion of a page from my notebook

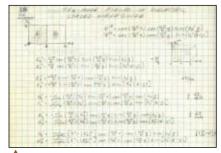
where I calculated these sines and cosines at the beginning of my PhD research. While the equations can fill pages, the basic ideas are simple.

Using an FFT like this in EM analysis has an important disadvantage that is identical to the disadvantage in using the FFT in signal processing. If you have a time signal and you want to do an FFT, the first thing you do is to uniform time sample the signal. In FFTbased EM analysis, the first thing you do is uniform space sample across the surface of the substrate. Thus the circuit analyzed is snapped to a fine uniform underlying FFT mesh. Fortunately, the FFT is so fast that this mesh can easily be 1000 by 1000 cells, which means FFT cell size can be as small as a pixel on a computer screen.

The advantage of using the FFT is that all coupling between all cells is quickly calculated to full numerical precision. This results in very high accuracy and a typical dynamic range of 100 to 180 dB. This advantage is identical to the high dynamic range provided by audio CDs. If you must meet an 80 dB filter rejection specification, it is easy to do using FFT-based analysis.

The second planar method of moments approach assumes an unshielded environment. Now, a numerical integration must be used to calculate the fields. The advantages and disadvantages of this approach nicely compliment the FFT approach. The advantage is that the numerical integration may be performed over any limits, thus subsections can be triangles or rectangles of any size. The disadvantage is that numerical integration is slower than an FFT for a given subsection count and that numerical integration error reduces dynamic range.

Ideally, a designer should have access to both types of analyses. The experienced designer can effectively enjoy the advantages of both approaches.



▲ Fig. 4 A page from the author's PhD notebook showing the sines and cosines of the waveguide modes summed by the FFT.

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Psat (dBm)	Sroadband	42.5	4	40
Frequency (GHz)		1-4	2 - 4	2-6
<u> </u>		-43	L0204-44	16-40
Model		L0104	L020	L020
		190 L0104		
VSWR DC Current (In/Out) @+12/+15VDC		190		150
VSWR DC Current (In/Out) @+12/+15VDC		+7 2.0:1 190	150	150
Bm) VSWR DC Current (In/Out) @+12/+15VDC	Amplifiers	+7 2.0:1 190	1.8:1 150	1.8:1 150
P1dB (dBm) VSWR DC Current min (In/Out) @+12/+15VDC	Moise Amplifiers ————————————————————————————————————	+7 2.0:1 190	1.2 +10 1.8:1 150	+10 1.8:1 150
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±1.0 +1.0

2.0 - 18.00.5 - 18.0

16 22

±2.25

±2.0

12.0 - 26.5

0.1 - 26.5

AML0518L1601-LN

AML412L3002

AML48L3001

AML016L2802

Model

AML0126L2202

AML1226L3301

Broadband Medium Power Amplifiers

±1.25

0.01 - 6.0

AML0016P2001

2.0 - 6.02.0 - 8.0

±2.5

±2.0 ±2.5 +2.5

30

32

2.0 - 18.0

6.0 - 18.0

AML618P3502-2W AML28P3002-2W AML26P3001-2W

AML218P3203

	1										ı											ı
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Model		L0104-43	L0204-44	L0206-40	L0218-30	L0408-43	L0618-43	L0812-44	L1218-43			L1826-34	L1840-27	L2632-37	L2640-27	L2630-37	L2732-35	L3040-30	L3236-36	L3640-36		
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-164.5 -168 -178

-165 -160

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Gain (dB)

Frequency (MHz)

Part Number

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-157.5 -153.5 -165

-152.5

-145.5 -155

18 28 20 15

2.0 - 6.0

AML26PN0904

AML26PN1201

2.0 - 6.0

-150

-167

-159

-154

17

8.5 - 11.08.5 - 11.08.5 - 11.0

AML811PN0908 AML811PN1508

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Gain Output Power

Frequency (GHz)

Part Number

±0.75

14.0 - 14.517.0 - 18.0

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For given circuit and accuracy requirements, one tool might be preferred over the other. In cases where high probability of success is critical, circuits should be analyzed using both approaches and any differences fully understood.

For example, if a circuit is to be used in an unshielded environment, an unshielded analysis is generally appropriate. If you want to quantitatively evaluate the significance of surface

wave coupling to nearby components, then analysis with a 3-D volume meshing tool including the specific nearby components is typically required.

If only the general importance of surface wave coupling is desired, an unshielded analysis by itself is difficult to use. This is because the effects of surface waves tend to be smooth with frequency and their existence is not easily discerned by just viewing the S-parameters. In this case, a shielded analysis

should be applied. If a circuit generating strong surface waves is placed in a shielding box, then the surface waves become easily recognized box resonances. If you see numerous box resonances in the shielded analysis, you can be confident that the actual unshielded circuit has a strong likelihood of surface waves and undesired coupling to nearby components.

If high accuracy is required for a filter in a shielding box, a shielded EM analysis must be used and the box set to the same size as in the actual circuit. A filter's enclosure and environment can have a strong and sometimes unexpected influence on the filter response.

Shielded analyses can approximate an unshielded environment and unshielded analyses can approximate a shielded environment. However, in each case, due to accuracy and speed issues, if both types of analysis are available, the appropriate native environment is preferred.

There are numerous volume meshing EM tools available. Most are based on or related to either finite elements or finite difference time domain. Typically, unless there is some kind of 3-D arbitrary attribute to the circuit (as in the stray coupling to external components example above), such analyses should not be used for planar circuits. Analysis times can be substantially longer than for a native planar analysis. While such analyses typically give a reasonable indication of the correct result, very high accuracy can be difficult to realize.

To get a quick indication of accuracy, just look at the current distribution. For example, accurate calculation of I²R loss requires an exceptionally accurate evaluation of S-parameters. This is because planar circuits naturally have very high current on all edges. Confining a large portion of the current to the edges significantly increases loss. In order to accurately calculate I²R loss, this high edge current must be accurately calculated. This, in turn, requires an exceptionally fine mesh right at the edges of all lines. This makes any volume mesh so fine that it is difficult to analyze. In contrast, volume meshing approaches tend to work well for 3-D arbitrary structures where planar approaches have difficulty.

Planar EM tools mesh only the metal of a circuit, not the volume. Typically,

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they can automatically and efficiently generate a fine mesh on edges, allowing accurate evaluation of the high edge current. For some tools, such "edge meshing" is default, in other cases it must be manually invoked. If high accuracy is required, edge meshing must be used. As an added benefit, when edge meshing is used, adaptive meshing is unnecessary. In fact, most planar EM tools do not even bother including an iterative adaptive mesh.

Whenever high accuracy is needed, and no matter what EM tool is being used, always view the current distribution for at least one or two frequencies. The current distribution must be smooth, physically reasonable and have high edge current. All of these characteristics are absolutely required if high accuracy results are to be realized.

Another excellent check for accuracy is to perform a convergence analysis. This is easily done for any EM

analysis; just keep making the mesh finer and finer. For example, if an initial analysis uses a mesh size of 20 subsections per wavelength (the minimum that should ever be used), repeat the analysis with 40, then 80 and then 160 subsections per wavelength. For FFT-based analyses, just keep cutting the cell size in half. Plot the results. You should see a clear convergence, with the difference between each set of curves (no matter what it is that you are plotting) reducing by about half each time you refine the mesh. If the difference remains constant, or if the difference starts increasing for finer meshes, the situation must be resolved or the design is at risk.

Also keep in mind that accuracy depends not only on the number of subsections per wavelength, but also on the size of the subsections with respect to current variation on the metal. This is why high accuracy requires narrow subsections at the edge of lines to adequately represent the high edge current. If thickness is important, multiple subsections through the thickness of the line can also be important.

CHARACTERISTIC WHAT?

When I first started working in numerical EM, most (of the very few) users had a good solid knowledge of microwave design. Over the years, with a few fortunate exceptions, many universities have dropped or compromised their EM and RF design courses. Perhaps they felt all that RF stuff was old fashioned and they wanted to work on modern topics. After all, Maxwell's equations are over 100 years old. Traveling waves and characteristic impedance are terribly complicated. All this is just a useless holdover from a by-gone era.

Suddenly, wireless is a hot topic. These universities are only just now realizing that they should at least maintain and maybe even increase their attention to RF design. In the meantime, I have seen a strong increase in the number of "RF designers" who have been almost literally dumped into the field with little or no preparation. We help them out as much as we can. Fortunately, most of them are receptive, but we are no substitute for a good solid academic grounding in EM and RF design.

Take, for example, silicon RFIC design. It is common for foundries to

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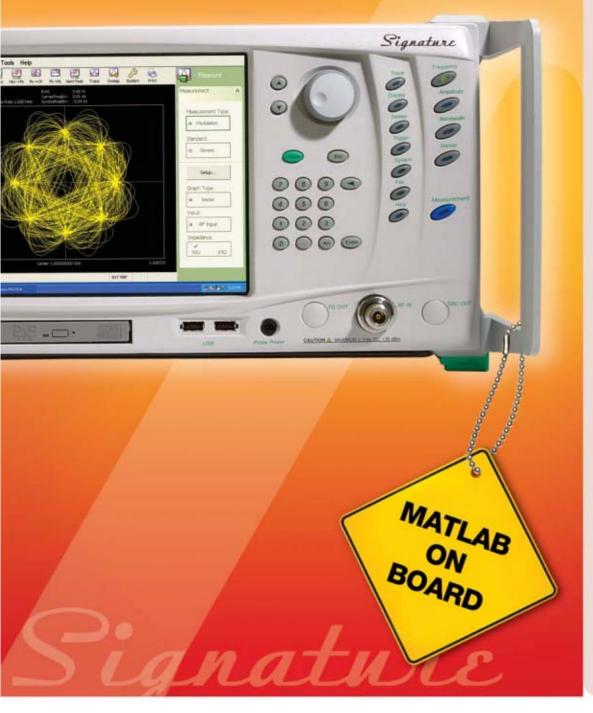








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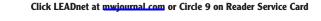


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measure a large set of components to facilitate the use of their process. Each component is fabricated with a "ground cage" (see Figure 5). The component is measured in coplanar waveguide (CPW), the ground cage strips forming the ground strips of the CPW.

For true CPW operation, if one amp of current goes into the signal line (the center contact), then one-half amp of current must come out of each of the two ground strips. The ground return currents are exactly balanced. The CPW characteristic impedance and velocity of propagation depend on balanced ground return current.

However, if the ground strips are not symmetric, the ground return current will also not be symmetric, one ground return path having lower reactance than the other. In measurements, this compromises the probe calibration as the probe characteristic impedance and velocity of propagation was calibrated assuming true CPW (balanced ground return currents) operation. Such error is reduced if the probe's ground strips are shorted together very close to the tip, but the error can still increase to significant levels at a sufficiently high frequency.

In addition, if yet another ground return path is used (the chip ground plane, or worse yet, the silicon substrate itself, for example) when the component is actually used in a circuit, different results (at high enough frequency) will again be obtained. Inexperienced designers forget that the ground return current is very real and is fully half of the circuit being analyzed. At sufficiently high frequencies and for certain circuit configurations, the designers will find themselves confronting old fashioned "ground loops" generating truly bizarre re-

To make matters worse, inexperienced RF designers often perform their measurements using a manufacturer-provided calibration kit, usually on alumina, and then make their measurements on silicon. This works at lower frequencies, but at high frequencies, where the exact probe tip discontinuity is important, significant error can be introduced.

When there are differences between measured and calculated results, the inexperienced designer is strongly tempted to blame the problem on the analysis software, materials and measurement equipment. However, the problem is actually defective design and measurement technique. This makes life hard for those of us who provide the software, materials and equipment. I am encouraged that this situation should gradually change as universities provide better-trained RF de-



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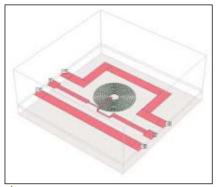
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📤 Fig. 5 A typical ground cage.

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sign professionals. In just the last month I have become aware of two major engineering universities starting up new RF design curricula. This transition can occur faster if those of us who are experienced in RF design take extra effort in helping new comers on board.

INTEROPERABILITY

As you might surmise from the above discussion, in order to be

competitive when faced with a wide variety of problems, a well equipped high frequency designer requires multiple EM tools. If best-in-class is desired for each tool, these tools will come from multiple vendors. In this case, interoperability in a heterogeneous EDA vendor environment is critical.

I mentioned that the 1980s was the decade of circuit theory, and the 1990s was the decade of ÉM-based design. What is the theme for this decade? In my opinion, it is interoperability. At the beginning of this decade, even basic interoperability between a framework vendor's own tools was a developing situation. Interoperability between multiple vendors was almost non-existent and sometimes even actively discouraged by "total solution" framework vendors.

In just the last several years we have seen significant interoperability arise, even between vendors who are to some degree competitive. I have been personally involved in four such substantial framework integrations. Each of these vendors has tools that are at least somewhat competitive. Why would they want to actively facilitate interoperability to a competitor? It is because they do not want to ever reply in the negative to a customer asking, "I need to use ABC software. Your competitors interface to it. You have a good interface to it too, don't you?"

In fact, I feel that interoperability is so important that by the end of this decade this issue alone will determine the success or failure of any and all frameworks in the high frequency EDA field.

CLOSING COMMENTS

I have been involved in high frequency EDA for over a quarter century. I have seen, and had the extreme pleasure of participating in the field of applied high frequency numerical EM analysis from the very beginning. One thing I really treasure and I think is very special is how well the practitioners of our field get along together. I can walk up to nearly anyone in any company and say, "Hi," and really feel good about it. In sharp contrast to the much larger non-RF EDA field, where businessas-usual lawsuits are common, lawsuits between competitors in our field are extremely rare and generally inappropriate. Yes, we all compete vigorously and now and then we have to posture and bluster, but we all get along together, too. This is important for the designer, because the interoperability that results is much greater and of higher quality. Even though we compete, when it is important for the designer, we also cooperate. And the designer wins. \blacksquare

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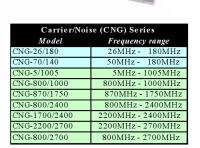
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		LOW	NOISE OCTA	VE BAND AMPLII	FIERS	
Model No.	Frequency	Gain	Noise Figure	Output Power (dBm)	3rd Order ICP	VSWR
	ĠHz	dB MIN	dB	MIN @ P1 dB Comp PT	dBm TYP	MAX
CA01-2110	0.5 - 1.0	28	1.0 MAX, 0.7 TYP	+10	+20	2.0:1
CA12-2110	1.0 - 2.0	30	1.0 MAX, 0.7 TYP	+10	+20	2.0:1
CA24-2110	2.0 - 4.0	32	1.2 MAX, 1.0 TYP	+10	+20	2.0:1
CA48-2110	4.0 - 8.0	32	1.4 MAX, 1.2 TYP	+10	+20	2.0:1
CA812-3110	8.0 - 12.0	27	1.8 MAX, 1.6 TYP	+10	+20	2.0:1
CA1218-4110	12.0 - 18.0	25	2.0 MAX, 1.8 TYP	+10	+20	2.0:1

	ULIKA-	SKOAD	BAND & MU	TII-OCIAVE BAN	ND AMPLIFII	:KS
Model No.	Frequency	Gain	Noise Figure	Output Power (dBm)	3rd Order ICP	VSWR
	ĠHz	dB MIN	dB	MIN @ P1 dB Comp PT	dBm TYP	MAX
CA0102-3110	0.1 - 2.0	28	2.0 Max, 1.5 Typ	+10	+20	2.0:1
CA0106-3110	0.1 - 6.0	28	2.0 Max, 1.5 Typ	+10	+20	2.0:1
CA0108-3110	0.1 - 8.0	26	2.2 Max, 1.8 Typ	+10	+20	2.0:1
CA0108-4112	0.1 - 8.0	32	3.0 MAX, 1.8 Typ	+22	+32	2.0:1
CA26-3110	2.0 - 6.0	26	2.0 MAX, 1.5 TYP	+10	+20	2.0:1
CA26-3113	2.0 - 6.0	28	4.0 MAX, 3.0 TYP	+27	+37	2.0:1
CA26-4114	2.0 - 6.0	22	5.0 MAX, 3.5 TYP	+30	+40	2.0:1
CA618-4112	6.0 - 18.0	25	5.0 MAX, 3.5 TYP	+23	+33	2.0:1
CA618-5113	6.0 - 18.0	24	5.0 MAX, 3.5 TYP	+27	+37	2.0:1
CA618-6114	6.0 - 18.0	35	5.0 MAX, 3.5 TYP	+30	+40	2.0:1
CA618-6115	6.0 - 18.0	35	6.0 MAX, 3.5 TYP	+32	+41	2.0:1
CA218-4110	2.0 - 18.0	30	5.0 MAX, 3.5 TYP	+20	+30	2.0:1
CA218-4112	2.0 - 18.0	29	5.0 MAX, 3.5 TYP	+24	+34	2.0:1
CA218-4113	2.0 - 18.0	29	5.0 MAX, 3.5 TYP	+27	+37	2.0:1

			NARROW BA	ND AMPLIFIERS		
Model No.	Frequency GHz	Gain dB MIN	Noise Figure dB	Output Power (dBm) MIN @ P1 dB Comp PT	3rd Order ICP dBm TYP	VSWR MAX
LOW NOISE:						
CA01-2110	0.4 - 0.5	28	0.75 MAX, 0.45 TYP	+10	+20	2.0:1
CA01-2112	0.8 - 1.0	28	0.75 MAX, 0.45 TYP	+10	+20	2.0:1
CA12-3116	1.2 - 1.6	25	0.75 MAX, 0.5 TYP	+10	+20	2.0:1
CA23-3110	2.2 - 2.4	30	0.75 MAX, 0.5 TYP	+10	+20	2.0:1
CA23-3110	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10	+20	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10	+20	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10	+20	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10	+20	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10	+20	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.5 TYP	+10	+20	2.0:1
CA1819-4110	17.7 - 18.3	20	2.0 MAX, 1.8 TYP	+10	+20	2.0:1
MEDIUM PO\						
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33	+41	2.0:1
CA23-4110	2.7 - 2.9	32	4.0 MAX, 3.0 TYP	+33	+41	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35	+43	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30	+40	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33	+41	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33	+42	2.0:1
CA1218-5116	12.0 - 18.0	35	6.0 MAX, 5.0 TYP	+30	+40	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30	+40	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21	+31	2.0:1
CA1718-4110	17.7 - 18.1	25	5.0 MAX, 4.5 TYP	+27	+37	2.0:1

		CO	MPETITIVE	PRICING OFFERED	
Model No.	Frequency GHz	Gain dB MIN	Noise Figure dB	Output Power (dBm) MIN @ P1 dB Comp PT	Unit Price Oty 1-9 \$US
CA12-A02	1.0-2.0	26	1.6	+10	Qty 1-9 \$US \$ 395
CA24-A02	2.0-4.0	26	1.8	+10	\$ 395
CA48-A02	4.0-8.0	24	2.0	+10	\$ 395
CA812-A02	8.0-12.0	22	2.5	+10	\$395
CA1218-A02	12.0-18.0	16	3.5	+10	\$ 395

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Defense News

US Air Force Research Laboratory Exercises Option for X-band Thin Radar Aperture

Raytheon Co.'s option to proceed with its X-band thin radar aperture (XTRA) contract has been exercised, allowing the company to produce the next generation radar antenna technology for the J-UCAS (Joint Unmanned Air Combat System) that could revolutionize

manned and unmanned combat systems. The AFRL (Air Force Research Laboratory) exercised the option following the proof of concept phase of the contract that was issued in April 2004. "This is a significant confirmation of the innovative technologies that are at the heart of the next generation systems Raytheon is developing for our smaller and lighter unmanned systems," said Tom Kennedy, vice president, Unmanned and Reconnaissance Systems business unit. "We look forward to applying XTRA to a variety of platforms." The XTRA array technology has advanced transmit and receive capabilities, is light weight and lower cost than existing technology, and is suitable for the larger unmanned combat systems, such as the J-UCAS, as well as smaller unmanned airborne systems and other manned aircraft. The initial funding for this effort is \$4 M. Raytheon received its first award to develop the design for XTRA in April 2004. XTRA is one of several revolutionary approaches to small and affordable arrays in development by Raytheon.

Northrop Grumman Readies Commercial Aircraft Anti-missile System

Northrop Grumman Corp. announced it will install and flight test its commercial aircraft protection system on a Boeing 747 and MD-11 this year. The system, called Guardian, represents the successful transfer of proven military directional infrared countermeasures

(DIRCM) technology to protect commercial aircraft from attack by ground-based, shoulder-fired missiles. Under its contract with the US Department of Homeland Security (DHS), Northrop Grumman recently completed the design and fabrication of the first Guardian system. This year's testing will be part of the Federal Aviation Administration certification process. The company estimates its Guardian system, which is based on combat-proven, laserbased technology currently in production for the US military and international customers, will ultimately cost approximately half of recent published reports. "Guardian builds on our highly successful military system to offer DHS, airlines and the flying public, a reliable, superior system with affordable life-cycle costs," said Robert Del Boca, vice president of Infrared Countermeasures and Laser Systems for Northrop Grumman's Electronic Systems sector. Northrop Grumman is uniquely qualified in providing defensive systems for aircraft for more than sixty years, including industry leading infrared and laser technologies for the past 35 years. As an industry leader in the design, development and production of lasers, producing more annually than all other tactical laser manufacturers combined, the Guardian system is well positioned to protect commercial aircraft from the threat of heat-seeking missiles. The Northrop Grumman military system is currently protecting more than twenty different aircraft types and hundreds of aircrafts fielded today. Northrop Grumman is supported by two key industry partners on its counter-MANPADS team, Federal Express and Northwest Airlines. Federal Express will provide engineering services for installation and aircraft modification and certification. Northwest Airlines will provide engineering and technical services to develop a commercially viable equipment set suitable for operation within commercial airframes.

Raytheon's Affordable Ground Based Radar Passes Milestone

Radar (AGBR) passed a critical milestone during a recent United States Marine Corps test in support of the goal to field future radar sensors configured in a tactical and highly mobile design for the Marine Expeditionary Forces world-

wide. In line with the schedule laid out three years ago, in mid-December 2004 the AGBR Science and Technology concept demonstrator successfully performed air surveillance and tracking of simulated and real airborne targets while rotating at both thirty and sixty revolutions per minute. This achievement validates the concept for a battlefield sensor mounted aboard a HMMWV (High Mobility Multipurpose Wheeled Vehicle). Further AGBR testing and evaluations are underway. The Marines envision eventually fielding multi-purpose radars to perform air surveillance, air defense, ground weapon locating and air traffic control. Currently, those roles are each performed separately by aging legacy radars designed for one single purpose, using technology that is decades old. The USMC has designated this new development program as G/ATOR (Ground/Air Task Oriented Radar); the award of which is anticipated sometime in 2005, following a full and open industry competition. Sponsored by the Office of Naval Research (ONR), the USMC's AGBR contract was awarded in 2002 to Raytheon and is being executed at the Integrated Defense System's Surveillance and Sensors Center, located in Sudbury, MA. To date, the US Marine Corps Systems Command, located at Quantico Marine Base, VA, has observed more than fifty percent of the planned AGBR prototype tests being conducted by Raytheon. "The results of these tests will furnish the Marine Corps additional insights into the path ahead, validate the concept for highly mobile multi-purpose radars for the future Marine Expeditionary Forces, and in turn, sup-

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DEFENSE NEWS

port the Marines' milestone decision to move forward with the G/ATOR program," explained Robert Pool, Raytheon's program manager. "Raytheon is looking forward to completion of the remaining AGBR tests and the opportunity to compete for the follow-on G/ATOR development program."

Lockheed Martin Conducts Fourth Successful Test of **Guided MLRS**

ockheed Martin conducted the fourth flight test of a Guided Multiple Launch Rocket System (GMLRS) Unitary rocket at White Sands Missile Range, NM. Test objectives included demonstrating the GMLRS Unitary rocket in the delay mode, the improved guidance software,

and the warhead and fuzing mechanism under cold weather conditions. The warhead will have a tri-mode fuze, which allows airburst, point impact and delay modes for penetrator capability. This was the first flight of the GMLRS Unitary rocket with the enhanced capability fuze

architecture. "This delay mode test of the GMLRS Unitary rocket demonstrates the ability to attack point targets with low collateral damage and takes us one step closer to bringing this capability to the war fighter," said Al Duchesne, Lockheed Martin Missiles and Fire Control director of MLRS Rocket Programs. Guided MLRS Unitary integrates a 180-pound unitary warhead into the GMLRS rocket, giving battlefield commanders the ability to attack targets up to 70 km away with high precision. This low cost, low risk program will greatly reduce collateral damage by providing enhanced accuracy to ensure delivery of the warhead to the target. Lockheed Martin received a \$119 M contract to conduct System Development and Demonstration (SDD) for a GMLRS variant with a single warhead in October 2003. The SDD contract includes 86 rockets, 71 of which are flight articles, with the balance supporting tests and other activities. The contract also provides test hardware to support 26 flight tests for an initial configuration and 39 flight tests of a follow-on configuration. The SDD phase of this program was preceded by a successful system demonstration in 2002 of a Quick Reaction Unitary rocket and a nine-month Component Advanced Development program. The Guided Unitary SDD program will continue through 2007. ■



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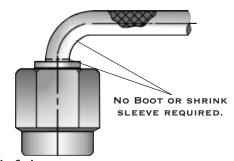
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Filtronic and RFMD Broker Strategic Supplier Relationship

Filtronic plc, a global designer and manufacturer of customised microwave electronic subsystems and components for the wireless telecommunications and defence industries, and RF Micro Devices Inc. (RFMD), have signed a supply agreement for the manufacture of high

volume pHEMT GaAs products on the Filtronic 6 inch processing facility based in Newton Aycliffe, UK. As a manufacturer of proprietary radio frequency integrated circuits for wireless communications products, based on its HBT GaAs technology, RFMD will incorporate Filtronic's pHEMT GaAs products into its own modules aimed at mobile handset and WLAN applications. Under the terms of the agreement Filtronic has become RFMD's Tier 1 supplier for GaAs pHEMT technology, where RFMD will use Filtronic as its preferred supplier of pHEMT integrated products for all its requirements. The two companies have been collaborating to develop and qualify a range of multi-throw switch products. Initial pre-production is already underway and volume production is due to commence in Q2 2005. Commenting, Professor David Rhodes, Filtronic's chairman, said: "The addition of RFMD as a customer for the foundry at Newton Aycliffe is a major step in delivering our strategy of merchant and custom semiconductor product sales. Filtronic looks forward to supporting RFMD in their many projects going forward."

Alliance Extends Semiconductor R&D Activities

The Crolles2 Alliance partners, Freescale Semiconductor, Philips and STMicroelectronics, have extended the scope of their joint semiconductor research and development activities to include R&D related to wafer testing and packaging, in addition to the original development of

sub 100 nm CMOS process technologies. This agreement reflects the special needs of wafer testing and packaging for devices produced on 300 mm wafers in 90 nm, 65 nm CMOS and beyond. It will look at all aspects of post-fabrication wafer processing including probing, grinding, sawing, die attach, wire-bonding, flip chip and package moulding techniques as well as optimization of bond-pad stack design. The expanded relationship builds on two years of successful collaboration in the semiconductor industry's largest R&D alliance. By combining efforts, alliance members have achieved several milestones in 90 nm production and 65 nm process development. The partners will establish a new research laboratory in Grenoble (France) staffed by about 20 scientists and technicians drawn from the three companies. The lab will fo-

INTERNATIONAL REPORT

Richard Mumford, European Editor

cus on bond-pad stack design and the assessment of low stress probing, sawing and assembly processes including laser cutting and low stress moulding materials. It will also investigate requirements specification for the next generation of assembly and test equipment. The new Crolles2 Alliance assembly and test R&D team will also work closely with key equipment suppliers.

Chipcon and Figure 8 Wireless Merger to Provide Ultimate ZigBee Solution Chipcon Group ASA has acquired Figure 8 Wireless Inc., in an all stock transaction. The merger between Chipcon AS, the provider of low power, low data rate RFICs, and Figure 8 Wireless, a provider of ZigBee ready software and firmware, will provide a

comprehensive end-to-end ZigBee platform. It will also provide the combined entity the ability to ensure customers receive the full cost and functionality benefits promised by the ZigBee Alliance. Under the agreement, Figure 8 Wireless has become a wholly owned subsidiary of Chipcon Group ASA and will continue to focus on Zigbee solutions and support all current customers. The combined company will provide a common global presence for its one-stop Zigbee solution with direct sales and support operations in Europe, North America and Asia. It will offer customers a full range of ZigBee ready radios, software, development tools and reference designs for end-to-end ZigBee solutions. In addition, it is expected that the software capabilities of Figure 8 Wireless will significantly enhance Chipcon's current and future proprietary RF and standards-based solutions. Commenting on the acquisition, Geir Førre, president and CEO of Chipcon AS, stated, "Over the course of our partnership in delivering ZigBee ready solutions for our RF transceivers, we developed a close working relationship with the Figure 8 team. Merging our two companies' activities will result in a tremendous enhancement in our software capabilities and will provide the resources to execute on our product strategy and ensure the success of the ZigBee standard and the company."

Intercellular Selects Harris for Nigeria Network Expansion

Intercellular Nigeria Ltd., a private telecommunications operator in Nigeria, has selected Harris Corp. to provide microwave radio links for a multi-million dollar network expansion. Taking advantage of the rapid and easy deployment of the company's family of

digital PDH microwave radios, the Harris line of radio systems will enable the rapid deployment of voice,

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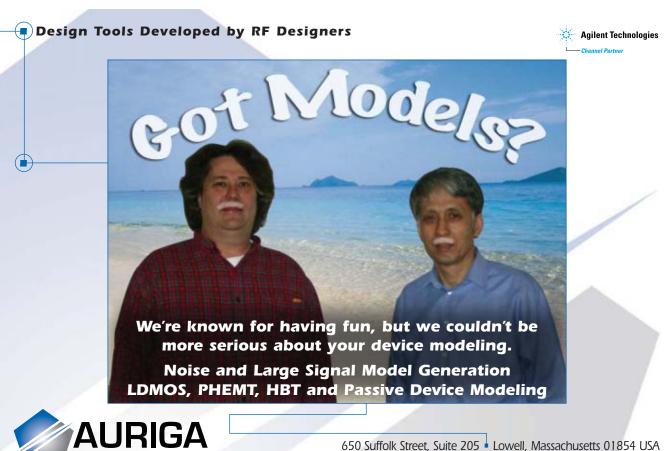
video and data services in new areas across Nigeria and the West African region.

Key to Intercellular awarding the contract to Harris is the company's family of digital PDH microwave radios that are designed for rapid and easy deployment, while open network management protocols ensure seamless integration with the network and easy scalability. Commenting, Bashir Ahmed el-Rufai, president and CEO of Intercellular Nigeria, said, "Harris has been important in helping Intercellular achieve our vision of a wireless Nigeria. As we expand our network to service more customers, Harris' commitment to innovation, quality and service will play a key role."

From the manufacturer's viewpoint, Joseph Joseph, Harris Microwave Communications division's regional director for the Middle East and Africa, remarked, "Working with Intercellular, we have created a highly scalable, easily upgradeable and cost-effective solution to meet the needs of one of Africa's fastest growing telecommunications markets." He explained, "Our investment in local personnel and our strong relationships with local subcontractors mean we can continue to provide the best support for our African customers, however fast the market grows."

Icomera Gets on Track in Sweden Scandinavian train operator, SJ, has awarded Icomera the €11 million contract to equip its fleet with the company's Wireless Onboard Internet Service. Under the terms of the contract Icomera will deliver its Intercity Edition for the current X2000 train type and Commuter Edition for the

new X40 fleet. Significantly too, the deal is said to represent the first full fleet rollout by a train operator of an onboard wireless Internet service and the world's first implementation of a 3G/satellite-enabled WiFi service. SJ plans to rollout the wireless onboard Internet solution on its fleet of 85 trains during the summer, enabling its Intercity and Commuter passengers to surf the Internet and check e-mails at broadband speeds, both on trains and at stations with guaranteed 100 per cent connectivity. Also, another Icomera customer, GNER, is currently testing the 3G system on its East Coast route in the UK. Icomera delivers a complete end-to-end service, from the provision of the technology and installation to negotiation with mobile operators and consultancy on certification and regulatory issues.



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ZX10-2-25	1-2.5	20	1.2	26.95
ZX10-2-42	1.9-4.2	23	0.2	34.95
ZX10-2-71	2.95-7.1	23	0.25	34.95
ZX10-2-98	4.75-9.8	23	0.3	39.95
ZX10-2-126	7.4-12.6	23	0.3	39.95
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ZX10-4-11	.8-1.125	20	0.6	38.95
ZX10-4-14	1.1-1.45	20	0.8	38.95
ZX10-4-19	1.425-1.9	20	0.75	38.95
ZX10-4-24	1.675-2.35	20	0.9	38.95
ZX10-4-27	2.225-2.7	20	1.0	38.95

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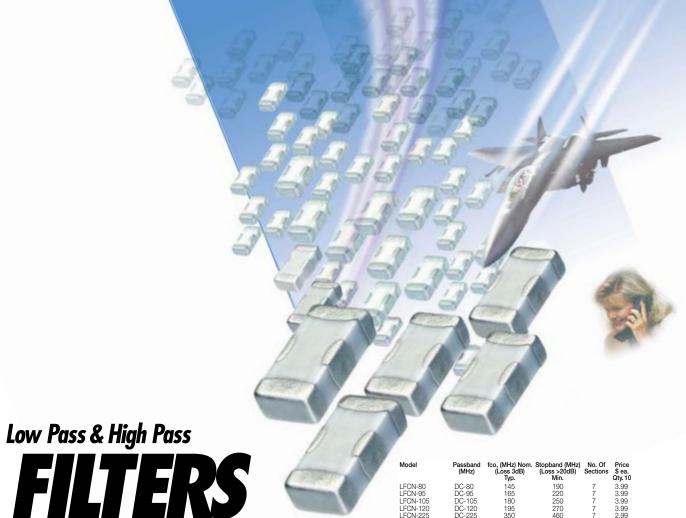
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LFCN = Low Pass, HFCN = High Pass

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Commercial Market

Government Mandates Key to Electronic Container Tracking's Success

S Customs and Border Protection (CBP) has recently announced plans to increase the level of support for the Customs-Trade Partnership Against Terrorism (C-TPAT), which grants shippers meeting security guidelines expedited processing at US ports. According to a new study by market

intelligence firm ABI Research, continuing government programs will be the main impetus for electronic container tracking. CBP is taking C-TPAT a step further by adding another tier of security, dubbed "C-TPAT Plus." This new program offers shippers immediate turnaround with no inspection upon arrival, in exchange for implementing more stringent requirements. These requirements include technologies that can monitor tampering from the point of origin and provide inspectors with a record of events. "This heightened level of support will boost electronic tracking of incoming containers," notes ABI Research analyst, David Schrier. "But a government mandate, rather than voluntary provisions, will be the only way the industry can realize significant volumes of electronically-tracked containers in the near future." The new ABI Research study, "Container Security and Tracking," examines evolving solutions and technologies for global electronic container tracking, including RFID, GPS, cellular, satellite, Ultrawideband, Bluetooth, barcode and optical character recognition. According to the study, myriad technologies have been developed for container tracking, but none of them have been commercially implemented to any great extent. Schrier adds, "The mass market devices will be those that can provide basic electronic supply chain management at a reasonable cost while working reliably within the port environment." While RFID-based solutions have met the requirements for military container tracking, the Wal-Mart and DoD mandates have been slow to take form. This created a lag in the RFID industry as a whole and slowed the adoption of container tracking across other industries. However, the study finds that there will be a significant market for RFID-based commercial container tracking.

Lab-on-a-Chip Finally Catching On in MEMS Field

fter two decades of de-Avelopment and despite increased competition from alternative technologies and from more companies developing lab-on-a-chip products, lab-on-a-chip technology finally appears to be making its mark within the Micro Electro MechanicalSystems (MEMS) industry,

according to In-Stat. Revenues of lab-on-a-chip devices are forecast to increase at a Compound Annual Growth Rate (CAGR) of 31.2 percent through 2008, with unit shipments nearly quadrupling over the same period. "Key applications include life science research (most notably genomic, pharmacogenomics and proteomics) as well as point-of-care diagnostics," said Marlene Bourne, In-Stat analyst. "The real application to keep an eye on, however, is the emerging field of clinical diagnostics. Here, lab-on-a-chip will allow physicians to diagnose infectious diseases, or even certain cancers, much more rapidly than they are able to now." The high tech market research firm has also found that over the next five years, point-of-care applications will continue to dominate total unit shipments of lab-on-a-chip devices, although life science research applications will be the primary driver behind revenue growth. Lab-on-a-chip devices have leveraged the field of microfluidics and the cost advantages of micromachining, allowing for the creation of complex arrays of channels, pumps and valves that have been etched into plastic, glass and/or silicon chips. Less than a dozen companies shipped lab-on-a-chip product for revenue in 2003, with those companies evenly split between those who are focused on point-of-care diagnostics and those who are focused on life science research as end-use markets. The report, "Market Snapshot: Lab-on-a-Chip," takes a look at the continually evolving lab-on-a-chip sector, including companies developing these devices and the markets they are pursuing. Forecasts of both unit shipments and revenues are provided through 2008. For more information, please visit: http://www.in-stat.com.

ABI Research Identifies Major Commercial **Telematics** Milestones for 2005

005 will witness two ma-Zjor commercial telematics developments across multiple continents, according to ABI Research. United Parcel Service (UPS) will introduce the first of 70,000 new Delivery Information Acquisition Devices (DI-ADs) it intends to deploy over the next three years,

starting with the US and Europe (DIADs are the wireless mobile terminals UPS drivers use to make their deliveries). "The DIADs now feature Global Positioning System (GPS)," says ABI Research analyst, David Schrier. "This makes them full-fledged commercial telematics devices that can now provide enhanced information regarding package delivery status, driver location, dispatching and routing. Dispatchers can issue turn-by-turn maps and directions, and change pickups, routes and schedules on the fly." ABI Research notes that in addition to GPS, the new mobile terminals will also feature Bluetooth and Wi-Fi. This will significantly widen the gap between UPS and its leading competitors, FedEx and DHL. Meanwhile, in Germany, the automated truck toll project finally went "live" on January 1st, after many long delays. What has been called "the world's most sophisticated road toll project" was resurrected early in 2004 in renewed negotiations between the German government and TollCollect, the consortium that includes DaimlerChrysler, Deutsche Telekom and French motorways operator Cofiroute. The addressable market of trucks that move to and through Germany is estimated at over one million. The required onboard units, featuring Siemens and Delphi Grundig equipment,

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Commercial Market

have been installed in some 150,000 trucks thus far. Schrier believes "there is a huge opportunity here for vendors to comarket their products to help shipping firms reduce idle time and overtime, track maintenance, among other fleet telematics applications. These can be combined with the onboard hardware of the toll system." ABI Research's "Commercial Telematics Service" examines the fleet telematics industry and provides insight into major market development such as those described above. Adjunct technologies such as cellular, satellite, DSRC, Wi-Fi, UWB and Bluetooth are also analyzed for their potential.

RFID Tag Market to Approach \$3 B in 2009

RFID tags are poised to become the most farreaching wireless technology since the cell phone, according to high tech market research firm In-Stat. Worldwide revenues from RFID tags will jump from \$300 M in 2004 to \$2.8 B in 2009. During this period, the technology will ap-

pear in many industries with significant impact on the efficiency of business processes. "By far the biggest RFID segment in coming years will be the cartons/supply

chain," says In-Stat analyst, Allen Nogee. "This segment alone is forecasted to account for the largest number of tags/labels from 2005 through 2009." Wal-Mart, which has mandated that top suppliers use the technology, will drive this market segment. In-Stat also found that the wide spread adoption of the technology will take a couple of years to really ramp up, as tags are still relatively expensive, ranging from a low of around \$0.15 to a high of over \$100. Privacy issues remain a concern for many applications, and currently courts and governments around the world are in the process of determining related legal issues. The second largest market for RFID, at least in the latter years of forecast, is consumer products, even though this market is one of the most privacy-sensitive areas. The report, "RFID Tags and Chips: Changing the World for Less Than the Price of a Cup of Coffee," investigates the many uses of RFID, looks at the costs of making the tags and examines many issues, including privacy, that can potentially slow its momentum. The report contains estimates and a five-year forecast for the number of tags, revenue from tags and semiconductor revenue from tags, broken-down into the following segments: livestock, domestic pets, humans, carton/supply chain security, pharmaceuticals, large freight containers, package tracking, consumer products, security/banking/purchasing/access control, and other. In addition, there are estimates and forecasts for tag/label ASP for each of these segments.

Surface Mount Noise Sources





Model#	Frequency	Amplitude
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SMN3110	100 kHz to 3.0 GHz	22 dB ENR
SMN7114	100 MHz to 3.0 GHz	45 dB ENR
SMN3018	200 MHz to 6 GHz	26 dB ENR

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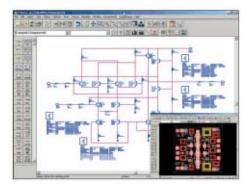
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AMPLIFIERS

Model Number	Frequency Range (GHz)	Gain (Min./Max.) (dB)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	Nom. DC Power (+15 V, mA)
	TEI	MPERATU	RE COMPI	ENSATED	AMPLII	FIERS		
AFS3-01000200-15-TC-6	1-2	36-40	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-02000400-15-TC-6	2-4	22-26	1.00	1.5	2.0:1	2.0:1	+5	125
AFS3-02000400-15-TC-6	2-4	26-30	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-04000800-20-TC-2	4–8	17-22	1.00	2.0	2.0:1	2.0:1	+5	70
AFS3-04000800-18-TC-4	4-8	25-30	1.00	1.8	2.0:1	2.0:1	+8	100
AFS2-02000800-40-TC-2	2-8	14-19	1.50	4.0	2.0:1	2.0:1	+5	70
AFS3-02000800-30-TC-4	2-8	22-27	1.50	3.0	2.0:1	2.2:1	+8	150
AFS2-08001200-30-TC-2	8-12	12-16	1.00	3.0	2.0:1	2.0:1	+5	70
AFS3-08001200-22-TC-4	8-12	24-28	1.00	2.2	2.0:1	2.0:1	+8	100
AFS4-12001800-30-TC-8	12-18	22-26	1.00	3.0	2.0:1	2.0:1	+8	250
AFS4-06001800-35-TC-8	6–18	22-26	1.00	3.5	2.0:1	2.0:1	+8	250
AFS6-06001800-35-TC-8	6–18	30-34	1.00	3.5	2.0:1	2.0:1	+8	400
AFS4-02001800-45-TC-5	2–18	18-24	1.50	4.5	2.2:1	2.2:1	+8	120

Note: All specifications guaranteed -54 to +85°C.

Many other frequencies, noise figures and gain windows are available.

Model Number	Frequency Range (GHz)	Gain (Min./Max.) (dB)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	DC Power
		HIGHE	R POWER	AMPLIFIE	RS			
AFS3-00050100-25-27P-6	0.05-1	36	1.50	2.5*	2.0:1	2.5:1	+27	300
AFS3-00100100-25-27P-6	0.1–1	33	2.00	2.5	2.0:1	2.5:1	+27	300
AFS3-00100200-25-27P-6	0.1-2	34	1.50	2.5	2.0:1	2.5:1	+27**	275
AFS3-00100300-25-23P-6	0.1–3	28	1.50	2.5	2.0:1	2.5:1	+23	275
AFS3-00100400-26-20P-4	0.1-4	24	1.50	2.6	2.0:1	2.0:1	+20	250
AFS4-00100600-25-20P-4	0.1–6	30	1.50	2.5	2.0:1	2.0:1	+20	300
AFS4-00100800-28-20P-4	0.1–8	30	1.50	2.8	2.0:1	2.0:1	+20	300
AFS4-00101200-40-20P-4	0.1-12	27	2.00	4.0	2.0:1	2.0:1	+20	300
AFS4-00501800-60-20P-6	0.5-18**	25	2.75	6.0	2.5:1	2.2:1	+20	350
AFS3-01000200-25-27P-6	1-2	32	1.50	2.5	2.0:1	2.0:1	+27	350
AFS4-02000400-30-25P-6	3 2-4	34	1.50	3.0	2.0:1	2.0:1	+25	250

- * Noise figure degrades below 100 MHz. Please consult factory for details.
- ** P1 dB spec below 0.2 GHz : +25 dBm.
- *** Usable to 0.1 GHz.

Note: Noise figure increases below 500 MHz in bands wider than .1-10 GHz.

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Model Number	Frequency Range (GHz)	Gain (Min.) (dB)	Gain Flatness (±dB)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	Nom. DC Power (+15 V, mA)
		MODE	RATE BAN	D AMPLIFI	ERS			
AFS2-00700080-06-10P-6	0.7-0.8	28	0.50	0.60	1.5:1	1.5:1	+10	90
AFS2-00800100-05-10P-6	0.8–1	30	0.50	0.50	1.5:1	1.5:1	+10	90
AFS3-01200160-05-13P-6 AFS3-01400170-06-13P-6	1.2–1.6 1.4–1.7	40 40	0.50 0.50	0.50 0.60	1.5:1 1.5:1	1.5:1 1.5:1	+13 +13	150 150
AFS3-01500180-06-13P-6	1.5–1.8	40	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-01500250-06-13P-6	1.5-2.5	38	1.00	0.60	1.8:1	1.8:1	+13	150
AFS3-01700190-06-13P-6 AFS3-01800220-06-13P-6	1.7–1.9 1.8–2.2	38 38	0.50 0.50	0.60 0.60	1.5:1 1.5:1	1.5:1 1.5:1	+13 +13	150 150
AFS3-01800220-00-13F-0	2.2-2.3	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02300270-06-13P-6	2.3-2.7	36	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02700290-06-13P-6	2.7-2.9 2.9-3.1	32 32	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02900310-06-13P-6 AFS3-03100350-06-10P-4	3.1-3.5	29	0.50 0.50	0.60 0.60	1.5:1 1.5:1	1.5:1 1.5:1	+13 +10	150 150
AFS4-03400420-10-13P-6	3.4-4.2	40	0.50	1.00	1.5:1	1.5:1	+13	200
AFS3-04400510-07-S-4	4.4–5.1	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-04500480-07-S-4 AFS3-05200600-07-10P-4	4.5–4.8 5.2–6	30 30	0.50 0.50	0.70 0.70	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	100 100
AFS3-05400590-07-S-4	5.4-5.9	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05800670-07-S-4	5.8-6.7	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-07250775-06-10P-4 AFS3-07900840-07-S-4	7.25–7.75 7.9–8.4	30 30	0.50 0.50	0.60 0.70	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	100 100
AFS4-08500960-08-S-4	8.5–9.6	32	0.75	0.80	1.5:1	1.5:1	+10	125
AFS3-09001100-09-S-4	9–11	26	0.50	0.90	1.5:1	1.5:1	+10	100
AFS4-09001100-09-S-4 AFS4-10951175-09-S-4	9–11 10.95–11.75	32 32	0.75 0.75	0.90 0.90	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	125 125
AFS4-10951175-09-3-4 AFS4-11701220-09-5P-4	11.7–12.2	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS2-12201280-14-5P-2	12.2-12.8	14	0.75	1.40	1.4:1	1.5:1	+5	80
AFS4-12201280-13-12P-4 AFS4-12701330-15-10P-4	12.2–12.8 12.7–13.3	25 30	1.50 0.75	1.30 1.50	2.0:1 1.5:1	2.0:1 1.5:1	+12 +10	200 175
AFS4-12701330-13-10F-4 AFS4-13201400-16-10P-4	13.2–14	30	0.75	1.60	1.5:1	1.5:1	+10	175
AFS4-14001450-15-10P-4	14-14.5	30	0.75	1.50	1.5:1	1.5:1	+10	175
AFS4-20202120-25-8P-4	20.2–21.2 21.2–24	24 23	1.00 1.00	2.50 2.80	1.5:1 2.0:1	1.5:1 2.0:1	+8 +10	175 100
AFS4-21202400-28-10P-4	21.2-24	23		2.60		2.0.1	+10	100
		OCT	AVE BAN	D AMPLIFIE	ERS			
AFS3-00120025-09-10P-4	0.1225	38	0.50	0.9	2.0:1	2.0:1	+10	125
AFS3-00250050-08-10P-4	0.25-0.5	38 38	0.50 0.50	0.9 0.8	2.0:1 2.0:1	2.0:1	+10	125
		38	0.50	0.9	2.0:1			
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6	0.25-0.5 0.5-1 1-2 1.2-2.4	38 38 38 38 34	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1	+10 +10 +10 +10	125 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4	38 38 38 38 34 32	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10	125 150 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6	0.25-0.5 0.5-1 1-2 1.2-2.4	38 38 38 38 34	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1	+10 +10 +10 +10	125 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12	38 38 38 38 34 32 28 28 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16	38 38 38 38 34 32 28 28 28 26 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +8	125 150 150 150 125 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2.6-5.2 4-8 8-12 8-16 12-18	38 38 38 34 32 28 28 26 28 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10	125 150 150 150 125 125 125 126 125 100
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16	38 38 38 38 34 32 28 28 28 26 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +8	125 150 150 150 125 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-005001100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24	38 38 38 34 32 28 28 26 28 28 24	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10	125 150 150 150 126 125 125 125 100 125
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-08001800-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5	38 38 38 38 34 32 28 28 26 28 28 24 18	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-005001100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24	38 38 38 34 32 28 28 26 28 28 24	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10	125 150 150 150 126 125 125 125 100 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2	38 38 38 38 34 32 28 28 26 28 24 18 MULTIC	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +10 +10 +10 +10 +110 +1	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-18001200-09-10P-4 AFS3-18002650-30-8P-4 AFS4-12001400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5	38 38 38 38 34 32 28 28 26 28 24 18 MULTIO	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.50	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2	38 38 38 38 34 32 28 28 26 28 24 18 MULTIC	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +10 +10 +10 +10 +110 +1	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS4-12002400-30-10P-4 AFS3-0300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-09-10P-4 AFS4-02001800-23-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18	38 38 38 38 34 32 28 28 26 28 24 18 MULTIO	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 2.00 1.50 2.00 2.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +110 +1	125 150 150 125 125 125 125 125 125 125 85 125 125 80 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-99-10P-4 AFS3-02000800-99-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18	38 38 38 38 34 32 28 28 28 28 24 18 MULTIO 38 22 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 2.00 2.00 2.00 2.00 2.00 2.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +110 +15 +10 +15 +10 +10 +10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125 100 125 85 125 125 80 125 125 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS4-12002400-30-10P-4 AFS3-0300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-09-10P-4 AFS4-02001800-23-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18	38 38 38 38 34 32 28 28 28 28 24 18 MULTIO 38 22 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 2.00 2.00 2.00 2.00 2.00 2.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +110 +1	125 150 150 125 125 125 125 125 125 125 85 125 125 80 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS4-12002400-30-10P-4 AFS3-0300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-09-10P-4 AFS4-02001800-23-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18	38 38 38 38 34 32 28 28 28 28 24 18 MULTIO 38 22 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 2.00 2.00 2.00 2.00 2.00 2.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +110 +1	125 150 150 125 125 125 125 125 125 125 85 125 125 80 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-015001100-06-10P-6 AFS3-01200200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-120012400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-00500200-08-15P-4 AFS3-00500200-08-15P-4 AFS3-02001800-23-10P-4 AFS4-02011800-23-10P-4 AFS4-08001800-22-10P-4 AFS4-08001800-22-10P-4 AFS3-00100100-09-10P-4 AFS3-00100100-09-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18 8-18	38 38 38 38 34 32 28 28 26 28 24 18 MULTIO 38 22 38 30 26 25 25 28 28 24 38 30 26 38 30 27 30 28 30 28 30 30 30 30 30 30 30 30 30 30 30 30 30	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 1.00 1.50 2.00 1.50 1.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 1.	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2 ND AMPLII 0.9 1.0	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +10	125 150 150 125 125 125 125 125 125 125 85 125 125 125 125 125 125 125 125 125 12
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Note: Noise figure increases below 500 MHz in bands greater than 0.1-10 GHz.

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INDUSTRY NEWS

- San-tron Inc. has been awarded a long-term contract by Boeing Integrated Defense Systems to be the primary supplier for the cable connectors used in the Joint Direct Attack Munition (JDAM) system. The connectors will be supplied to Boeing from the company's Ipswich, MA facility, allowing for the continued growth of San-tron in the coming year. The JDAM was developed in the early 1990s and has been used extensively in Operation Iraqi Freedom. It is critical in providing the military with an autonomous, all-weather, near-precision bombing capability. According to a recent St. Louis Business Journal article, about 3000 JDAM kits are assembled each month at Boeing.
- Agilent Technologies Inc. announced that Innovative Wireless Technologies (IWT) has selected Agilent's advanced design system (ADS) electronic design documentation (EDA) software and ultra-wideband (UWB) design guide to help prove UWB design concepts for advanced design prototyping. The multiyear agreement with Agilent includes licensing for ADS and its circuit system simulators. It also includes the UWB design guide with its latest multiband orthogonal frequency division multiplexing (MB-OFDM) capability and Agilent test equipment.
- The Connor-Winfield Corp. announced that it is purchasing from AG Communication Systems (AGCS) its manufacturing facility in Genoa, IL. ACGS is a wholly owned subsidiary of Lucent Technologies Inc., who had announced the closing of that facility. The terms of the transaction between Connor-Winfield and AGCS were not disclosed. The purchase will merge these two assets together with those of the Custom Manufacturing Services (CMS) division of Connor-Winfield to form a new division called Advanced Global Manufacturing Services. The existing CMS division is skilled in a variety of technologies, including thick film, wire and die bonding, and hybrids. The company's customers include clients in the military, instrumentation, telecom and medical industries.
- The European Commission has signed a research agreement for a two-year, €20 million modeling solution for software systems (MODELWARE) project. Coordinated by Thales, a consortium of 19 partners will address the issues of software systems development productivity and next generation software systems engineering methods and tools. This consortium includes leaders of software intensive industry firms, tool vendors, academia and consultancy companies based in eight European countries. The initiative recognizes that the challenge of system and software engineering is vital for the European economy pushing the limits of systems complexity and providing the engineering for the infrastructure of societies.
- China Telecom Corp. Ltd. (China Telecom) has awarded Ericsson the contract to build its next-generation IP backbone network, known as ChinaNet Next Carrying Network (CN2). Under the contract, the company will

AROUND THE CIRCUIT

provide total solutions for China Telecom's entire national core network of CN2 and the major part of its backbone network in the southern and western parts of the country. Ericsson will provide systems integration, supervision, and support and training services, together with the provision of equipment in partnership with Juniper Networks. Delivery and implementation of the contract will start in the first quarter of 2005, and the CN2 network is expected to begin service by the end of the year.

- In a move designed to strengthen its international leadership in net-centric technologies **Lockheed Martin Corp.** has entered into a definitive agreement to purchase **STASYS Ltd.**, a technology and consulting firm specializing in network communications and defense interoperability. STASYS Ltd. is headquartered in Farnham, Surrey, UK, and employs over 200 people in Europe and the US. Lockheed Martin Integrated Systems & Solutions, based in Gaithersburg, MD, will manage the company's business, and its employees will report to the Lockheed Martin UK wholly owned subsidiary.
- UK-based RFI Global Services Ltd., a supplier of wireless and electronics product approvals, has formed a strategic partnership with Dublin-based Benetel Ltd., a global provider of RF design and development services, specializing in radio frequency product design for Bluetooth, WiFi, broadband wireless access systems, GPS, WiMAX, RFID and ultra wideband technologies. The relationship will allow Benetel, with RFI's approval, expertise and extensive facilities, to offer a complete solution to its customers from conception, RF design, development through to the compliance testing and certification of the finished product. In turn, RFI will be able to offer RF design services through the company to those customers needing support in this area.
- EMS Technologies Inc. received the Boeing Exceptional Company Performance Award for its contribution to the International Space Station (ISS). This award is part of NASA's Space Flight Awareness program that recognizes the highest levels of product quality, technical and cost performance, and adherence to challenging schedules. EMS Technologies' Space & Technology/Montreal division designed, integrated and tested all of the principal communications suites for the ISS, featuring fully redundant S-band Antenna Contingency System (ACS) antennas. The ACS provides telemetry, tracking and command as well as voice communications functions to and from the ISS and the Ku-band Space-to-Ground Antenna System (SGANT), providing video and high data-rate scientific data communications.
- AR Modular RF, a division of AR Worldwide, announced that its battle-tested KMW1030 (20 watts minimum CW, 30 to 512 MHz) man-pack booster amplifier has been successfully integrated into a mobile briefcase configuration by Diversified Technology LLC. The new configuration includes associated encrypted radio and battery/power supply systems, and will be deployed in high

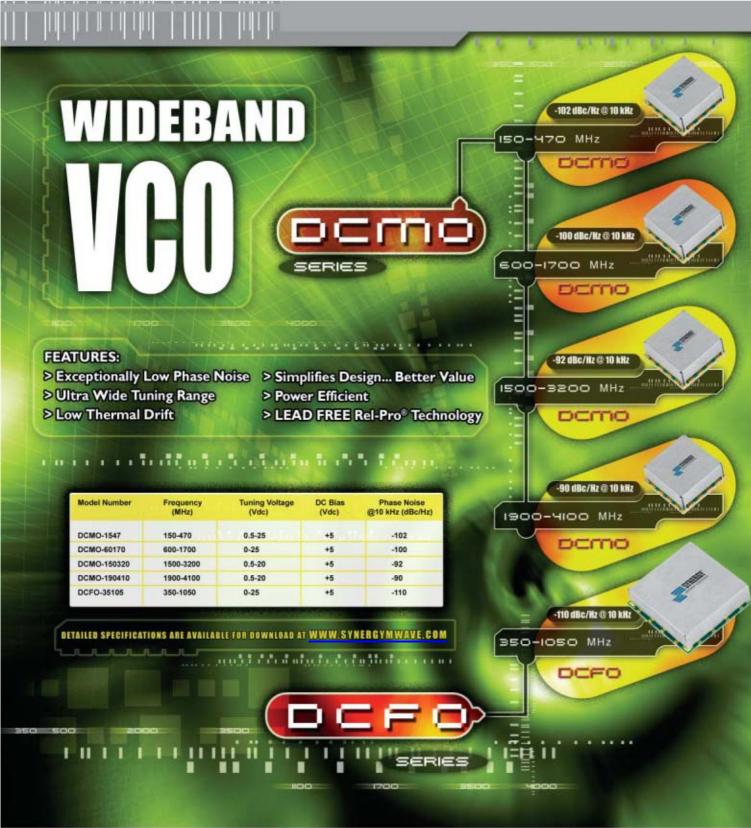
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AROUND THE CIRCUIT

level government security units. The exact application for the KMW1030 suitcase is classified information.

- Artesyn Technologies Inc. announced that it has received a 2004 Golden Link Award from Lucent Technologies' Supply Chain Networks Group. Lucent's Mobility Solutions Group is currently using Artesyn's network and packet processing blades in its FlexentTMRadio Network Controller, and to support its next-generation mobile data solutions. Lucent's optical group is using Artesyn's controllers in its DWDM (Dense Wave Division Multiplexing) optical long-haul equipment.
- Applied Wave Research Inc. (AWR®), a provider of high frequency electronic design automation (EDA) tools, announced that it is teaming with Rohde & Schwarz, a company with an international presence in the fields of test and measurement (T&M), information technology and communications. The partnership will offer test solutions using Rohde & Schwarz high specification T&M instruments and EDA software, as well as provide the unique ability to use measured data in place of models when simulating complex systems. In addition, Rohde & Schwarz will strengthen the AWR sales channel by providing Microwave Office® and Visual System Simulator™ (VSS) design solutions throughout Europe.
- Eagleware has changed its name to Eagleware-Elanix to reflect Eagleware's recent aquisition of Elanix Inc. All of the capabilities of both the Eagleware and Elanix product lines will continue to be sold, supported and enhanced. The products will be fully integrated to provide a complete algorithms-to-artwork design environment for communications systems.
- Northrop Grumman Space Technology (NGST) has announced that Mini-Systems Inc. (MSI) has once again reached GOLD Supplier status based on its ongoing efforts to supply excellent quality, repeated responsiveness and delivery performance. MSI supplies precision, high reliability passive components to industries such as medical, satellite, military and aerospace, and manufactures thick/thin film chip resistors, MOS capacitors, attenuators, hermetic packages and hybrid assemblies.
- Xilinx Inc. and Ansoft Corp. announced a new gigabit interconnect design kit that allows customers to perform accurate "what if" analyses on high speed printed circuit board (PCB) and backplane designs. Powered with Virtex-Il Pro™ X series FPGAs from Xilinx, the kit enables engineers to anticipate problems early in the design phase and predict the quality of a signal, thereby significantly minimizing lab debug times and costly board respins.
- IMS Connector Systems has expanded its worldwide network and gained the Italian company BCE srl. as a new sales partner, with the remit to include the company's complete product range alongside its own. This includes RF connectors and cable assemblies, components and antennas for mobile devices, as well as SMBA® connectors for in-car communication. BCE srl. has been sell-

ing electronic components for the past twelve years and provides project development and realization support for its customers in Italy.

- Aeroflex announced that it has changed the name of Racal Instruments Wireless Solutions (RIWS) to Aeroflex. The adoption of the new name completes the transition of RIWS to the Aeroflex brand. Aeroflex purchased RIWS, based in Burnham, England, from Racal Instruments Group Holdings on July 31, 2003. In related news, Aeroflex reported net sales for the first quarter ending September 30, 2004 at \$109.2 million, an increase of 43 percent over the same period last year.
- Andrew Corp. has acquired Xenicom Ltd., a privately held UK-based provider of software solutions that help telecommunications operators plan, launch and manage wireless networks. Under terms of the acquisition, Andrew paid approximately \$11.5 million (US) cash with additional cash considerations possible if certain financial performance goals are reached over a two-year period. Xenicom generated approximately \$11.0 million (US) in sales during the 12 months ending September 2004. Its customers include several European mobile operators. Xenicom's solutions and products help its customers achieve greater efficiency and cost savings, improved service levels, and increased flexibility and control in managing 2G, 2.5G and 3G wireless networks. With Xenicom's software capabilities and products, Andrew sees significant opportunity to help wireless operators manage and optimize infrastructure as they transition to new networks based on 3G standards.
- Advanced Power Technology Inc. announced that it has acquired the business assets of PowerSicel Inc. for approximately \$5.4 million in cash, 44,124 APT stock options in exchange for the PowerSicel stock options and 19,402 APT stock options for the retention of key employees. The transaction is consistent with APT's objective of expanding its technology leadership in high power, high frequency RF power and switching power, including through strategic acquisitions. PowerSicel's expertise in silicon carbide and other compound semiconductors complements APT's current portfolio of RF products, which operate at frequencies ranging from 1 MHz to 4 GHz and are sold into applications such as semiconductor capital equipment, medical imaging, radar, avionics and wireless communications.
- WJ Communications Inc. announced a definitive agreement to acquire privately held Telenexus Inc., Richardson, TX. Telenexus develops RFID products for a broad range of industries and markets. Under the terms of the agreement, WJ Communications will pay approximately \$10 million in cash and stock in exchange for all Telenexus stock. Additionally, if the Telenexus operations achieve certain revenue over an 18-month period, Telenexus shareholders will receive further consideration of up to \$5 million in a combination of stock and cash. The merger of Telenexus is subject to customary closing conditions.
- SiGe Semiconductor Inc. reported sales revenues of US\$20.1 million (CDN\$24.6 M) for 2004, a five fold increase compared to the previous year. The company's success was fueled by the growing demand for its integrated circuits (ICs) used in systems such as WLAN, BluetoothTM

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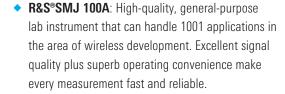


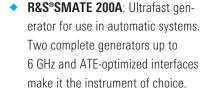


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AROUND THE CIRCUIT

and global positioning by satellite (GPS) systems. SiGe Semiconductor also ended the year with a shipping milestone, with more than 30 million units sent to customers around the world, a significant portion going to China.

CONTRACTS

- M/A-COM, a division of Tyco, a Lowell, MA-based manufacturer of radio systems, announced that it has won an \$18.9 million contract to provide a critical communications system to the city of Harrisonburg and Rockingham County, VA. The system will allow public safety and public service agencies to communicate with one another, during both emergency situations and day-to-day tasks. Until now, they have not been able to communicate over their disparate radio systems.
- Wi-LAN Inc., a global provider of broadband wireless communications solutions and technologies, and a charter member of the WiMAX Forum, announced the receipt of a US\$5.0 million order for Wi-LAN's broadband wireless solutions to provide data and voice services to remote towns in a harsh arid environment. Wi-LAN expects to fill the order in the first half of 2005.

FINANCIAL NEWS

Merrimac Industries Inc. announced results for the third quarter of 2004. Sales for the quarter were \$7,620,000, an increase of 19.9 percent compared to the third quarter of 2003 sales of \$6,357,000. Operating income in the third quarter of 2004 was \$384,000, compared to an operating loss of \$(431,000) in the third quarter of 2003. Net income for the third quarter of 2004 was \$315,000 or \$0.10 per share compared to a net loss of \$(484,000) or \$(0.16) per share for the third quarter of 2003.

PERSONNEL

- Andrew Monk has been appointed chief executive officer of Innos Ltd., the UK research and development company delivering expertise in silicon, MEMS and nanotechnologies. With over twenty years experience in high technology industries and ten years senior management expertise, he aims to lead the company into new commercial and industrial markets, while retaining its strong links with academic institutions. Previously, he was a successful business manager at the Center for Enterprise and Innovation (CEI).
- **William P. Sullivan** has been named president and chief executive officer of Agilent Technologies Inc. Sullivan, 55, currently Agilent's executive vice president and chief operating officer, succeeds Edward W. Barnholt, who has announced his retirement as chairman, president and CEO of the company. Bernholt, 61, had previously been an executive vice president of Hewlett-Packard and the general manager of its measurement organization that incorporated all of Agilent's business groups. In addition to his current responsibilities as executive vice president and COO of Agilent, Sullivan has had overall responsibility for the electronic products and solutions group (EPSG).

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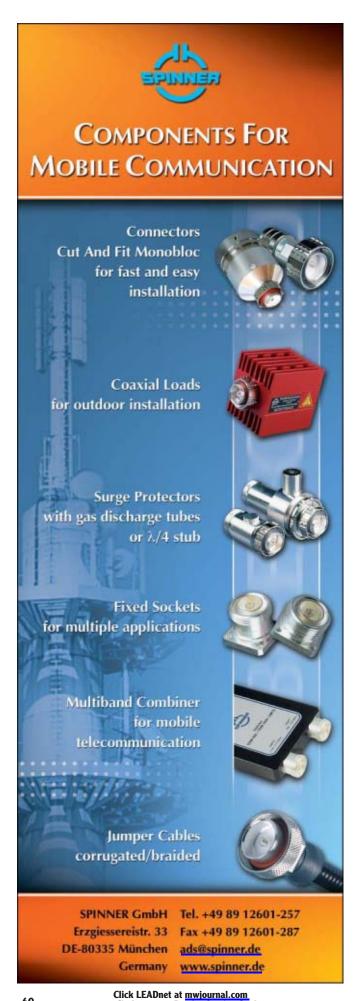
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AROUND THE CIRCUIT

- David Wightman will serve a dual role as president of Dow-Key Microwave and K&L Microwave. Both companies are part of Dover Corp., and report to the newly formed Dover electronics subsidiary. To assist him, Wightman appointed Adolf Cheung to general manager, Dow-Key Microwave. In this capacity Cheung will report directly to Wightman. In addition, Julie Williams returns to Dow-Key as territory sales manager and Vince Carter returns as product line sales manager.
- Jude Panetta has been named group vice president of Andrew Corp.'s satellite communications. Panetta, formerly vice president and general manager of RF power amplifiers for Andrew's base station subsystems group, replaces Paul Cox, who has resigned to become president of Smith's Interconnect, a business within the specialty engineering division of UK-based Smiths Group.



▲ Daryll Saunders

■ XMA Corp. announced the appointment of **Daryll Saunders** as VP, engineering and operations. In this position, Saunders will be responsible for expanding XMA's engineering and manufacturing capabilities in both Manchester, NH, and Tianjin, China. Saunders has over 20 years of technical experience as general manager of the Aeroflex China facility in Nanjing, as engineering manager at Aeroflex/In-

met and as outsourcing manager and member of the technical staff at Tyco M/A-COM.

- WJ Communications Inc. announced the appointment of **Ephraim Kwok** to the position of senior vice president and chief financial officer. Kwok has substantial experience as a CFO of both public and private semiconductor companies. Most recently, he was CFO of Summit Microelectronics, a privately held company. He also served as CFO of Elantec Semiconductor, a public company acquired by Intersil.
- Sonnet Software has appointed **Robert O'Rourke** as its western US sales engineer. O'Rourke has worked in the past for Tektronix, Picosecond Pulse Labs, Ansoft and Applied Wave Research. He is based in Colorado. Sonnet also named **Charlotte Blair** as its eastern US senior sales engineer based in Connecticut. Blair has over 15 years of design experience in the RF industry, which includes employment at Radio Frequency Systems, Lamina Ceramics and X-Cel Technologies. Finally, **Yun Chase** has been appointed Sonnet's technical marketing manager. In his new role, Chase will be responsible for increasing and maintaining Sonnet's exposure in the RF/high speed EDA market place as well as supporting the newly expanded sales force. Prior to joining Sonnet, Chase held technical marketing positions with DLI and AVX Corps.
- Park Electrochemical Corp. announced the appointment of **Jonathan Spiegel** as product director for the company. He will be responsible for management of a portion of the company's advanced technology products. Spiegel will coordinate product development activities

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Frequency (MHz)	Vtune (Vdc)	Kvco (MHz/V)	Ø _N @10KHz (dBc/Hz)	Output Power (dBm)	2nd Harmonic (dBc)	Pulling (MHz)	Pushing (MHz/V)	Vcc (Vdc)	lcc (mA)	Operating Temp (°C)
100 to 200	0 to 12.5	10	-111	7 ± 5	-10	<1	<1	12.0	26	-40 to 85
200 to 239	0.5 to 4.5	14	-120	7.5 ± 2.5	-22	<0.5	<0.5	5.0	16	-40 to 85
1213 to 1341	0.5 to 4.5	38	-108	2.5 ± 2.5	-15	<1	<1	5.0	22	-40 to 85
1710 to 1850	0 to 3	150	-89	3 ± 3	-10	<7	<5	3.0	12	-40 to 85
2600 to 2800	1 to 15	22	-110	10 ± 3	-15	<0.5	<0.5	10.0	34	-40 to 85
2760 to 3000	0 to 15	18	-110	12.5 ± 2.5	-20	<1	<1	10.0	29	-40 to 85
3900 to 6000	0 to 20	126	-80	4.5 ± 4.5	-14	<36	<14	5.0	21	-40 to 85
4499 to 4501	0.5 to 4.5	12	-104	2 ± 2	-15	<1	<2	5.0	20	-20 to 70
Frequency (MHz)	Step Size (kHz)	Output Power (dBm)	Ø _N @ 10KHz (dBc/Hz)	Ø _N @ 100KHz H (dBc/Hz)	2nd Iarmonic (dBc)	Ref Sup (dBc)	Lock Time (msec)	Vcc (Vdc)	Icc (mA)	Operating Temp (°C)
	Size	Power	10KHz	100KHz H	larmonic .	Sup	Time			Temp
(MHz)	Size (kHz)	Power (dBm)	10KHz (dBc/Hz)	100KHz H (dBc/Hz)	larmonic (dBc)	Sup (dBc)	Time (msec)	(Vdc)	(mA)	Temp (°C)
(MHz)	Size (kHz)	Power (dBm) 5 ± 2	10KHz (dBc/Hz)	100KHz H (dBc/Hz)	larmonic (dBc)	Sup (dBc)	Time (msec)	(Vdc)	(mA) 40	Temp (°C) -40 to 85
(MHz) 1444 to 1446 1500 to 1600	Size (kHz) 1000 1000	Power (dBm) 5 ± 2 1.5 ± 2.5	10KHz (dBc/Hz) -120 -103	100KHz H (dBc/Hz) -140 -124	-20	Sup (dBc) -59 -70	Time (msec) 3 3	5.0 5.0	(mA) 40 40	Temp (°C) -40 to 85 -40 to 85
(MHz) 1444 to 1446 1500 to 1600 2762 to 2824	Size (kHz) 1000 1000 250	Power (dBm) 5 ± 2 1.5 ± 2.5 0 ± 3	10KHz (dBc/Hz) -120 -103 -102	100KHz (dBc/Hz) -140 -124 -123	-20 -15 -15	Sup (dBc) -59 -70 -70	Time (msec) 3 3 2	5.0 5.0 5.0	(mA) 40 40 35	Temp (°C) -40 to 85 -40 to 85 -40 to 85
(MHz) 1444 to 1446 1500 to 1600 2762 to 2824 3230 to 3260	Size (kHz) 1000 1000 250 125	Power (dBm) 5 ± 2 1.5 ± 2.5 0 ± 3 0 ± 3	10KHz (dBc/Hz) -120 -103 -102 -106	-140 -124 -123 -129	-20 -15 -15	Sup (dBc) -59 -70 -70 -70	Time (msec) 3 3 2	5.0 5.0 5.0 5.0	(mA) 40 40 35 40	Temp (°C) -40 to 85 -40 to 85 -40 to 85 -40 to 85
(MHz) 1444 to 1446 1500 to 1600 2762 to 2824 3230 to 3260 3305 to 3335	Size (kHz) 1000 1000 250 125 125	Power (dBm) 5 ± 2 1.5 ± 2.5 0 ± 3 0 ± 3 0 ± 3	10KHz (dBc/Hz) -120 -103 -102 -106 -106	-140 -124 -123 -129 -130	-20 -15 -15 -12	Sup (dBc) -59 -70 -70 -70 -70	Time (msec) 3 3 2 1 1	5.0 5.0 5.0 5.0 5.0	(mA) 40 40 35 40 35	-40 to 85
	(MHz) 100 to 200 200 to 239 1213 to 1341 1710 to 1850 2600 to 2800 2760 to 3000 3900 to 6000	(MHz) (Vdc) 100 to 200 0 to 12.5 200 to 239 0.5 to 4.5 1213 to 1341 0.5 to 4.5 1710 to 1850 0 to 3 2600 to 2800 1 to 15 2760 to 3000 0 to 15 3900 to 6000 0 to 20	(MHz) (Vdc) (MHz/V) 100 to 200 0 to 12.5 10 200 to 239 0.5 to 4.5 14 1213 to 1341 0.5 to 4.5 38 1710 to 1850 0 to 3 150 2600 to 2800 1 to 15 22 2760 to 3000 0 to 15 18 3900 to 6000 0 to 20 126	(MHz) (Vdc) (MHz/V) (dBc/Hz) 100 to 200 0 to 12.5 10 -111 200 to 239 0.5 to 4.5 14 -120 1213 to 1341 0.5 to 4.5 38 -108 1710 to 1850 0 to 3 150 -89 2600 to 2800 1 to 15 22 -110 2760 to 3000 0 to 15 18 -110 3900 to 6000 0 to 20 126 -80	Frequency (MHz)Vtune (Vdc)Kvco (MHz/V) $\emptyset_N@10KHz$ (dBc/Hz)Power (dBm)100 to 2000 to 12.510-111 7 ± 5 200 to 2390.5 to 4.514-120 7.5 ± 2.5 1213 to 13410.5 to 4.538-108 2.5 ± 2.5 1710 to 18500 to 3150-89 3 ± 3 2600 to 28001 to 1522-110 10 ± 3 2760 to 30000 to 1518-110 12.5 ± 2.5 3900 to 60000 to 20126-80 4.5 ± 4.5	Frequency (MHz) (Vdc) (MHz/V) $\oslash_{N}@10\text{KHz}$ Power (dBm) (dBc) (dBc) (dBc) (dBc) (dBc) (dBm) (dBc) (dBc) (dBc) (dBc) (dBc) (dBm) (dBc)	Frequency (MHz) Vtune (Vdc) Kvco (MHz/V) $\emptyset_N@10\text{KHz}$ (dBc) Power (dBm) Harmonic (dBc) Pulling (MHz) 100 to 200 0 to 12.5 10 -111 7 \pm 5 -10 <1	Frequency (MHz) Vtune (Vdc) Kvco (MHz/V) \emptyset_N @10KHz (dBm) Power (dBm) Harmonic (dBc) Pulling (MHz/V) 100 to 200 0 to 12.5 10 -111 7 ± 5 -10 <1	Frequency (MHz) Vtune (Vdc) Kvco (MHz/V) $\emptyset_N@10\text{KHz}$ (dBc/Hz) Power (dBm) Harmonic (dBc) Pulling (MHz) Vcc (Vdc) 100 to 200 0 to 12.5 10 -111 7 ± 5 -10 <1	Frequency (MHz) Vtune (Vdc) Kvco (MHz/V) $\emptyset_N @ 10 \text{KHz}$ (dBc/Hz) Power (dBm) Harmonic (dBc) Pulling (MHz) Pushing (MHz/V) Vcc (Vdc) Icc (MA) 100 to 200 0 to 12.5 10 -111 7 ± 5 -10 <1

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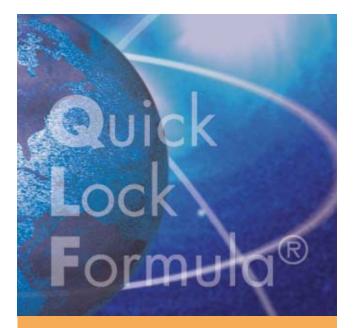
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from research and development project criteria identification through product commercialization.

■ MIMIX Broadband Inc. announced the appointment of **Peter J. Hales** to vice president European sales. Hales has 21 years of experience in sales and marketing in the microwave and millimeter-wave industry. Previously, he was the director of European sales for Raytheon's commercial electronics division. In related news, **Vincent E. Pelliccia** has been appointed vice president North American sales. Pelliccia has 19 years of experience in microwave modules, semiconductors and systems. Most recently, Pelliccia was with Paratek Microwave. Also, **Kit Yong** was named vice president for business development and Asian sales. Previously, Yong was VP business development at LinCom Wireless.

REP APPOINTMENTS

- Richardson Electronics, LaFox, IL, announced it has signed a distribution agreement with Fractus, Barcelona, Spain, a developer of antennas for the telecommunications, electronics and military industries. Under the terms of the agreement, Richardson Electronics will operate as a global distributor for Fractus' complete line of embedded antennas for short-range wireless applications, filling a need in Richardson's components solutions line card. Richardson's product offering will now encompass a wide array of components for the emerging broadband wireless access market to accommodate WiFi, WiMAX, Zigbee and Bluetooth technologies.
- XMA Corp., Manchester, NH, and BFi OPTiLAS, Evry, France, announced the signing of a distribution agreement. Under the terms of the agreement, BFi OPTiLAS will distribute XMA's full line of standard RF and microwave components including terminations, attenuators and other passive products in the European markets. BFi OPTiLAS, a subsidiary of AVNET Corp., is a pan European technical distributor of specialist products and services.
- Applied Wave Research Inc. (AWR) announced the appointment of TeraSoft Inc. as a value-added reseller of AWR software in Taiwan. Under the terms of the agreement, TeraSoft will provide electronic systems and integrated circuit designers with AWR products and technical support. TeraSoft will handle sales, support and administration for the complete line of AWR next-generation products, including Microwave Office, Visual System Simulator™ and Analog Office.™ Timing Huang of TeraSoft can be contacted by phone at (03) 611-5678 or e-mail: awr@terasoft.com.tw.
- MIMIX Wireless Inc. announced the appointment of sales representatives in China (Fortress), in South Korea (S-TEC Int'l. Co. Ltd.) and China (Skypeak).
- TRM (Technical Research and Manufacturing) announced the appointment of four new representative organizations for its North American network. They are: Brooks Associates, Pennsylvania, upstate New York and southern New Jersey; Merridian Marketing, Montana, Wyoming, Utah and Colorado; T&E Repco, Florida; and WES TECH Associates, the 13 mid-western states.

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TECHNICAL FEATURE

DE-EMBEDDING USING A VECTOR NETWORK ANALYZER INCLUDING CALIBRATION AND MEASUREMENT TECHNIQUES

The inclusion of adapters and test fixtures in a measurement setup is often necessary even if the consequence is less accuracy. De-embedding the device characteristics has been traditionally the most effective method of minimizing the negative effects. However, the process of de-embedding has been a laborious, expensive procedure restricted to a laboratory environment. De-embedding has recently been automated to utilize the technique in both the laboratory and production environments. This article reviews S-parameter and vector network analyzer (VNA) fundamental concepts and describes the process of modeling adapters and de-embedding their effects. A summary of the advantages of using de-embedding techniques in a production environment is presented.

MEASURING NON-INSERTABLE DEVICES

The potential for significant measurement errors must be addressed when measuring devices that are non-insertable. In a coaxial environment, a device under test (DUT) with a male-to-male or female-to-female connector configuration and devices with different connector styles are considered to be non-in-

sertable. These types of devices are difficult to measure accurately because the test ports cannot be directly mated during the through calibration process without the addition of an adapter. A typical VNA calibration requires connection of a through device with zero electrical length and uses the information to correct for errors associated with the load match. However, if the electrical length of the through varies from calibration to measurement, then the phase relationship changes. As a result, the error correction for the load deteriorates. The amount of deterioration depends on the difference in line length between the two events. As a guideline, if the change in line length varies by more than one tenth of a wavelength, there will be no improvement in the load match compared to the system's raw performance. If the difference in line length is a quarter wavelength, the system performance can be 6 dB worse than the raw uncorrected performance. At 10 GHz, one-quarter wavelength is about 0.3 inch, in air. This clearly

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Fig. 1 DCM COAX-3000 system with modeled adapters and de-embedding module.

demonstrates the need for minimizing the effects of adapters in measurements. It also illustrates how often removal of the adapter effect is needed. Any device that has a maleto-male or female-to-female configuration, or uses different connector types, needs some form of adapter removal technique applied. The most significant effects on measurements occur when measuring devices with poor return losses, such as at the output port of an amplifier, or devices with low insertion loss, such as cable assemblies. As will be seen, de-embedding the adapter is found to be the most accurate measurement method, and when the entire process is automated, such as with the system shown in *Figure 1*, the most practical.

VECTOR NETWORK ANALYZER MEASUREMENTS

A well-designed vector network analyzer has the ability to provide very accurate measurements of the phase and magnitude of a signal over a broad frequency range. A primary reason for the accuracy is the ability to identify and remove the systemic errors inherent in the measurement system. The most popular method of error correction applied during VNA measurements is the twelve-term error correction, also known as a full two-port S-parameter calibration, and is possible due to the following capabilities:

• Phase-locked frequency. It provides repeatable frequency performance characteristics over time. Frequency sensitive errors are correctable because errors measured at specific frequencies during calibra-

tion will be repeated during measurement.

- Stability over time. Errors measured during calibration should not drift. The longer the system is stable, the longer the calibration remains valid. An additional caveat to calibration stability is test port connector wear and damage. As long as the test port remains intact, the calibration will be valid.
- Stability over temperature. System characteristics should have minimal drift over the designated operating temperature range. Variations due to temperature drift should be specified in order to determine their effects on the measurement.
- Ability to measure phase. This is the key attribute of the VNA and a primary reason for its accuracy. The effective measurement range of the VNA is much wider than for a scalar network analyzer due to its ability to identify and remove the phase and magnitude contribution of error signals.

TWELVE-TERM ERROR CORRECTIONS

System errors exist in any measurement system. The following significant system errors, inherent in vector network analyzers, are found when the incident, reflected and transmitted signals are measured:

- *Directivity error*: The lack of separation between the incident and reflected signals.
- Reflection tracking: Variations in system response to the reflected signal.
- Source match: How well matched the test port is to the transmission line characteristic impedance.
- *Transmission tracking:* Variations in system response to the forward propagating signal.
- Load match: The quality of the test port match when used as a termination for the reverse signal.
- Cross talk: System leakages.

During calibration, six significant system errors are identified in both the forward and reverse directions giving the full twelve terms. The VNA is able to identify system errors by measuring known devices and comparing the measured results to the expected results. The calibration procedure then removes the extraneous error signals and provides the corrected mea-

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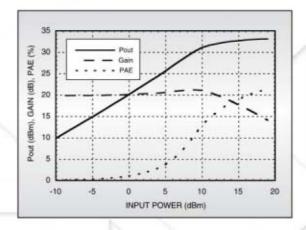
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surements. For example, the directivity performance determines how well the coupler in the measurement system separates the reflected signal from the incident. If a coupler has a specified directivity of 40 dB, then the leakage signal will be 40 dB down from the incident signal and will define the limit of the reflected measurements. The magnitude and phase of the forward directivity leakage is measured during calibration by inserting a reference termination in port 1 and measuring the leakage signal at each calibration frequency. Notice that since the termination is not perfect, the signal measured will be a combination of directivity error and termination reflection. Since the directivity error is the dominant signal, it is possible to identify the phase and magnitude of directivity error down to the level of the termination leakage. During the error correction process, the VNA mathematically removes the identified directivity error. If the termination return loss is 60 dB, then the error correction process will improve the system directivity from the 40 dB

hardware limit to an effective directivity of 60 dB.

The process of identifying the six system errors requires a set of known calibration devices attached to the test ports of the VNA, which in turn establishes the calibrated measurement planes. Note that the measurement plane can exist at the system front panel or at the end of a cable. The location of the calibrated measurement plane is established during the connection of the open and short reference devices. Typically, calibration is performed at the end of phase stable test port cables for various reasons. One is due to the requirement for connection of the two test ports during the through calibration. Test port cables also provide a means of extending the calibrated measurement port to the DUT.

ALTERNATIVE CALIBRATIONS

The calibration process described thus far includes the connection of a short, open, load and through, and is commonly referred to as a SOLT calibration. As was seen, there are times, such as when a non-insertable device

is being measured, when a direct through connection is not possible. There are also situations, such as using test fixtures or measuring onwafer, when a quality termination is difficult to provide. Alternative types of calibrations have been offered in order to circumvent the requirement for terminations or through connections. Note that as long as the six terms are identified in both directions, then a full twelve-term error correction is still possible when using alternative calibration procedures. Following is a summary of the more commonly used alternatives.

Through Reflect Line (TRL)

This method uses a through, reflection and line length during the calibration process. The advantage of this method is the elimination of the need for a termination device. Any known reflective device, typically a short, can provide the reflection step. Since this method requires a through connection, it does not resolve the problem of measuring a non-insertable coaxial device.

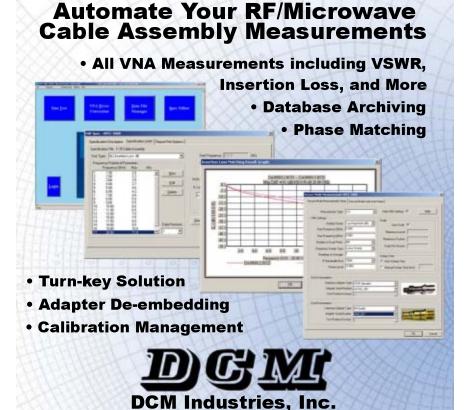
Line Reflect Line (LRL)

LRL calibration does not require a through connection of zero electrical length for calibration. Instead, two known lengths of transmission line are used. This method is more commonly used for on-wafer rather than coaxial measurements. For coaxial measurements, the two line lengths need to be manufactured with high precision and mirror the same connector configuration as the device being measured. For example, if the device to be tested is a Type N male to 3.5 mm male, then two line lengths with Type N male to 3.5 mm male configurations are required. Although this process eliminates the need of the through calibration step, the line lengths are time consuming and expensive to produce. Also, a calibration kit for each device configuration needs to be produced and the method is bandwidth-limited.

Through-line Standard

This method uses the same basic components as the SOLT except that the calibration kit is modified to include a through line of known performance. The same limitations apply as with the previous alternatives; multiple devices must be manufactured, the devices must be accurately measured and the error correction model

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NEW!	0.4 - 2.2	Power Amp, 1 Watt	16	48	7	30	ST89	HMC452ST89
NEW!	0.4 - 2.2	Power Amp, 1.6 Watt	14.5	50	7	32	ST89	HMC453ST89
	0.4 - 2.5	High IP3 Amp, 1/2 Watt	12.5	42	6	27	ST89	HMC454ST89
NEW!	0.45 - 2.2	Power Amp, 1 Watt	16	48	7	30	QS16G	HMC452QS16G
NEW!	0.45 - 2.2	Power Amp, 1.6 Watt	14.5	50	7	32	QS16G	HMC453QS16G
NEWI	0.8 - 1.0	Medium Power Amp	26	40	8.5	26	QS16G	HMC450QS16G
	1.6 - 2.2	Medium Power Amp	22	40	5.5	27	QS16G	HMC413QS16G
NEW!	1.7 - 2.2	Power Amp, 1 Watt	26	46	5.5	30.5	QS16G	HMC457QS16G
	2.2 - 2.8	Power Amplifier, 1/2 Watt	20	39	7	27	MS8G	HMC414MS8G
	3 - 4	Power Amplifier, 1/2 Watt	21	40	5	27	MS8G	HMC327MS8G
NEW!	3.3 - 3.8	Power Amplifier, 1 Watt	31	45.5	6	30.5	LP4	HMC409LP4
	5-7	Medium Power Amp	15	40	5.5	25	MSBG	HMC407MS8G
	5.1 - 5.9	Power Amplifier, 1 Watt	20	43	6	30	LP3	HMC408LP3

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must be modified. Due to sensitivities of modeling techniques and bandwidth limitations, this procedure is only useful for frequencies up to 6 GHz.

ALTERNATIVE VNA MEASUREMENT METHODS

In addition to alternative calibration techniques, there are alternative measurement methods that have been used for adapter extraction:

Port Extension/Electrical Delay

This is usually performed from the VNA front panel operation. The technique mathematically moves the measurement plane towards the DUT by a given electrical length. This technique is a pure mathematical calculation and assumes that the adapter has no effects on the phase or magnitude of the incoming signal. Since this is never the case, the use of this function seldom provides satisfactory improvements and is typically only used as an electrical delay when analyzing phase variations in the DUT.

Direct Measurement

This is often cited as a method for calibrating test fixtures when used in a coaxial-to-microstrip situation. As mentioned previously, the difficulty is to provide accurate reference standards, which limits the effective directivity of the calibration. Also, notice that the through calibration is a concern since the probe tips cannot be directly connected. A preferred method is to characterize the test fixture using one of the alternative calibration techniques described, or removing the effects through de-embedding.

Adapter Substitution

During the open, short and load calibration, an adapter with the correct connector type for the device being measured is used. The electrical length of the adapter must be known. Then, when the calibration calls for the through connection, the adapter is removed and replaced with an adapter with an alternative connector configuration allowing direct connection of the two test ports. This second

adapter must have the same electrical length as the adapter used during the previous calibration steps. This method minimizes the errors due to different electrical lengths but does not address the changes in impedances between the two adapters. This method requires extensive, well-defined adapter kits for each measurement condition, which are difficult and expensive to provide.

Time Domain

Time domain techniques can be used to measure the performance characteristics of a device after a oneport calibration. This is done by using the standard calibration devices of an open, short and termination. Note that a through connection is not required. For best results, the calibration and measurement need to be performed over as broadband condition as possible. This should be a minimum of 50 GHz for a 20 GHz device. During measurement in the time (or distance) domain, the port of the DUT is located and 'gated.' While using the gated function in the time domain, the fast fourier transform function (FFT) transfers the time domain information to the frequency domain and provides S-parameter information relative to frequency. This method can provide very good results; however, it is a complicated, labor-intensive procedure requiring careful planning and execution. It also requires a costly broadband system (50 to 60 GHz) with the appropriate calibration kits.

De-embedding

If the scattering parameters of an adapter are known, then the effects of the adapter can be de-embedded from the measurements mathematically. Since the method is a mathematical process, the results will be as accurate as the S-parameters used to model the adapter. Because of this, de-embedding can produce very accurate results and is the preferred method when available. The dilemma is that obtaining accurate S-parameters of the adapter is as challenging as measuring the non-insertable DUT. It has been found that characterizing the adapters using the time domain technique is the most accurate and practical method and the process has been automated in the laboratory.



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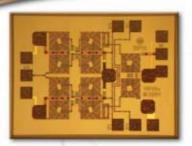


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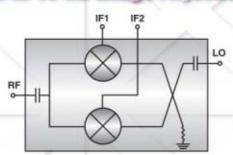


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NEW	4 - 8.5	I/Q Mixer / IRM	DC - 3.5	-7.5	40	23	Chip	HMC525
	5.9 - 12.0	I/Q Mixer / IRM	DC - 1.5	-8	30	18	Chip	HMC256
NEW!	6 - 10	I/Q Mixer / IRM	DC - 3.5	-7	40	22	Chip	HMC520
NEWI	6 - 10	I/Q Mixer / IRM	DC - 3.5	-7	40	23	LC4	HMC520LC4
NEW!	6 - 10	I/Q Mixer / IRM	DC - 3.5	-7.5	40	28	Chip	HMC526
NEWI	8.5 - 13.5	I/Q Mixer / IRM	DC - 3.5	-7.5	40	24	Chip	HMC521
NEW!	8.5 - 13.5	I/Q Mixer / IRM	DC-2	-7.5	35	28	Chip	HMC527
NEW!	11 - 16	I/Q Mixer / IRM	DC - 3.5	-7.5	35	24	Chip	HMC522
NEW!	11 - 16	I/Q Mixer / IRM	DC - 3.5	-7.5	35	24	LC4	HMC522LC4
NEW!	11 - 16	I/Q Mixer / IRM	DC - 3.5	-8	35	27	Chip	HMC528
NEW!	15 - 23.6	I/Q Mixer / IRM	DC - 3.5	-8	27	25	Chip	HMC523
NEWI	22 - 32	I/Q Mixer / IRM	DC - 3.5	-10	23	20	Chip	HMC524
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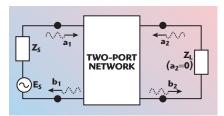


Fig. 2 Simplified representation of a two-port network.

Other reasons why the de-embedding process has not been more widely used are the effort needed to develop the algorithms in a software program and the time delay (refresh rate) when presenting the corrected data on a computer. Circuit modeling programs provide the ability to embed/de-embed networks for analysis purposes. However, they are not optimized for use in production or on the test bench in the laboratory. In order to make the de-embedding process more practical, a commercially available characterized adapter set and a program that automatically takes the S-parameters of the adapter, de-embeds the effects from the measurements and provides a real-time dis-

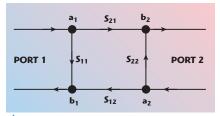


Fig. 3 Flow-graph representation of a two-port network.

play of the results is needed. A commercial system is provided that includes the characterized adapters with data files, automatically downloads the adapter S-parameters into the software and de-embeds the effects. Also, to overcome the issue of time delay of the corrected display, the modified error models are automatically downloaded to the VNA, thereby providing a real-time display of de-embedded measurements on the CRT.

S-PARAMETER REVIEW

In order to understand the process of de-embedding, it is helpful to first review scattering (S) parameters. At low frequencies, circuits are typically characterized in terms of impedance, admittance and conductance (z, y and h). However, at higher frequencies, these measurements are often not practical. An easier method is to make swept-frequency, wideband measurements of the device with all ports terminated in their own characteristic impedances. S-parameters are a description of how well matched the ports are within the operating system when terminated by the characteristic impedance. Scattering parameters are defined as the ratio of the emerging to incident signals at each port. A two-port device can therefore be described by four S-parameters:

 S_{11} – indicates how well matched port 1 is to the characteristic impedance of the transmission line.

 S_{21} – is the forward transmission characteristics of the device.

 S_{22} – indicates how well matched port 2 is to the transmission line characteristic impedance.

 S_{12} – is the reverse transmission characteristics of the device.

MODELING A TWO-PORT NETWORK

Figure 2 is a simplified representation of a two-port network. The two-port device is connected to the output port of a signal generator and terminated by a load. In an ideal case, the source impedance Z_S , the load impedance Z_L and the system characteristic impedance Z_0 are equal. Typically, the port impedances differ from Z₀, and a portion of the incident signal is reflected due to the mismatch. The incident and reflected signals are represented on separate paths for clarity in this representation. Incident signals to any port N are denoted by the term a_N. Signals emerging from port N are denoted by the term b_N . S_{11} defines how well port 1 is matched to the characteristic impedance of the transmission line. S_{11} properties can therefore be measured by comparing the reflected signal b₁ to the incident signal a_1 .

The two-port network may also be represented using signal flow graph analysis, as shown in *Figure 3*, and includes the four S-parameters. Each port has an incident and reflected signal associated with it. In the flow graph, the 'a' node of the port represents the incident signal and the 'b' node represents the emerging signal.

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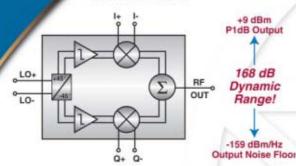
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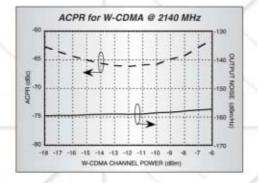
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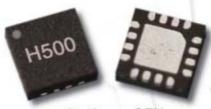
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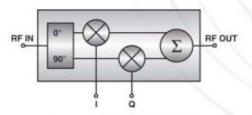
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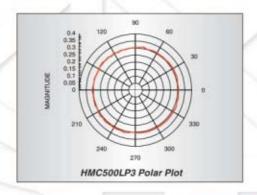


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 S_{11} is given as the ratio of $b_1/a_1.$ Note that two signals enter the b_1 node, one from the a_1 node and a second from the a_2 node. Because a_2 contributes to the b_2 signal, it must be eliminated when measuring $S_{11}.$ The a_2 signal is set to zero by terminating port 2 with a load of $Z_L = Z_0.$ The conditions, which apply when considering S-parameters, can now be seen. Depending on the S-parameter, either the a_1 or a_2 signal must be set to zero. The b_N signals and the S-parameters can now be defined as

$$\begin{aligned} \mathbf{b}_1 &= \mathbf{S}_{11} \mathbf{a}_1 + \mathbf{S}_{12} \mathbf{a}_2 \\ \mathbf{b}_2 &= \mathbf{S}_{21} \mathbf{a}_1 + \mathbf{S}_{22} \mathbf{a}_2 \end{aligned} \tag{1}$$

$$\begin{array}{lll} S_{11} = b_1/a_1 & a_2 = 0 \\ S_{12} = b_1/a_2 & a_1 = 0 \\ S_{21} = b_2/a_1 & a_2 = 0 \\ S_{22} = b_2/a_2 & a_1 = 0 \end{array} \tag{2}$$

A signal flow graph can be expanded to include all significant errors in a VNA system when considering the twelve-term error correction model (see *Figure 4*). Through algebraic manipulation of the equations derived from the signal flow graph, the

error terms are modeled and extracted from the measurement. For a descriptive discussion on the twelveterm error model, see the referenced application note.¹

The use of signal flow graphs is an excellent method for analyzing microwave networks. The graphs can model the most complex multi-port systems and provide an understanding of the interrelationships of multiple devices in a system. Also, a tool called the Mason's rule can be used to simplify the complex signal flow relationship and reduce many of the algebraic manipulations. For further information on signal flow graphs and use of the Mason's rule, the reader is referred to Adam² and Mayaddat.³

THE DE-EMBEDDING PROCESS

In order to address the technique of de-embedding, consider the signal flow graph of two cascaded two-port devices (see **Figure 5**). The composite S_{11}^{C} parameter includes the S_{11}^{2} characteristics of the second device and therefore also includes the contributions of S_{21}^{1} and S_{12}^{1} of the first

device as part of the new signal flow. Using Mason's rule, the S_{11}^{C} parameter is derived as

$$S_{11}^{C} = \frac{\left[S_{11}^{1} - \left(\Delta_{s}^{1}\right)S_{11}^{2}\right]}{\left[1 - S_{22}^{1}S_{11}^{2}\right]} \tag{3}$$

where

$$\Delta_s^1 = S_{11}^1 S_{22}^1 - S_{12}^1 S_{21}^1$$

The process of analyzing cascaded multiple devices in a system can be further simplified by converting the scattering parameters to a new set known as the transfer scattering parameters or the T-parameters. The T-parameters are similar to the S-parameters, except that the signals seen at port 1 are now related to the signals at port 2. The differences can be diagrammed using matrix notation. The $b_{\rm N}$ relationships are defined in Equation 1 for scattering parameters. The scattering matrix Σ of a two-port network is defined as

However, for the T-parameters, port 1 signals must be related to port 2 signals:

$$\begin{vmatrix} a_{1} & | T_{11}T_{12} | | b_{2} | \\ | & | = | & | & | \\ | b_{1} & | T_{21}T_{22} | | a_{2} | & (5) \end{vmatrix}$$

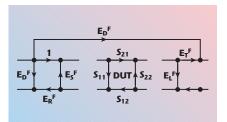


Fig. 4 Signal flow-graph of a two-port network including measurement errors.

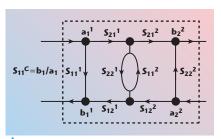


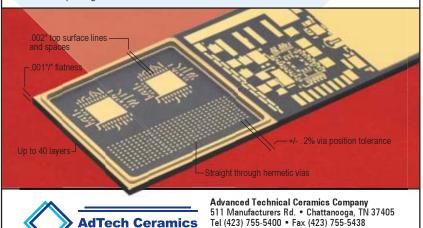
Fig. 5 Signal flow-graph of two cascaded two-port networks.

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In expanded form:

$$a_1 = T_{11}b_2 + T_{12}a_2 \tag{6a}$$

$$b_1 = T_{21}b_2 + T_{22}a_2$$
 (6b)

Using Equation 1, a_1 and b_1 can be solved as:

$$a_1 = -(S_{22}/S_{21})a_2 + (1/S_{21})b_2$$
 (7a)

$$b_1 = -(\Delta_S/S_{21})a_2 + (S_{11}/S_{21})b_2$$
 (7b)

where

$$\Delta_{S} = S_{11}S_{22} - S_{12}S_{21}$$

Comparing Equations 6 and 7, the relationship of the T-parameters to S-parameters can be found:

$$T_{11} = 1/S_{21}$$
 (8a)

$$T_{12} = -S_{22}/S_{21}$$
 (8b)

$$T_{21} = S_{11}/S_{21}$$
 (8c)

$$T_{22} = -(\Delta_S/S_{21})$$
 (8d)

The relationship between the S-parameters and the T-parameters can also be found:

$$S_{11} = T_{21}/T_{11}$$
 (9a)

$$S_{12} = \Delta_T / T_{11}$$

$$S_{21} = 1/T_{11}$$
 (9c)

$$S_{22} = -T_{12}/T_{11}$$
 (9d)

where

$$\Delta_{\rm T} = T_{11}T_{22} - T_{12}T_{21}$$

The cascaded network now takes on the appearance shown in $\emph{Figure 6}$:

In matrix form, these two networks are

and

Since $b_2^1 = a_1^2$ and $a_2^1 = b_1^2$, then

The combined network can be expressed by the single transfer scattering matrix:

$$T^{C} = T^{1}T^{2} \tag{12}$$

The process of relating port 1 signals to port 2 signals allows the cascading of a series of devices using Tparameters and determining the overall relationships. By rearranging the scattering parameter relationships into the transfer scattering format, matrix multiplication can now be used when cascading multiple twoport networks. The overall scattering parameters of a cascaded network may be found using Equations 8 and 9 and expanding Equation 12 in terms of T-parameters. (For a more rigorous analysis, refer to Chapter 2 of Mavaddat³).

$$S_{11}^{C} = \frac{\left(T_{21}^{1}T_{11}^{2} + T_{22}^{1}T_{21}^{2}\right)}{\left(T_{11}^{1}T_{11}^{2} + T_{12}^{1}T_{21}^{2}\right)}$$
(13a)

$$S_{12}^{C} = \frac{\left(\Delta_{T}^{1} \Delta_{T}^{2}\right)}{\left(T_{11}^{1} T_{11}^{2} + T_{12}^{1} T_{21}^{2}\right)}$$
 (13b)

$$S_{21}^{C} = \frac{1}{\left(T_{11}^{1}T_{11}^{2} + T_{12}^{1}T_{21}^{2}\right)} \quad (13c)$$

$$S_{22}^{C} = \frac{\left(T_{11}^{1}T_{12}^{2} + T_{12}^{1}T_{22}^{2}\right)}{\left(T_{11}^{1}T_{11}^{2} + T_{12}^{1}T_{21}^{2}\right)}$$
(13d)

where

$$\Delta_{\mathrm{T}}^{1} = \mathbf{T}_{11}^{1} \mathbf{T}_{22}^{1} - \mathbf{T}_{12}^{1} \mathbf{T}_{21}^{1}$$

$$\Delta_T^2 = T_{11}^2 T_{22}^2 - T_{12}^2 T_{21}^2$$

And in terms of S-parameters:

$$S_{11}^{C} = \frac{\left(S_{11}^{1} - \Delta_{S}^{1} S_{11}^{2}\right)}{\left(1 - S_{22}^{1} S_{11}^{2}\right)}$$
(14a)

$$S_{12}^{C} = \frac{\left(S_{12}^{1}S_{12}^{2}\right)}{\left(1 - S_{22}^{1}S_{11}^{2}\right)}$$
(14b)

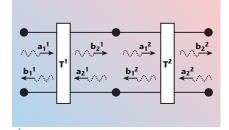


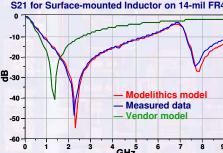
Fig. 6 Cascaded two-port networks using T-parameters.

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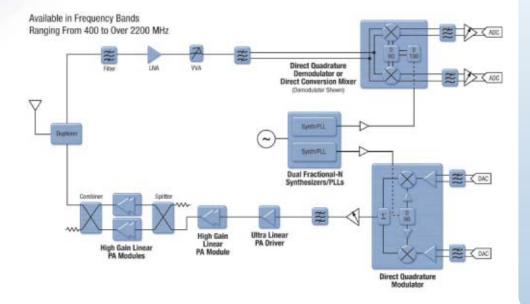




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Part Number	RF Output Frequency (MHz)	CDMA Channel Power (dBm)	ACPR (dBc)	Carrier / Sideband Suppression (dBc)	Broadband Noise Floor (dBm/F
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inear Pov	ver Amplifiers (+5	VDC)			
Part					
Number	RF Frequency (MHz)	Pout (dBm)	Gain (dB)	Output IP3 (dBm)	Efficiency (%)
Number CX65002	RF Frequency (MHz) 700-1400	Pout (dBm) 24	Gain (dB) 18	Output IP3 (dBm) 44	Efficiency (%)
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CX65002 CX65003	700-1400 1400-2500	24 24.5	18 11.5	44 48	38 38
CX65002 CX65003 SKY65004	700-1400 1400-2500 250-2700	24 24.5 25	18 11.5 15.5	44 48 42	38 38 48
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^{*} at 10 KHz offset

$$S_{21}^{C} = \frac{\left(S_{21}^{1} S_{21}^{2}\right)}{\left(1 - S_{22}^{1} S_{11}^{2}\right)} \tag{14c}$$

$$S_{22}^{C} = \frac{\left(S_{22}^{2} - \Delta_{S}^{2} S_{22}^{1}\right)}{\left(1 - S_{22}^{1} S_{11}^{2}\right)}$$
 (14d)

where

$$\Delta_{S}^{1} = S_{11}^{1} S_{22}^{1} - S_{12}^{1} S_{21}^{1}$$

$$\Delta_S^2 = S_{11}^2 S_{22}^2 - S_{12}^2 S_{21}^2$$

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Finally, the relationship between the composite S-parameters, the Sparameters of the first device and the S-parameters of the second device, can be seen from Equation 14a-d. The composite S-parameters for the cascaded network are determined during the measurement process and the S-parameters for the adapter (the first cascaded device) are provided from the previous characterization process. The characteristics of the second cascaded device, the device under test, can now be determined through mathematical substitution. The converting of S-parameters to Tparameters, solving for the cascaded network, de-embedding the adapter and ultimately solving for the DUT is the procedure that is automated by the software. All that is required is the data file containing the adapter Sparameters, which can also be provid-

In summary, the process of de-embedding is simplified by using T-parameters. By using T-parameters, any number of two-port devices may be cascaded and quickly analyzed for total system performance. The overall scattering parameters can be deter-

1. Converting the S-parameters of each device to T-parameters

2. Determining the combined T-parameters using matrix multiplication

3. Converting the system T-parameters to composite S-parameters

Once the overall composite scattering parameters are known through measurement, and the scattering parameters for the adapter are known through characterization, the effects of the adapter on the composite measurement may be de-embedded to reveal the S-parameters of the device under test.

ADDITIONAL ADVANTAGES FOR THE LABORATORY **AND PRODUCTION**

In addition to improvement in measurement accuracy, there are additional benefits using the adapter de-embedding technique. First, it is possible to change the test port connector type by simply adding the appropriate adapter (see Figure 7). The process of de-embedding moves

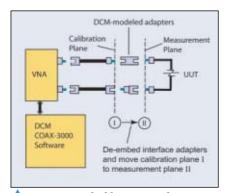


Fig. 7 De-embedding process by using modeled adapters.

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1 MHz	-141	-135	-129	-123			
10 MHz	-150	-150	-146	-140			



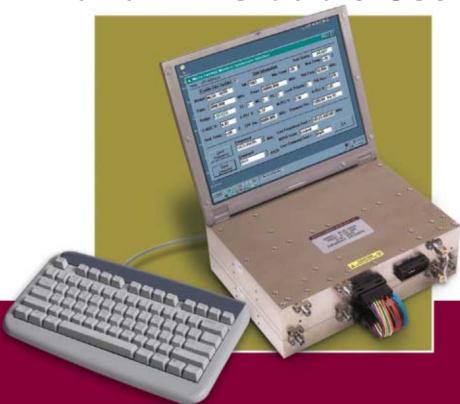
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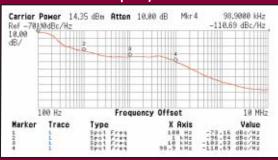
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the calibration plane from the end of the test port cables to the end of the adapters. Thus, it is possible to change the connector type by adding the appropriate adapter, activate the de-embedding routine and continue with the error corrected measurement without re-calibration. Reducing the frequency of calibration procedures helps to reduce potential errors from an improper calibration and is a significant time saver. A second major advantage using this technique is eliminating the need for multiple calibration kits. With a single calibration kit and multiple pre-characterized adapters, the VNA may now be calibrated and reconfigured for a wide variety of device configurations while reducing costs.

CONCLUSION

Removing adapter error contributions using de-embedding techniques The success of the de-embedding process is determined by the quality of the adapter characterization. There are two challenges when implementing the de-embedding process: obtaining accurate characterization of the adapter and developing the software algorithm for the error extraction. In order to address the characterization concern, a one-port time domain measurement can provide accurate results when properly configured, although the process can be time consuming and require costly broadband measurement systems operating to at least 50 GHz. For the software algorithm requirement, circuit modeling programs exist that offer embed/de-embed routines. However, these programs are optimized for R&D development rather than for production or for the laboratory test bench. A software program and calibration system that automates the de-embedding process simplifies the procedure and provides the benefits with minimal effort. The automated de-embedding process now delivers benefits to both production and the laboratory.



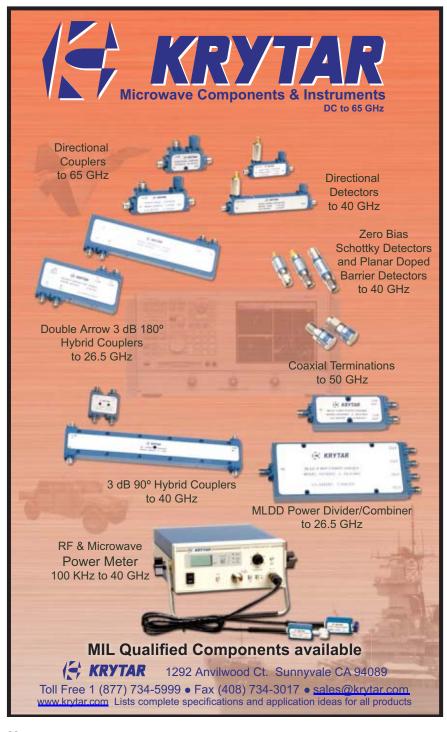
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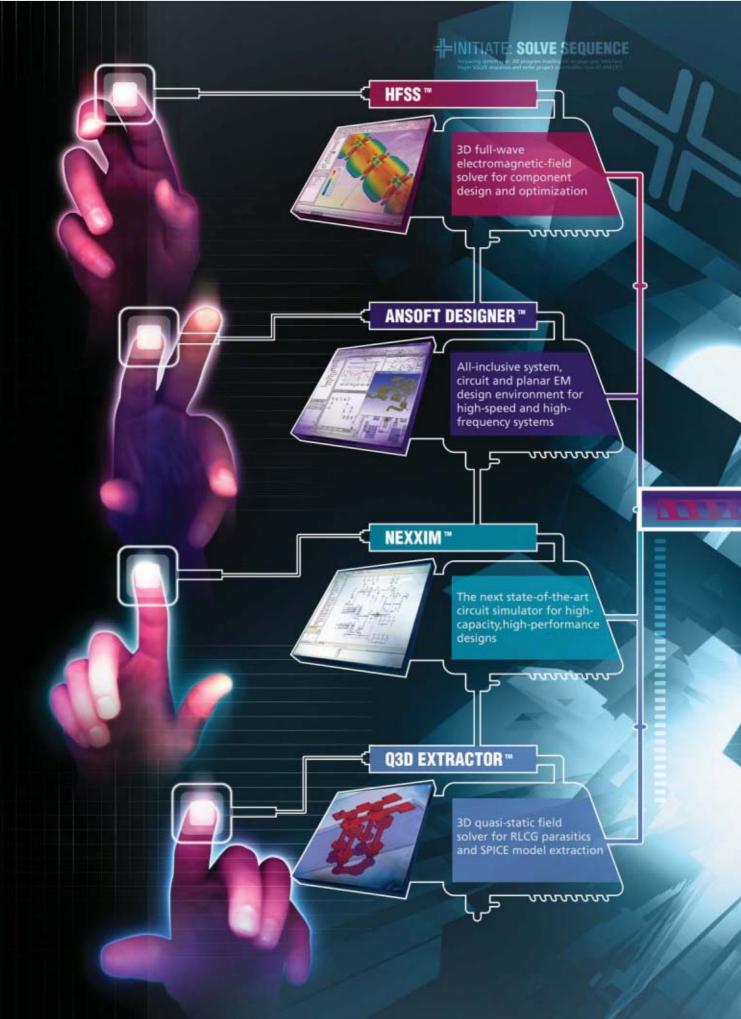
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A CAD ALGORITHM FOR RF/MICROWAVE INTERCONNECT MODELING

This article presents a numerical technique (CAD) to model and analyse interconnects encountered in the design of high speed/high frequency analog RF/microwave circuits with mixed, lumped and distributed elements to be implemented on-chip. In this method, the interconnect networks are modeled by lossless two-ports composed of simple lumped elements and commensurate transmission lines, which are defined by two-variable scattering functions. Two examples are given to describe the application of the proposed method in the modeling of interconnects.

ecause of the rapid growth in density and complexity of modern integrated circuit interconnects, modeling has been a requirement in circuit design and simulations. On-chip interconnects have achieved a dominant role, especially in determining the performance of RF and monolitic microwave integrated circuits (MMIC). In the last two decades, the characterization of high frequency packages has become of considerable interest for MMIC applications. 1,2 In spite of the production of many interconnect modeling tools based on certain techniques,3-8 a compact model for RF/microwave interconnects does not yet exist. Therefore, the development of a compact model for interconnects has become very important to achieve 'design convergence.

It is well known that at RF and microwave frequencies, to represent signal retardation, interconnects have been modeled by transmission lines. However, for high frequency analog RF and microwave circuit realization on one chip, a major problem is the physical implementation of interconnections that behave as transmission lines. It is therefore more convenient to model the interconnections as transmission lines, where the discontinuities and parasitics are modeled as lumped LC elements. For a more accurate electronic package, a typical single interconnect may be modeled with a transmission line of characteristic

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10S1G4A 13 Watt .8-4.2 GHz	60S1G3 60 Watt .8-3.0 GHz	10ST1G18 10 Watt .8-18 GHz	200T1G3A 200 Watt .8-2.8 GHz	300T2G8 300 Watt 2.5-7.5 GHz	1000T1G2B 1000 Watt 1-2.5 GHz	1500T1G3 1500 Watt 1-2.5 GHz	M
10S4G11 10 Watt 4-10.6 GHz	100S1G4 100 Watt .8-4.2 GHz	20ST1G18 20 Watt .8-18 GHz	200T2G4 200 Watt 2-4 GHz	500T1G2 500 Watt 1-2.5 GHz	1000T2G8B 1000 Watt 2.5-7.5 GHz	1500T2G8 1500 Watt 2.5-7.5 GHz	
15S1G3 15 Watt .8-3.0 GHz	120S1G3 120 Watt .8-3.0 GHz	15T4G18 15 Watt 4.2-18 GHz	200T2G8A 200 Watt 2.5-7.5 GHz	500T2G8 500 Watt 2.5-7.5 GHz	1000T8G18B 1000 Watt 7.5-18 GHz	1500T8G18 1500 Watt 7.5-18 GHz	

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impedance Z_0 , terminated with shunt capacitors and serial inductors, as shown in Figure 1. Here, the package interconnection can be modeled by a transmission line Z_0 , the physical length of the line can be represented by the delay length τ , the bonding wires and pads can be characterized by the serial inductances L_1 and L_2 , and the shunt capacitances C_1 for the die pad and C_{2b} for the board pad, respectively.9

In general, the interconnect models used for RF/microwave circuits can

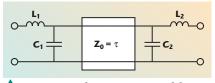


Fig. 1 A simple interconnect model.

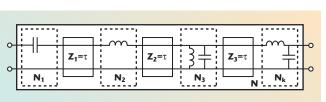


Fig. 2 A more general and accurate interconnect model.

be characterized by transfer functions such as scattering parameters or lumped, distributed, mixed equivalent circuits representing the interconnects. In recent years, some studies have shown that in the design of RF/MMICs on-chip, the use of mixed, lumped-distributed elements instead of solely lumped or distributed elements is much more practical for physical realization. 10–13 Therefore, in this work, mixed, lumped-distributed equivalent circuits are used to describe, model and analyse interconnects, in terms of simple lumped and distributed elements, so that all the parameters are naturally embedded in the design configurations. By utilizing these lumped-distributed models to describe lossless RF/microwave interconnects, a novel approach is present-

> ed. Thus, the modeling of interconnects encountered in the design of lossless RF/microwave circuits on-chip becomes more practi-

SCATTERING MATRIX DESCRIPTION FOR THE INTERCONNECT MODEL WITH MIXED ELEMENTS

As shown in **Figure 2**, the lossless two-port is composed of lumped elements and uniform transmission lines connected in cascade, and can be used to model the more general and accurate RF/microwave interconnects. Thus, the problem of interconnect modeling is reduced to the design of cascaded two-port networks with mixed, lumped-distributed elements. The lossless two-port constructed with a cascade connection of low pass ladders isolated with commensurate transmission lines has been described by using the two-variable scattering approach.¹³

Utilizing the properties (2 and 3) given in Aksen and Yarman,13 and by removing the cascaded transmission lines and the high pass type lumped elements (floating capacitors/shunt inductors) and the lumped elements from the composite interconnect structure, the low pass lumped and distributed models obtained are represented with the scattering matrices $S_L(p)$ and $S_D(\lambda)$, respectively, as

$$\begin{split} S_{L}\left(p\right) &= \\ &\frac{1}{g_{L}\left(p\right)} \begin{bmatrix} h_{L}\left(p\right) & \sigma f_{L}\left(-p\right) \\ f_{L}\left(p\right) & -\sigma h_{L}\left(-p\right) \end{bmatrix} & (1) \\ S_{D}\left(\lambda\right) &= \end{split}$$

$$\frac{1}{g_{D}(\lambda)} \begin{bmatrix} h_{D}(\lambda) & \sigma f_{D}(-\lambda) \\ f_{D}(\lambda) & -\sigma h_{D}(-\lambda) \end{bmatrix}$$
(2)

ed transmission lines and the low pass (floating inductors/ elements shunt capacitors) removed, one would obtain a typical high pass lumped model. Like the low pass counterpart, the high pass interconnect model is represented with a scattering matrix $S_H(p)$

$$S_{H}(p) = \frac{1}{g_{H}(p)} \begin{bmatrix} h_{H}(p) & \sigma f_{H}(-p) \\ f_{H}(p) & -\sigma h_{H}(-p) \end{bmatrix}$$
(3)

Where p denotes the complex frequency variable for the lumped models, λ is the Richard variable for the cascaded transmission lines, the $h_L(p), g_L(p), h_D(\lambda), g_D(\lambda), h_H(p),$ $g_H(p)$ polynomials are real, all $\{g_L(p),$ $g_D(\lambda)$, $g_H(p)$ } polynomials are strictly Hurwitz, $f_L(p) = 1$, $f_H(p) = p^k$, $f_D(\lambda) =$ $(1-\lambda^2)^{n_\lambda/2}$ (here, k and n_λ denote the numbers of high pass type elements and unit elements, respectively).

Eventually, the interconnect network model with mixed elements giv-

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TABLE I

INDEPENDENT SCATTERING POLYNOMIALS FOR THE PRESELECTED INTERCONNECT **NETWORK TOPOLOGIES**

	Front-end Interconnect	Back-end Interconnect
Low Pass model	$\mathbf{h}_{\mathrm{LFE}}(\mathbf{p}) = \mathbf{h}_{\mathrm{LFE0}} + \mathbf{h}_{\mathrm{LFE1}}\mathbf{p} + \mathbf{h}_{\mathrm{LFE2}}\mathbf{p}^2$	$\mathbf{h}_{\mathrm{LBE}}(\mathbf{p}) = \mathbf{h}_{\mathrm{LBE0}} + \mathbf{h}_{\mathrm{LBE1}} \mathbf{p}$
High Pass model	$\mathbf{h}_{\mathrm{HFE}}(\mathbf{p}) = \mathbf{h}_{\mathrm{HFE0}} + \mathbf{h}_{\mathrm{HFE1}} \mathbf{p}$	$\mathbf{h}_{\mathrm{HBE}}(\mathbf{p}) = \mathbf{h}_{\mathrm{HBE0}} + \mathbf{h}_{\mathrm{HBE1}}\mathbf{p} + \mathbf{h}_{\mathrm{HBE2}}\mathbf{p}^2$
Distributed model	$\mathbf{h}_{\mathrm{DFE}}(\lambda) = \mathbf{h}_{\mathrm{DFE0}} + \mathbf{h}_{\mathrm{DFE1}}\lambda + \mathbf{h}_{\mathrm{DFE2}}\lambda^2$	$\mathbf{h}_{\mathrm{DBE}}(\lambda) = \mathbf{h}_{\mathrm{DBE0}} + \mathbf{h}_{\mathrm{DBE1}}\lambda + \mathbf{h}_{\mathrm{DBE2}}\lambda^2$







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Click LEADnet at <u>mwjournal.com</u> or Circle 24 on Reader Service Card en above can be described by means of a two-variable scattering matrix as

$$\begin{split} & g(p,\lambda) = \\ & \frac{1}{g(p,\lambda)} \begin{bmatrix} h(p,\lambda) & \sigma f(-p,-\lambda) \\ f(p,\lambda) & -\sigma h(-p,-\lambda) \end{bmatrix} \end{aligned} \tag{4}$$

Where $h(p,\lambda)$, $g(p,\lambda)$ and $f(p,\lambda)$ are real polynomials of complex variables p and λ , $f(p,\lambda)$ is monic and contains the transmission zeros of the mixed structure. In a mixed structure constructed by a cascade connection of n_p lumped and n_λ distributed sections, the polynomial $f(p,\lambda)$ is defined by

$$f(p,\lambda) = \left[\prod_{i=1}^{n_p} f_i(p)\right] \left[\prod_{j=1}^{n_{\lambda}} f_j(\lambda)\right] (5)$$

 σ is a unimodular constant; $|\sigma|=1$, $g(p,\lambda)$ is a scattering Hurwitz polynomial.

In another hand, the two-variable, real polynomials $g = g(p,\lambda)$ and $h = h(p,\lambda)$ can be expressed in coefficients form as

$$g(p,\!\lambda) = p^T \Lambda_g \lambda; \quad h(p,\!\lambda) = p^T \Lambda_h \lambda$$

Where Λ_g and Λ_h area called as the coefficient matrices of the $g(p,\lambda)$ and $h(p,\lambda)$ polynomials as

$$\begin{split} \boldsymbol{\Lambda}_{g} &= \begin{bmatrix} g_{00} & g_{01} & \mathbf{L} & g_{0n_{\lambda}} \\ g_{10} & g_{11} & \mathbf{L} & g_{1n_{\lambda}} \\ \mathbf{M} & \mathbf{M} & \mathbf{O} & \mathbf{M} \\ g_{n_{p}0} & g_{n_{p}1} & \mathbf{L} & g_{n_{p}n_{\lambda}} \end{bmatrix} \\ \boldsymbol{\Lambda}_{h} &= \begin{bmatrix} h_{00} & h_{01} & \mathbf{L} & h_{0n_{\lambda}} \\ h_{10} & h_{11} & \mathbf{L} & h_{1n_{\lambda}} \\ \mathbf{M} & \mathbf{M} & \mathbf{O} & \mathbf{M} \\ h_{n_{p}0} & h_{n_{p}1} & \mathbf{L} & h_{n_{p}n_{\lambda}} \end{bmatrix} \\ \boldsymbol{p}^{T} &= \begin{bmatrix} 1 & p & p^{s} & \mathbf{L} & p^{n_{p}} \end{bmatrix} \\ \boldsymbol{\lambda}^{T} &= \begin{bmatrix} 1 & \lambda & \lambda^{s} & \mathbf{L} & \lambda^{n_{\lambda}} \end{bmatrix} \end{split}$$

THE CAD MODELING ALGORITHM

The main goal of this algorithm is to construct the composite scattering matrix $S(p,\lambda)$, characterizing the mixed element interconnect structure by means

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of the polynomials $h_L(p)$, hH(p) and $h_D(\lambda)$, using the following steps.

The Algorithm:

The inputs of this algorithm consist of the numbers of lumped and distributed elements in the mixed elements model and the independent coefficients used in describing the proposed interconnect networks together with the transmission zeros.

Inputs

• n_P and $n\lambda$, the total numbers of lumped elements and commensurate transmission lines, respectively

• Coefficients of the $h_L(p)$, $h_H(p)$ and $h_D(\lambda)$ polynomials, which represent the low pass lumped, the high pass lumped and the cascaded commensurate lines interconnect models, respectively

• k, the number of high pass type of elements with transmission zeros at origin in the p-domain

Step 1:

• Using the losslessness conditions of the models with one-kind of elements (the low pass type or the high pass type lumped elements, or only transmission lines), generate the equations into an even polynomial identity in p as follows:

$$\begin{split} G_{L}\left(-p^{2}\right) &= h_{L}\left(p\right)h_{L}\left(-p\right) + 1\\ G_{H}\left(-p^{2}\right) &= h_{H}\left(p\right)h_{H}\left(-p\right) + \left(-1\right)^{k}p^{2k}\\ G_{D}\left(-\lambda^{2}\right) &= h_{D}\left(\lambda\right)h_{D}\left(-\lambda\right) + \left(1-\lambda^{2}\right)^{n_{\lambda}} \end{split} \tag{7}$$

• Find the roots of the polynomials $G_L(-p^2)$, $G_H(-p^2)$ and $G_D(-\lambda^2)$ obtained in Equation 7.

• Choose the LHP (left hand plane) zeros to form $g_L(p)$, $g_H(p)$ and $g_{ab}D$ (λ) polynomials as strictly Hurwitz.

Step 2:

• For the algebraic decomposition, select the degrees of both the lumped and distributed models.

• Apply the algebraic decomposition algorithm¹⁴ to decompose the lumped networks and the cascaded commensurate transmission lines into lower order subsections.

As a result of decomposition, the canonic scattering polynomials sets $\{g_{Li}(p), h_{Li}(p), f_{Li}(p)\}, \{g_{Hi}(p), h_{Hi}(p), h_$

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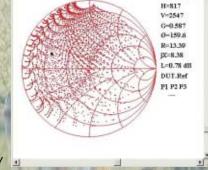


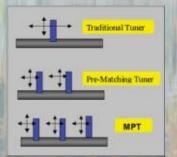
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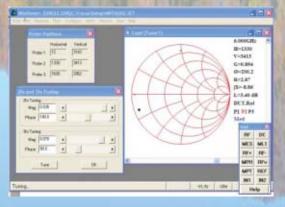
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TABLE II

COEFFICIENTS OBTAINED AS A RESULT OF OPTIMIZATION FOR EXAMPLE 1

Low Pass Model $h_{\rm LFE1} = 0.0491,\, h_{\rm LFE2} = 0.3162,\, g_{\rm LFE1} = 0.7967,\, g_{\rm LFE2} = 0.3162$

High Pass Model $h_{HFE0} = 0.1702, g_{HFE0} = 0.1702$

Distributed Model

 $h_{\rm DFE1} = 1.227, h_{\rm DFE2} = -1.0843, g_{\rm DFE1} = 2.5408, g_{\rm DFE2} = 1.475$

The canonic polynomial coefficients in the matrix from given in (6) for the mixed interconnect model.

$$\Delta_{h} = \begin{bmatrix} 0.1702 & -0.098 & -0.0593 \\ 0.1272 & 1.2428 & -1.0341 \\ 0.0491 & 2.0658 & 0.1256 \\ 0.3162 & 0 & 0.8092 \end{bmatrix} \Delta_{g} = \begin{bmatrix} 0.1702 & 0.2236 & -0.0593 \\ 0.1272 & 2.797 & 1.5252 \\ 0.7967 & 2.0658 & 2.0391 \\ 0.3162 & 0 & 0.8092 \end{bmatrix}$$

 $f_{Hi}(p)$ and $\{g_{Di}(\lambda), h_{Di}(\lambda), f_{Di}(\lambda)\},\$

which define the low pass (Equation

1), high pass (Equation 3) lumped

and distributed (Equation 2) models,

Form the transfer scattering para-

meters for each subsection $T_{Li}(p)$,

• Multiply them in a desired order

respectively, are obtained.

 $T_{Hi}(p)$ and $T_{Di}(\lambda)$.

Step 3:

structure. As an example, the [LL1D1LH1D2......] order of the obtained simple subsections can be

$$T(p,\!\lambda)\!\!=\!\!T_{Li}(p)_{Di}\!\lambda T_{Hi}(p)T_{D2}(\lambda)......$$

In this step, the canonical polynomials $h(p,\lambda)$, $g(p,\lambda)$ and $f(p,\lambda)$ of the mixed structure in Equation 4 are obtained completely.

matrix $T(p,\lambda)$ for the mixed model computed as

Step 4:

-0.5917

-0.0569

0.5792

[0.1915 -0.1724

0.2166

1.2198

0.5307

0.6569

0.089

0.3625

Low Pass Model

 $h_{LBE1} = 0.9111, g_{LBE1} = 0.3625$

High Pass Model

 $h_{BE0} = 0.1915,\, h_{BE1} = 0.6569,\, g_{BE0} = 0.1915,\, g_{BE1} = 0.9025$

Distributed Model

 $h_{\rm DBE1} = 0.7109, \, h_{\rm DBE2} = -0.4859, \, g_{\rm DBE1} = 2.1746, \, g_{\rm DBE2} = 1.1118$

The canonic polynomial coefficients.

Selecting the coefficients of h_L(p), $h_H(p)$ and $h_D(\lambda)$ polynomials as free parameters of the mixed structure, optimize the transducer power gain of the composite interconnect model over the operating frequencies, given

[0.1915 0.1724

2.6836

 $0.3625 \quad 0.5307 \quad 0.5792$

0.5917

1.5408

0.9025

1.089

$$T = \frac{\left(1 - \left|S_{G}\right|^{2}\right)\left(1 - \left|S_{L}\right|^{2}\right)\left|f\right|^{2}}{\left|g - hS_{G} + \sigma S_{L}h_{\circ} - S_{G}g\right|^{2}}$$
(8)

Where S_G and S_L are the reflections of the generator and the load networks.

Remark:

In order to model interconnects, one must obtain the measured data for the terminals so that the optimization algorithm is invoked for the modeling process.

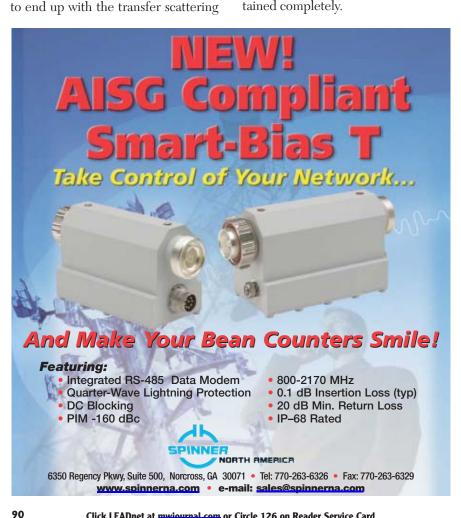
APPLICATION

In this section, to validate the CAD method, two examples are considered. First, in a single-stage FET amplifier design, the front- and backend interconnect circuits are modeled using the new CAD method. The second example deals with the modeling of a symmetric microstrip line. Both modeling examples are implemented on a computer by means of a MAT LABTM toolbox, not generated as hardware. Thus, all the data obtained are only numerical optimization results, not actual measured results.

Example 1

By utilizing the CAD method proposed in this work, the source-to-active device and active device-to-load

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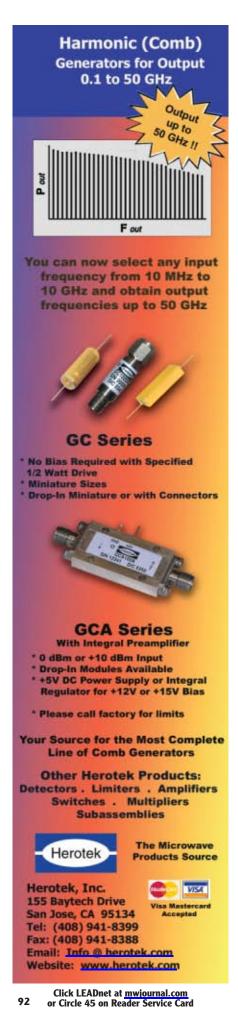
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interconnects encountered in the design of a single-stage FET amplifier are modeled by mixed structures constructed with lumped and distributed components for 50 Ω terminations. The measured scattering parameters for the amplifier active device

(HFET2001) are given in Yarman and Carlin. ¹⁵ In this example, two unit elements (UE) and three lumped elements are used for the input (front-end interconnect) and output (back-end interconnect) models, that is $n\lambda = 2$ and $n_p = 3$.

HFET 2001

50 L₁ C₂ C₃ L₄ C₅

Z₁=τ₁ Z₂=τ₁ Z₃=τ₂ Z₄=τ₂ S 50

INPUT INTERCONNECT MODEL OUTPUT INTERCONNECT MODEL

L₁=0.8458, C₂=2.9378, C₃=0.7477, L₄=0.7251,
C₅=0.6413, L₆=4.0725, Z₁=1.0586, Z₂=2.7903,
τ₁=1.22, Z₃=1.1108, Z₄=1.7747, τ₂=0.91

🛕 Fig. 3 Final amplifier circuit.

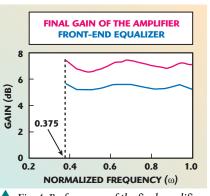


Fig. 4 Performance of the final amplifier.

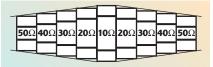


Fig. 5 The symmetric microstrip line prototype.

In the above CAD procedure, $f_L(p) = 1$, $f_H(p) = p$ for the input and $f_L(p) = 1$, $f_H(p) = p^2$ for the output interconnect model are selected, which means that there will be one zero of transmission at p = 0 and two zeros of

transmission at $p = \infty$ for the first, two zeros of transmission at p = 0 and one zero of transmission at $p = \infty$ for the second model, as given in **Table 1**.

Here, in order to end up with a transformer-free structure, h_{LFE0}, h_{LBE0}, h_{DFE0}, h_{DBE0}, h_{HFE1} and h_{HBE2} are set to zero. Using the above algorithm, the main goal of the design is to maximize the transducer power gain (TPG) given in Equation 8, over the normalized frequencies $\omega_1 = 0.375$ (6 GHz) to $\omega_2 = 1$ (16 GHz). Therefore, initializing the unknown model parameters (h_{LFE1}, h_{LFE2} , h_{LBE1} , h_{HFE0} , h_{HBE0} , h_{HBE1} , h_{DFE1} , h_{DFE2} , h_{DBE1} , h_{DBE2}), the TPG is optimized by means of the Levenberg Marquard LMS algorithm.

As the result of optimization, the following coefficients are obtained, describing the input and output intercon-

nect networks as in *Table 2*. The final amplifier circuit and its performance characteristics are depicted in *Figures 3* and *4*, respectively.

TABLE III

SCATTERING POLYNOMIALS OF THE REFERENCE MODEL

$$\begin{split} h_D(\lambda) &= -6.0167\lambda - 0.4576\lambda^3 + 1.3792\lambda^5 + 5.4547\lambda^7 - 0.3595\lambda^9 \\ g_D(\lambda) &= 1 + 11.8167\lambda + 47.2167\lambda^2 + 106.0576\lambda^3 + 153.7875\lambda^4 + \\ 149.7083\lambda^5 + 98.025\lambda^6 + 41.4328\lambda^7 + 10.049\lambda^8 + 1.0627\lambda^9 \\ f_D(\lambda) &= (1 - \lambda^2)^{9/2} \\ \tau_D &= 0.52 \text{ (delay length of the line)} \end{split}$$

C₁=0.5463, L₁=1.1829, L₂=0.8503, C₂=3.3832, Z₀=0.4549, τ=0.1376

Fig. 6 The proposed CAD model for the symmetric microstrip line.

Example 2

As is commonly known, a microstrip line is normally used at the motherboard level on MMICs, due to its low loss. Thus, in Example 2, in order to get a more accurate microstrip line model as an interconnect structure, a symmetric microstrip line is modeled with mixed, lumped and unit elements by applying the method developed in this article. The canonic polynomial forms of







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TABLE IV COEFFICIENTS OBTAINED AS A RESULT OF OPTIMIZATION FOR EXAMPLE 2 Lumped Model Distributed Model $\begin{array}{l} h_{L,1} = -0.9482, \ h_{L2} = -1.1180, \ h_{L3} = 0.9157, \ h_{L4} = -0.9295 \\ g_{L1} = 2.9814, \ g_{L2} = 3.9947, \ g_{L3} = 2.4872, \ g_{L4} = 0.9295 \end{array}$ $h_{D1} = -0.8718$ $g_{D1} = 1.3266$ Composite Interconnect Model $h(p,\lambda) = \begin{bmatrix} 1 & p & p^2 & p^3 & p^4 \end{bmatrix} \begin{vmatrix} -0.9482 & 1.0108 \\ 2.8840 & -3.1872 \\ -1.8789 & 3.1365 \end{vmatrix} \begin{bmatrix} 1 \\ \lambda \end{bmatrix}$ $g(p,\lambda) = \begin{bmatrix} 1 & p & p^2 & p^3 & p^4 \end{bmatrix} \begin{bmatrix} 2.9814 & 3.1286 \\ 3.9947 & 5.3984 \\ 1.8789 & 4.3444 \end{bmatrix}$

the scattering parameters for the theoretical reference model of the microstrip line in Figure 5 are given in **Table 3**. In this example, the chosen reference model does not represent the real parameters of an actual microstrip line. However, this model is most appropriate for the interconnects encountered in practice, especially on MMIC.

In the example, four low pass type lumped elements and only one unit element, that is $n_p = 4$ and $n\lambda = 1$ for the proposed model, are used. Applying the above CAD technique, the and h_{D0} are set to zero

(
$$\rm h_{L0}\!=0,\,h_{D0}\!=0$$
).

The Model Parameters:

$$\begin{aligned} h_L(p) &= h_{L0} + h_{L1}p + h_{L2} \ p^2 \\ &+ h_{L3}p^3 + h_{L4} \ p^4, \\ h_D(\lambda) &= h_{D0} + h_{D1}\lambda, \\ \tau(\text{delay length of the unit element}) \end{aligned}$$

coefficients of the following h polynomials as free parameters in the optimization scheme are selected. Here, for a transformer-free structure, h_{L0}

mization, the coefficients describing the proposed model depicted in Figure 6 are obtained in Table 4; its performance characteristics are given in Figure 7.

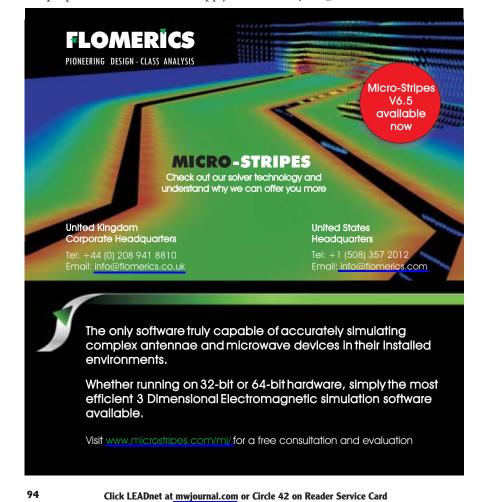
As the result of the numeric opti-

Here, the magnitude and phase of the input reflection function S_{11} are chosen as the objective function, Equation 9, employed by the least square error criteria in the optimization scheme.

$$\delta = \sum_{k=1}^{N} \left[\left(\left| S_{11} \right| - \left| S_{P} \right| \right)^{2} + \left(\Phi \left(S_{11} \right) - \Phi \left(S_{P} \right) \right)^{2} \right]$$

$$(9)$$

Where $\{ |S_P| \text{ and } \Phi(S_P) \}$ and $\{ |S_{11}| \}$ and $\Phi(S_{11})$ represent the magnitude and phase of the input reflection functions for the reference model and the CAD model, respectively. As seen clearly, a good agreement between the reference model and the



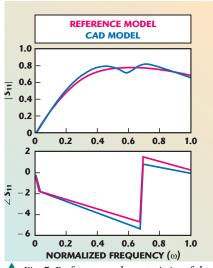


Fig. 7 Performance characteristics of the







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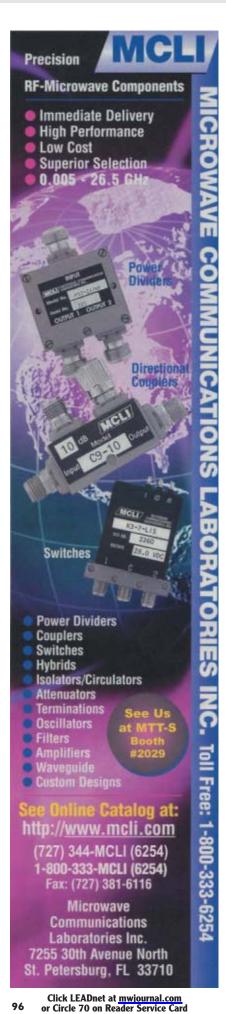
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proposed CAD model shows the validity of the method in the modeling of real RF/microwave interconnects.

CONCLUSION

In this article, a CAD procedure is presented for modeling interconnects with lumped and distributed components, based on combining the simplified real frequency technique with the Fettweis's network decomposition algorithm. In the new method, the interconnect modeling networks are described by two-variable scattering parameters. Using any unconstraint routine in the optimization process, the free model parameters, initialized by ad-hoc choices (±1), are obtained easily.

This method provides a more general and accurate modeling of RF/microwave interconnects in terms of simple lumped elements and commensurable transmission lines. Also, the method makes the implementation of RF/microwave circuits practical by modeling the interconnects accurately such that the parasitic effects and discontinuities are naturally embedded in the design configurations.

The proposed CAD method is applied to a microwave amplifier design and a microstrip modeling, where lumped and distributed elements are used to model the parasitics and discontinuties in MMIC designs. However, the method can also be applicable to the modeling of high speed digital IC interconnects and electronic packages. It is hoped that this technique can be used in generating models as a CAD tool for complex interconnect networks.

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A CAD-ORIENTED APPROACH TO DESIGN OF LOAD IMPEDANCE AND INPUT MATCHING IN ACTIVE TRANSMITTING **ANTENNAS**

This article discusses a general computer-aided design (CAD) approach to obtain the optimal fundamental load impedance and design the input matching circuits for an active integrated antenna of the transmitting type. A case study of a design for 1.6 GHz is used to confirm the design principle, and uses a previously reported patch antenna shape to achieve class-F operation with an alternative type of power transistor.

n active integrated antenna (AIA) may be defined as a system in which an active device, usually a transistor, is closely integrated within an antenna, using a minimum of intervening circuitry. In recent years, AIAs have been considered a useful approach for improving performance and reducing size in front-end wireless communications applications. The antenna is not only a radiating element, but also a part of the input or output tuning circuits, and may present optimised impedances that are non-standard and partly reactive. In contrast to the design methodology of the conventional 50 Ω interface, an AIA can be regarded as an amplifying active microwave circuit that has free space termination as its input or output.

In a transmitting context, attempts have been made to use AIAs to improve the poweradded efficiency (PAE) of power amplifiers. Several novel high efficiency PA designs have been proposed by using AIAs to perform harmonic tuning. 1-5 In these articles, the antennas are attached directly to the active devices and play a role in terminating higher order harmonics at the PA's output to achieve high output power (P_{out}) and high PAE.

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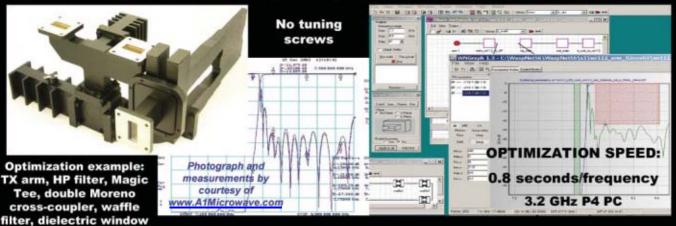
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Here, a CAD-oriented approach is discussed to optimise the fundamental load impedance in the design of a class-F power amplifier used as a transmitter in an AIA. A 2 × 2 coupler at the input stage is used in designing the input matching circuit by showing the effect of various load impedances on the input reflection coefficients. To demonstrate the principle, the case study of a 1.6 GHz, class-F power amplifier AIA design

for wireless communications is presented. A published design¹⁰ for the antenna structure has been chosen, but has been integrated with a different transistor.

AIA AMPLIFIER DESIGN

Class-F operation is a well-known technique for improving the PAE of RF power amplifiers. It uses a multiresonator to control the harmonic waveforms so that the drain voltage waveform (ideally) becomes rectangular and the drain current waveform becomes half sinusoidal, thereby reducing the DC power dissipation and increasing efficiency. This requires an impedance optimised at the fundamental, a low impedance at the even harmonics and a very high impedance at odd harmonics. A simple method is to interpose a quarter-wave length line between the drain and the final load and to design the latter to have the lowest possible impedance at all harmonics above the fundamental.

For the AIA harmonic tuning, it is convenient to use the same technique. This has been done by others, 3-5 where, to obtain class-F operation, the second and third harmonics are shaped through the input resistance of the antenna. This technique allows these harmonic resistances to be almost zero at twice and three times the design frequency, so that harmonic power is efficiently suppressed from radiation by the antenna. In addition, the input impedance of the antenna at the fundamental frequency (f_o) should be equal to the optimum load impedance (Z_{opt}) at f_o of the amplifier for $\operatorname{maximum}^{\mathsf{T}}\operatorname{PAE}$ and $\operatorname{P}_{\operatorname{out}}.$ In this design approach, an output matching circuit is eliminated because the antenna impedance is directly transformed to the Z_{opt} for maximum efficiency, thus decreasing the circuit complexity and power losses.

In this CAD-oriented approach, due to the intrinsic active device nonlinear behaviour, the PA design is based on large-signal simulation. The class-F power amplifier was designed and optimised at 1.6 GHz using Agilent Technologies' Advanced Design System (ADS). Following selection of a suitable output power and operating frequency range, the active device selected was the TriQuint CLY5 power GaAs field effect transistor (FET). For a simple design, it is desirable to use a device like the CLY5, which does not include built-in matching circuits, other than unavoidable parasitics, within the package. Even with CAD tools, it is a very difficult problem to optimise all aspects of the design in one pass. No exact synthesis technique is known for shaping a patch antenna to achieve prescribed impedances at a set of harmonically related frequencies. However, it is feasible to use the method of Refer-

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ences 2 and 3, whereby the fundamental impedance can be kept reasonably close to optimum, while higher resonances of the patch can be separated as much as possible from harmonics of the operating frequency, so that the input resistance of the patch remains low at the harmonics. This may, of course, be a realistic target only for the first few harmonics, which fortunately dominate the efficiency optimisation. Feedback effects

on input impedance at harmonic frequencies is a complex issue. In this case study, the procedure starts by initially optimising the fundamental load impedance only, and this value is used in optimising the input match, again initially neglecting harmonic frequency feedback.

The nonlinear model of this device (which was provided by the device manufacturer), and harmonic balance simulation, including the first five

harmonics, were used in the simulation. The drain bias voltage, V_{ds}, was 5 V, while the gate bias voltage, $V_{\rm gs}$, was set to be -2.25 V, so that DC drain current is 155 mA. Figure 1 shows the DC characteristics of the device and the selected quiescent bias point.

A set of large-signal S-parameters is usually required for matching network design in PAs. However, the measurement of these S-parameters is not well defined. An alternative method is to derive the reflection coefficients of the active device from measurements of the voltages of the incident and reflected waves. In this AIA scenario, only the input reflection coefficient (Γ_{in}) needs to be obtained, because of the elimination of the output matching. A 2×2 simple coupler was inserted at the input stage of a class-F harmonic load-pull measurement design circuit (which was in ADS's amplifier design guide), in order to measure $\Gamma_{\rm in}$ of large-signal S-parameters of the nonlinear model. The simulation circuit with a coupler for the input matching design is shown in Figure 2. In this circuit, the coupler is connected between a signal generator and the active device, in order to make a measurement of the incident voltage (V_{in}) incoming from the source and the reflected voltage (V_{ref}) reflected back from the active device. It should be noted that the coupler is not intended to be a realizable hardware component, but is defined in software as the operation of converting actual current and voltage into equivalent forward and reverse wave components. The Γ_{in} of the transistor is then calculated according to the defining equation



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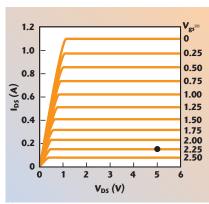


Fig. 1 DC characteristics of the device and the selected quiescent bias point.

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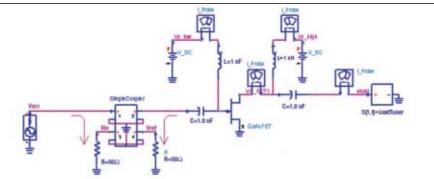




Fig. 2 Harmonic load-pull simulation circuit with a coupler.

$$\Gamma = \frac{V_{\text{ref}}}{V_{\text{in}}} \tag{1}$$

The principle of this CAD load-pull measurement circuit design is to obtain the $\boldsymbol{Z}_{\text{opt}}$ at the fundamental design frequency of the PA with a class-F biasing operation at fo for maximum PAE and P_{out} (the accepted power to the load or antenna), using an algorithm to vary the fundamental load impedances which are contained in a one-port device as S_{11} data. In fact, the algorithm is provided by the ADS package, arbitrarily setting a center point and radius for a circle on the Smith chart and also setting the number of points on the circle (making sure the generated circle is fully inside the Smith chart). Each point of the circle gives an individual value of the load impedance. The optimum load impedance can be obtained by changing the location of the circle on the chart. In addition, the source and load impedances at harmonic frequencies were defined arbitrarily as 50 Ω . These assigned values are somehow sub-optimal. Thus, the obtained PAE and Pout from this simulation design are not finalized and the design can be used as a starting point when the one-port block is replaced by the antenna, which should hopefully provide the correct harmonics load impedances. The input reflection coefficients were also simulated as a function of the output load impedances for maximum power and efficiency. Due to the dependence between the input reflection coefficient $\Gamma_{\rm in}$ and the load reflection coefficient Γ_{load} of the two-port device, the advantage of this proposed design approach is that it simplifies the considerations of designing the output matching circuit and the simulation only aims to obtaining Z_{opt}. Once the Z_{opt} with the required output power and efficiency was obtained, the corresponding $\Gamma_{\rm in}$ with this Z_{opt} value was also calculated so that the input matching circuit could be designed accordingly with the aid of the Smith chart.

Under the biasing condition previously mentioned, the Γ_{in} value when Z_{opt} was optimised was found to be 6.049–j10.096 $\Omega.$ With the help of the Smith chart tool, an input matching circuit with two lumped elements

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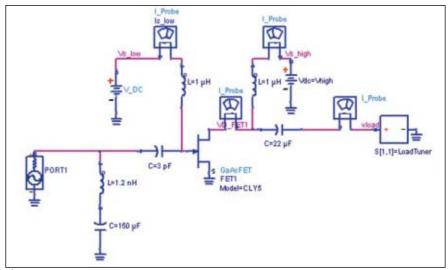


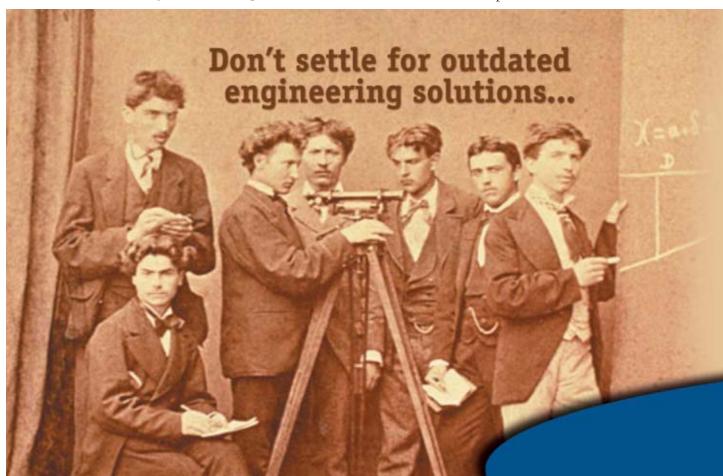
Fig. 3 Harmonic load-pull simulation circuit with input matching.

was plotted and replaced the coupler at the input stage. Discrete components could be used for the matching network because these components have been characterised well enough at the lower microwave communication frequencies. A modified measurement circuit with optimal components' values is shown in *Figure 3*.

After introduction of the input matching, the PAE and P_{out} of the PA were dramatically improved, while the Z_{opt} was still found to be 16.049–j10.096 Ω with the same input power level. Once the Z_{opt} value was set, microstrip lines were required to connect these components together. An Ultralam 2000 substrate

with $\varepsilon_{\rm r}$ = 2.55, thickness T = 1.524 mm, metal thickness $T_m = 0.035$ mm and $\tan \delta = 0.0019$ was assumed. **Fig**ure 4 shows the design circuit connected using microstrip lines with optimal lengths and widths of MLINs, MTEEs and STUBs. One-tune swept harmonic balance analysis, with load impedances at harmonic frequencies set at 50Ω and the optimum load impedance at the fundamental frequency set as 16.049-j10.096, was employed. The output power Pout and the PAE characteristics from the active device versus input driving power at 1.6 GHz are shown in *Figure 5*. The PAE of the transistor reaches 69.7 per cent with an input power level of 18 dBm. The corresponding performances are 27.81 dBm output power and 9.85 dB gain. Table 1 shows the power amplifier's performances with the same input power level versus various load impedances at harmonic frequencies.

Various antenna types could be chosen for the radiating element of the AIA, including patch antennas² and planar inverted-F antennas.⁴ To



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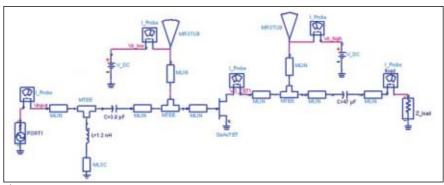
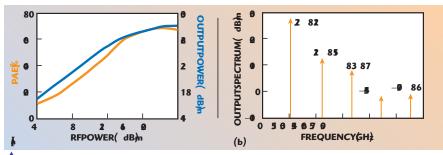


Fig. 4 Simulated circuit model with optimum load.



▲ Fig. 5 Simulated performance of the power amplifier; (a) P_{out} and PAE, and (b) higher harmonic level.

realise class-F operation with the AIA concept, this study followed the ap-

proach of References 3 and 5 and adopted the same antenna geometry

as in Radisic, et al.,5 which used a circular-sector microstrip patch antenna, as shown in *Figure 6*. It had been checked that the antenna shown in $Radisic^5$ was actually fed at the edge of the patch, and a quarter-wave transmission line was believed to have been added to transfer the antenna's input impedance to the drain output of the active device. It is also necessary to point out that the operating frequency of the whole active antenna in Radisic⁵ was chosen to be near the first resonant frequency of the patch. The same antenna design procedure was used in this study. However, the active device chosen was different. The optimum fundamental load was found to be 16.049-j10.096 Ω . It was also discovered that an output matching network would have to be included⁶ between the drain and antenna input port. In order to avoid this network, the antenna size had to be increased in order to be able to make a match near the patch antenna's second resonance. Figure 7 shows the simulated input impedance for an antenna ra-



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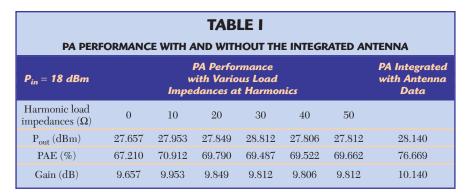
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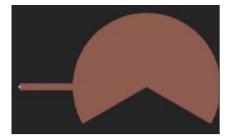


Fig. 6 Layout of the circular-sector microstrip antenna.

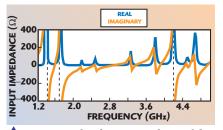


Fig. 7 Simulated input impedance of the circular-sector microstrip antenna with a radius of 45 mm.

TABLE II INPUT IMPEDANCES OF THE ANTENNA AT FUNDAMENTAL AND HARMONICS							
At the At the Feeding Edge of Edge of Point the Patch of the $4/\lambda$ (Ω) Line (Ω)							
Z_{opt}	-	16.049–j10.096					
f_1	99.231+j59.964	16.684–j9.895					
f_2	13.849+j65.921	10.912+j59.253					
f_3	5.067+j24.870	12.706-j73.388					

dius of 45 mm, the intended operating frequency being 1.6 GHz. The antenna's impedance at the first three harmonic frequencies is also shown in *Table 2*.

The antenna was incorporated in the class-F PA simulation as a oneport device containing the S-parameter data from 0.2 to 9 GHz. The final simulated model, including the antenna data, is shown in Figure 8. The amplifier performance with the integrated antenna as harmonic loading is shown in *Figure* 9. It is obvious from the data that an increase in PAE, output power and power gain at 18 dBm input power have been obtained. These results demonstrate an approach to show how the harmonic loading of the actual antenna can contribute to the PA performance as compared to the simple harmonic loading (that is without the actual antenna data) introduced by the ADS package. Figure 10 shows the simulated drain

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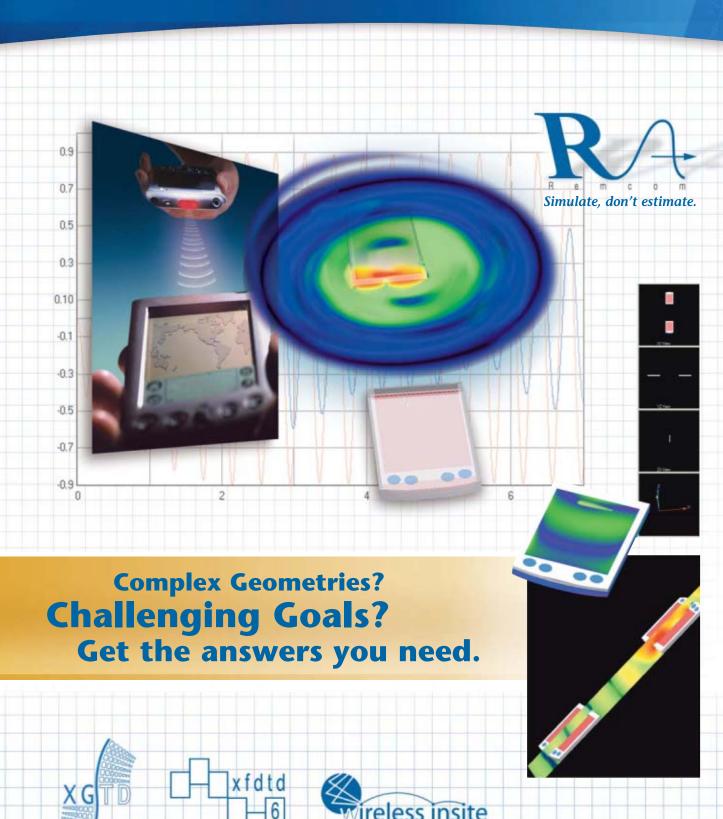
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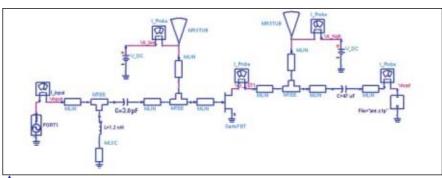
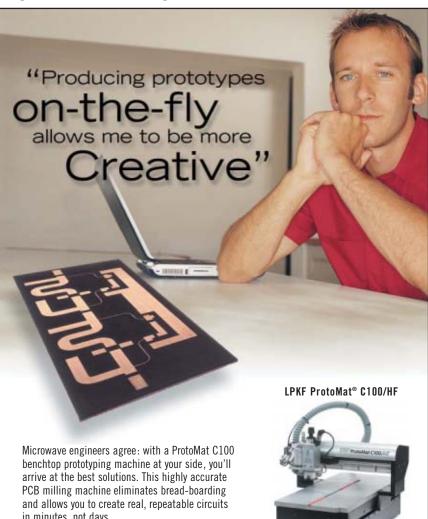


Fig. 8 Final simulated model integrated with the antenna data.



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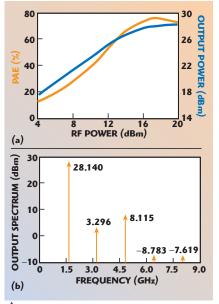
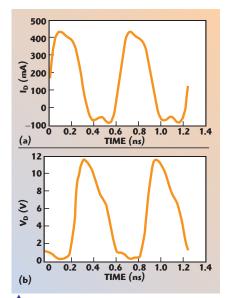


Fig. 9 Improved simulated performance of the power amplifier; (a) Pout and PAE, and (b) higher order harmonic level.



🛕 Fig. 10 Simulated drain current (a) and drain voltage (b) waveforms.

voltage and drain current waveforms. They show deviations from the ideal case waveforms, but a performance improvement has nevertheless been obtained. These deviations are believed to be due to the parasitic reactive elements of the nonlinear model of the active device, particularly the packaging parasitics at the drain and in the common (source) lead. A check was made to show that including more harmonics would have little effect on these results. Similar waveform deviations were observed in Radisic,⁵ where four harmonics were used for the simulation work.

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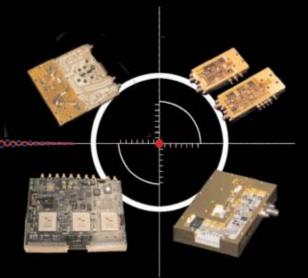




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CONCLUSION

A simple CAD-oriented approach to optimise load impedance at the fundamental frequency for the application of the active antenna concept was described. The design method and procedure were presented. In addition, one design example at an operating frequency of 1.6 GHz was demonstrated to verify the design principle. It was confirmed that performance could be substantially en-

hanced in an active integrated antenna. ■

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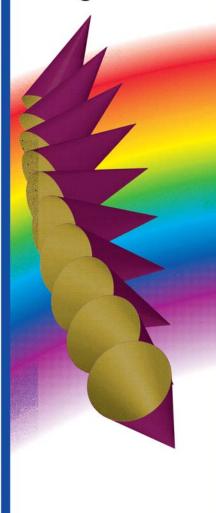
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TRANSIENT SIMULATIONS AT RF FREQUENCIES

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TRANSIENT SIMULATION OF DISTRIBUTED NETWORKS WITH DISPERSION

As design frequencies increase, so does the need for accurate modeling of distributed elements. These elements may form intentional design components, such as filter structures or matching networks, or they may represent the unintentional parasitic effects extracted for an interconnect system. In either case, an effective modeling approach is to partition the overall distributed network into single and coupled transmission lines, with separate models for discontinuities such as bends, steps in width, tee-junctions and crosses. Transmission lines are known to satisfy the telegrapher's equations, which (in the time domain) are given by

$$\frac{\partial V(x,t)}{\partial x} = -\left(R + L\frac{\partial}{\partial t}\right)I(x,t)$$
$$\frac{\partial I(x,t)}{\partial x} = -\left(G + C\frac{\partial}{\partial t}\right)V(x,t)$$

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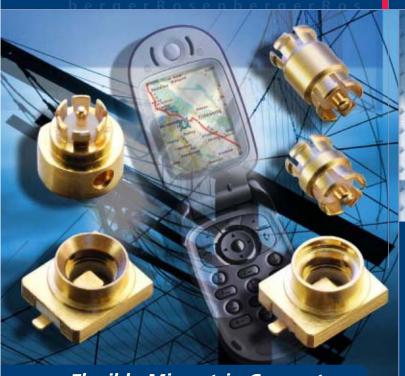








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Application Note

Transient simulation with constant values for R, L, G and C is therefore a fairly straightforward process. However, dispersion, skin effect and dielectric losses all contribute to significant frequency dependencies in the RLGC values. EM solvers of various degrees of accuracy, ranging from 2D quasi-static to 3D full-wave, can extract these RLGC values and their frequency dependence. Using these values for frequency-domain simulations is also a relatively straightforward process, and well documented in the literature. Transient simulation techniques for handling these frequency-dependent RLGC values, however, are actively being researched. A unique advantage of the HSPICE® circuit simulator is its implementation of an advanced technique for handling frequency-dependent RLGC matrices for coupled transmission line systems. Known as the W-element, HSPICE uses recursive convolution methods^{2,3} to accelerate the time-domain simulations, while still making accurate use of the frequency-domain RLGC data.

The W-element is widely used for high speed digital printed circuit board (PCB) signal integrity applications, typically in the range of 1 to 6 GHz. However, the W-element algorithm has no hard frequency limits. Its frequency range of applicability is limited only by the range of applicability of transmission line theory to the component geometry, and by the accuracy of the frequency-dependent RLGC parameters provided. Successful use of the W-element for RF and microwave frequencies is then contingent upon good extractions of the required RLGC data. The integration approach described in this article provides such a solution. Frequency-dependent RLGC data is computed accurately within the RF and microwave design software for each transmission line structure. The appropriate W-element models are then constructed for HSPICE transient simulation.

In other transient simulation tools, transmission lines are modeled with oversimplified low frequency approximations, such as an assumption of constant, frequency-independent, RLGC parameters, or by completely neglecting losses. At microwave frequencies, however, dispersion, skin

effect and other frequency-dependent losses must be modeled accurately to obtain useful simulation results. The HSPICE W-element approach is based on decomposing the coupled transmission line system into several well-behaved transfer functions based on the system's characteristic admittances and complex propagation factors. The decomposition is such that frequency dependencies can be accurately taken into account in the time domain with rational function approximations analyzed with recursive convolution. This approach has several distinct advantages over other available techniques:

- Performance is superior to that of direct numerical convolution available in competing products (linear vs. quadratic scaling of the CPU time with the length of transient simulations). After initialization, a W-element is not much more expensive in transient simulations than a resistor.
- The frequency dependence of RLGC parameters can be user-specified (in tabular format), or extrapolated based on standard skin effect and loss-tangent parameters.
- Coupled transmission lines with any number of signal conductors can be modeled.

Modal decomposition for multiconductor lines is handled automatically.

As with any modeling approach, some caution must be exercised with the W-element to avoid possible undesirable effects:

- Transient simulations of extremely short and extremely long transmission lines should typically be avoided.
- The interdependencies of frequency-domain RLGC data should be preserved (for example, the relationship between R (f) and L (f) values due to skin-effect). This is necessary to ensure causality in the time-domain simulation.
- Correct asymptotic behavior of the RLGC data at high frequencies is needed for causality and accuracy in broadband simulations.

With careful generation of the RLGC data, and by observing the cautions noted above, the W-element provides exceptional accuracy. In the Analog OfficeTM environment, the RLGC model generation is performed automatically, in accordance with the described precautions. As a

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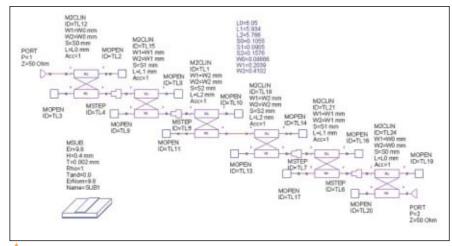
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igtriangleq Fig. $1\,$ A bandpass filter implemented with edge-coupled transmission lines.

result, transient simulations with multiple W-elements produce errors in the calculated voltages that never exceed 0.1 per cent.

The need for transient simulation is especially important for circuits containing nonlinear devices (including FETs, bipolar junction transistors (BIT) and diodes), but the accuracy of this approach is more clearly demonstrated with a simple linear example. As a typical RF/microwave design with distributed components, consider the bandpass filter based on edge-coupled transmission lines shown in **Figure 1**. Note that the filter schematic includes models to account for line-width discontinuities (microstrip-step (MSTEP) models open-circuit end-effects (MOPEÑ) models). The Analog Office software includes sophisticated frequency-domain models for each element within the filter based on geometric and substrate parameters. These models include dispersion and frequency-dependent loss effects.

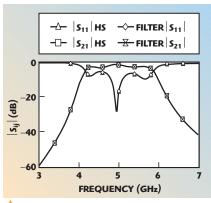
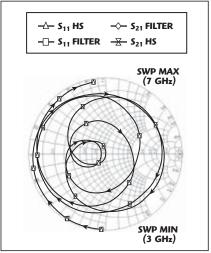


Fig. 2 Filter S-parameters calculated using internal models (Filter) and HSPICE (HS).

From these internal models, an equivalent HSPICE W-element model is generated as a frequency-dependent RLGC data set. The quality of the Analog Office-to-HSPICE translation can be examined in the frequency-domain using scattering parameters. *Figures 2* and 3 show this comparison in terms of the input reflection coefficient and insertion loss for the complete filter. Both the dB plots and Smith chart loci show excellent agreement.

The quality of the translation for the purposes of transient simulation can be examined through the use of Fourier analysis.⁴ The Fourier analysis will yield the steady-state waveforms of the circuit, while the transient simulation will follow the timedomain waveform evolution of the circuit. These two types of analyses can be compared through the appro-



▲ Fig. 3 S-parameters of the edge-coupled filter calculated from internal models (Filter) and HSPICE (HS).

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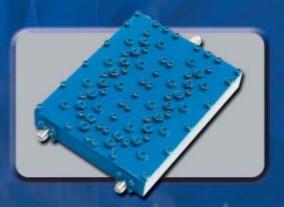


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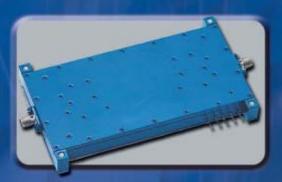


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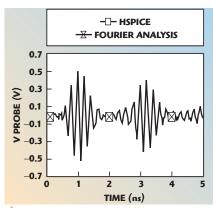


Fig. 4 Transient simulations using HSPICE compared with Fourier analysis (F=0.1 GHz).

priate choice of simulation conditions. The steady-state results calculated using Fourier analysis and the transient simulation results are suitable for comparison if:

- The transient simulation is run for a time interval sufficiently long for the transient processes in the circuit to die out, and steady state is reached;
- The period of the fundamental frequency used for Fourier analysis is

much greater than the duration of the transient processes (pseudo-transient analysis using Fourier expansion).

In order to evaluate the accuracy of the transient simulations with the described approach, a classic test circuit was constructed by connecting a pulse voltage source at port 1 with an amplitude of 5 V, a rise/fall time of 0.1 ns and a pulse width of 2 ns. The filter is loaded at port 2 with a 100 Ω resistor. Since the test circuit is linear, Fourier analysis can evaluate the reference solution. A large fundamental period (10 ns) and a large number of harmonics (n = 4096) are used to ensure Fourier series convergence for all practical intents and purposes. Furthermore, the transient simulations were run for 80 ns (8 periods of the fundamental frequency), and only the last period was shown for comparison. The Fourier analysis was performed using the harmonic balance simulation capabilities of the design software. The pulse response comparison between the Analog Office and HSPICE models is shown in *Figure* 4. As before, excellent agreement was

achieved, validating that this approach provides a means to realize accurate transient, time-domain simulations by translating frequency-domain models into HSPICE W-elements.

TRANSIENT SIMULATION WITH MODELS OBTAINED FROM EM ANALYSIS

At RF and microwave frequencies, numerical EM analysis is the most trusted method for characterizing many components. Often it is necessary to incorporate the results from EM analysis (typically frequency-dependent N-port S-parameters) as models for transient simulation. Methods based on fitting lumped circuits of fixed topology do not typically achieve the required accuracy (-30 to -20 dB) over a wide frequency range. In this approach, two methods are provided to incorporate the tablespecified, frequency-dependent S-parameters into a transient simulation:

- 1. Rational function approximation of the N-port admittance matrices.
- 2. Direct numerical convolution.

Method 1 can be used only for passive devices and has been shown to be highly accurate and computationally efficient (note that for the purpose of this discussion passivity means that the device does not generate power, so devices such as spiral inductors, couplers, filters, transmission line discontinuities, etc., are certainly passive). The rational function approximation is performed within the Analog Office software. The method used is a combination of those described in various references, including the vector fitting (VECT-FIT) method by Bjorn Gustavsen and Adam Semlyen. 5,6 The method operates on N-port admittance matrices and ensures passivity of the generated model. The rational functions computed are then translated to HSPÎCE in the form of voltage-controlled current sources (VCCS) with Laplace transfer functions. The MNA stamps for these sources are calculated efficiently using a state-variable formulation, and no numerical convolution is necessary.

Method 2 is more general, and allows for active devices (such as S-parameters for a biased FET) and may be more tolerant of noisy data. Yet, its accuracy for distributed models is lower (in the authors' experience)

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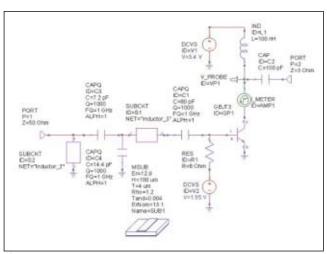


Fig. 5 HBT amplifier with spiral inductors modeled using Sparameters derived from EM analysis.

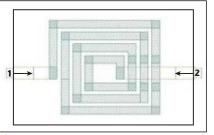


Fig. 6 Spiral inductor used for tuning of the HBT amplifier.

and the CPU time scales quadratically with the length of the simulated transient. Method 2 also permits simulations with non-causal models (if desired), while causality is strictly enforced with Method 1. Transient simulation with non-causal models is discouraged, since the results may not be physically meaning-

An example using EM-derived data is the heterojunction bipolar transistor (HBT) amplifier with spiral inductors shown in Figures 5 and 6. The scattering parameters for the spiral inductors were computed from EM analysis, and rational function approximations (Method

1) were used to translate the EM analysis results into HSPICE models for transient simulation. A Gummel-Poon BJT model was used for the HBT device.

The transient simulation results for the HBT amplifier example are shown in **Figure 7**. Since large capacitors (100 pF) and inductors (100 nH) were present in the circuit, it takes on the order of 160 ns for the transient processes to finish. The rational approximation is constructed during an initialization stage that takes approximately one second of CPU time.

In order to verify that the transient simulation produces results consistent with the frequency-domain data,

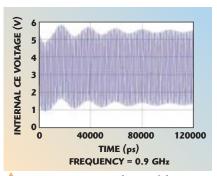


Fig. 7 Transient simulation of the HBT amplifier.

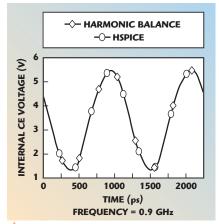


Fig. 8 Transient HPSICE simulation results at steady state compared with the waveform computed using harmonic balance.

the transient waveforms at steady state can be compared with those computed from harmonic balance analysis. In Figure 8, the last two periods of the transient waveform are

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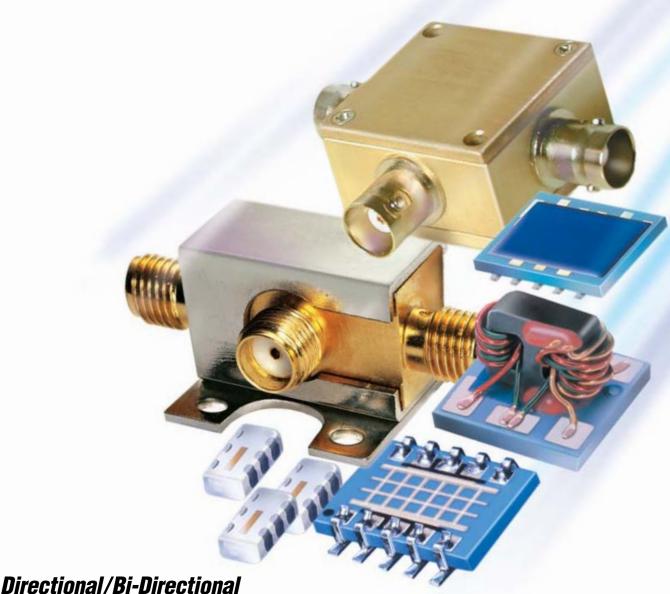
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plotted with the steady-state waveform derived from HB analysis. The plots demonstrate outstanding agreement between HSPICE transient and harmonic balance simulations.

CONCLUSION

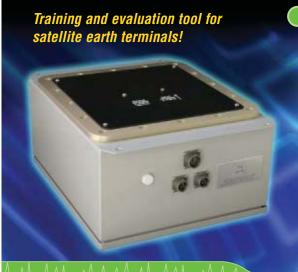
This article presents a unique approach to transient simulations of microwave and RF circuits using Applied Wave Research's (AWR) Analog Office software for high frequency

design integrated with HSPICE from Synopsys. The approach is based on decomposing circuits into components that are either uniform transmission lines, or elements of reasonably small electrical length. Accurate modeling of distributed components such as interconnects, transmission lines, transmission line discontinuities (such as T-junctions, crosses, etc.) and microwave devices (such as spiral inductors and baluns) is essential if

accurate simulation results for the complete circuit are to be obtained. Accurate transient simulation of transmission lines is obtained by using the HSPICE W-element with frequency-dependent RLGC matrices that are automatically generated from the internal frequency-domain component models in Analog Office software. Also demonstrated was an accurate and efficient approach to transient simulation using models for passive components based on rational function approximations of frequency-dependent N-port parameters. Especially useful for simulations based on EM-analysis results, the rational function approximations are converted to Laplace transfer function models for efficient HSPICE simulation. Extensive testing with realistic user circuits has demonstrated the success of these approaches. \blacksquare

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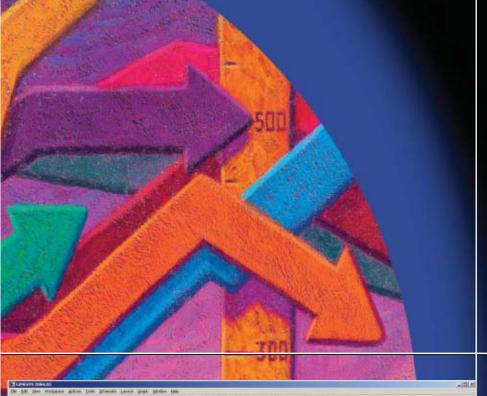
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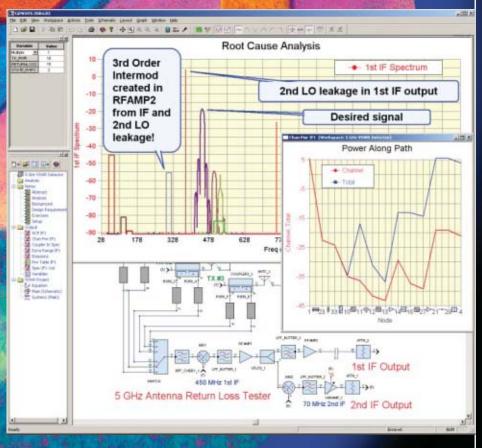
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TECHNICAL NOTE

THE IMPORTANCE OF SWEEP RATE IN DC IV MEASUREMENTS

The importance of taking due care in setting up IV measurement sweep rate is explored for the case of a GaAs MESFET and a silicon MOSFET. A numerical metric, called the normalized difference unit (NDU), is shown to be useful in determining appropriate delay factor settings for obtaining robust measurements using a Keithley 4200 DC parameter analyzer. The MESFET device initially exhibited erroneous measurements in the knee region, due to slow trapping effects, while only thermal effects are evident in the MOSFET results.

The DC IV characterization of a device is important in predicting RF operation. DC IV results predict the quiescent bias and low frequency IV characteristics for a device, while in some cases they can be corrected to represent RF characteristics at a given quiescent bias point.^{1,2} In addition, they can be used in measurement of the thermal resistance of a device³ and analysis of the type and time-dependence of processes present in a device.4 În using static DC IV measurements for these applications, it is assumed that the dwell time in each region is sufficiently long for device thermal and trapping processes to reach steady state at each point measured. If this is not the case, the true DC IV results may not be achieved, but a set of IV curves where each measured data point has an incorrect thermal and/or trapping dependence is obtained. In the experiment presented herein, the dependence of the results on the delay factor in IV measurements made using a Keithley 4200 DC parameter analyzer is explored for GaAs MESFET and Si MOSFET example devices. It is found that for the GaAs device that has significant trapping effects apparently possessing long time constants, the accuracy of the static IV curves is compromised if the delay time is too low. However, for the Si MOSFET, the lowest delay factor setting (fastest sweep) can be used with excellent accuracy.

THERMAL AND TRAPPING PROCESSES

Thermal and trapping effects have been shown to play a part in the measurement of static IV curves.^{5–7} These effects are known as "slow processes" and do not have time to occur in RF operation due to the short dwell time at each signal location; hence, pulsed IV measurement methods are often used to find the "RF IV" curves. DC IV curves, however, are still necessary in applications where the

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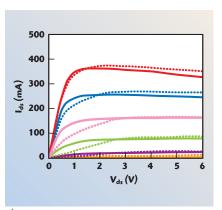
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▲ Fig. 1 Comparison of the GaAs MESFET IV curves for DF=100 (solid curves) and DF=1 (dashed curves) at NDU=0.065.

quiescent bias point is not known or is changing, such as in class B, AB, E, or F operation. In static DC IV measurement, it is necessary that the slow processes have time to reach steady state at each measurement point. This can be accomplished if the sweep rate of the curve tracer is low enough that the dwell time in each measurement region is sufficiently higher than the time constant of the effect. In other instruments, which do not sweep the curves but perform steps between points, the incorporation of a delay between measurements allows the device to remain biased at each point for a longer period of time.

How long does the dwell time in each region need to be? Walker gives an approximate room-temperature time constant of a thermal effect as 156 µs,8 while Ladbrooke and Bridge conclude that thermal time constants can lie in the tens of microsecond range. This means that the (V_{GS}, V_{DS}) bias of the device must remain in the same region longer than this length of time to provide an accurate measurement. Some trapping processes are even slower, stated to be on the order of milliseconds. Thus, the bias placed on the device must be in the region of measurement a minimum time of 0.1 to potentially even on the order of 100 milliseconds, depending on the device and its effects, before a measurement is performed.

THE NORMALIZED DIFFERENCE UNIT

For many years, sets of currentvoltage (IV) curve data have been compared qualitatively. The degree to which the sets of IV curves are correlated is often determined by visual inspection in which it is determined that the curves either match well or deviate unacceptably. Quantitative comparison provides a method of numerical analysis of IV curve differences and the ability to plot the differences in the IV curves versus a variable (such as sweep rate). The normalized difference unit, which can be used for such comparisons, is defined as^{2,4}

$$NDU = \frac{1}{N} \left(\frac{\sum_{i=1}^{N} |I_{DS1i} - I_{DS2i}|}{|I_{DSmean}|} \right)$$
 (1)

where I_{DS1i} and I_{DS2i} are the drainsource current values at the ith (V_{GS},V_{DS}) points of measurement on the two current-voltage characteristics and I_{DSmean} is the average of the current values over all measured points from both characteristics:

$$I_{DSmean} = \frac{1}{2N} \sum_{i=1}^{N} (I_{DS1i} + I_{DS2i})$$
 (2)

While this unit can be used to compare virtually any two sets of IV data for the same device, it is used to compare static DC IV data obtained using different delay settings in this experiment.

EXPERIMENTAL RESULTS

To examine the variation of IV measurements with dwell time and sweep rate, the DC IV characteristics of a commercial 1 W GaAs MESFET and a 7 W power Si MOSFET were measured using a Keithley 4200 Semiconductor Characterization System. The dwell time in each region during measurement was altered by adjusting the instrument delay factor (DF) to values ranging from 1 to 100. The delay factor is multiplied by a base delay time of 4.5 milliseconds to obtain the total delay time before the data is acquired at each measurement point. The NDU was used to compare the IV data measured for each DF setting to the IV curves measured for DF = 100 (delay time = 450 ms), the largest DF used in the experi-

For the GaAs MESFET, the settings used were as follows:

 $\label{eq:Gate Forcing Function: Voltage Step} V_{GS} Start: -2.2 V V_{GS} Stop: -0.7 V V_{GS} Step: 0.3 V $Data Points: 6$ Gate Source Range: Best Fixed Gate Port Compliance: 0.1 A$

Drain Forcing Function: Voltage Sweep

 V_{DS} Start: 0 V V_{DS} Stop: 6 V V_{DS} Step: 0.05 V Drain Source Range: Best Fixed Drain Compliance: 0.5 A Filter Factor: 1 Delay Factor: Varied; Used 1, 2, 5, 10, 20, 50, 100

A DC IV measurement was performed with the above settings for delay factors of 1, 2, 5, 10, 20, 50 and 100. A filter factor of 1 was used, meaning that the base data acquisition time of 8 ms per data point is used for all measurements. Before the data is acquired, a delay time of 4.5 ms (the base delay time) multiplied by the delay factor is enforced. From observation, it appeared that the delay factor of 100 with a step size of 0.05 V yielded a sweep rate of approximately 0.1 V/s, which coincides with the rate estimated using the delay and filter factors. Similarly, use of a DF = 1 setting can be estimated to result in a sweep rate of approximately 4 V/s. For higher delay factors, the overall measurement time was significantly larger than for low delay factors, matching these expectations.

First, the repeatability of the instrument was measured by using the NDU to compare IV curves for identical DF settings. Averaging the NDU comparisons of identical measurements with DF = 1, 10 and 100 provides a repeatability noise floor of NDU = 9.98×10^{-4} , or approximately 0.001.

An examination of the IV curves shows a marked difference between the results obtained for DF = 1 and DF = 100 (see **Figure 1**). The NDU value expressing the difference between these results is 0.065. The largest differences in these results appear to be in the knee region and for high values of V_{DS} in the upper curves. The knee region discrepancies are suspected to be due to trapping effects, as has been seen in pre-

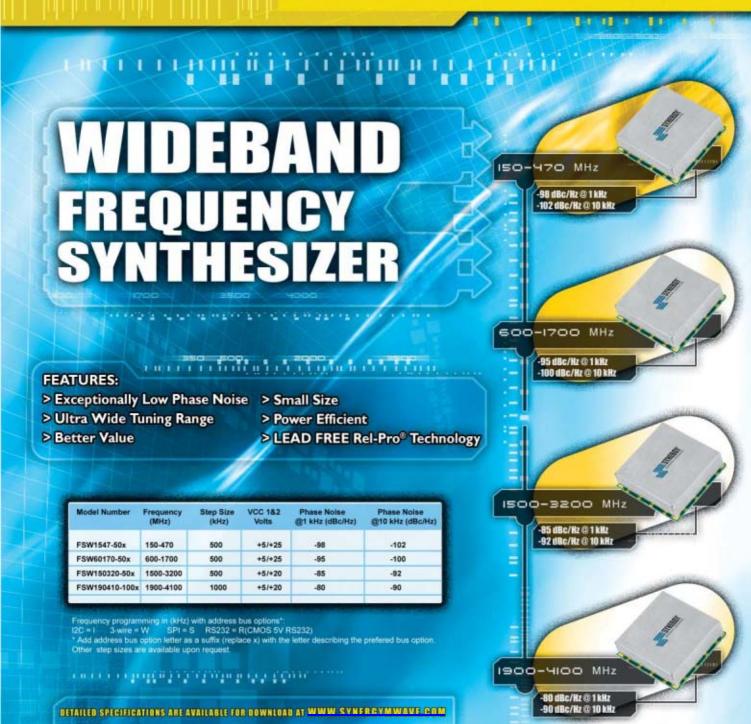
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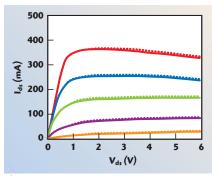


Fig. 2 Comparison of the GaAs MESFET IV curves for DF=100 (solid curves) and DF=50 (dashed curves) at NDU=0.005835.

vious experimentation by the authors. The discrepancies in the upper curves for large drain voltage are likely due to differences in self-heating in the devices at the time of measurement. Figure 2 shows that the difference between the DF = 50 curves and the DF = 100 curves is much lower (NDU = 0.005835).

As previously noted, a delay factor of 1 on the Keithley instrument corresponds to a delay time of approximately 4.5 ms. Thus, a delay factor of 50, for which good results are ob-

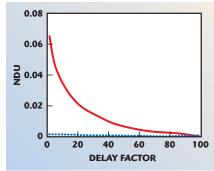


Fig. 3 NDU versus delay factor, comparing each measurement point with the DF=100 measurement (solid line) and instrument repeatability NDU (dashed line).

tained, is estimated to correspond to a delay time of 225 ms. While this seems like a long time for trap effects to reach steady state, it is quite consistent with the estimate of milliseconds for a time constant given in Reference 10 for trap effects. In addition, the GaAs MESFET used in this experiment does not have a gate recess, which tends to cause increased surface-state trap effects.¹⁰

For each DF setting, the NDU was computed between the IV curves

resulting from that DF setting and the DF = 100 curves (the measurement with the longest delay). The values of NDU are plotted against the delay factor value in *Figure* 3, showing that the difference between the curves decreases (and hence the accuracy of the DC IV measurement increases) with increasing delay factor. The measurement repeatability line of NDU = 9.98×10^{-4} is also shown. It is interesting to note that the NDU value approaches the repeatability NDU as the DF is increased.

This illustrates that for the "normal" setup with filter factor = 1 and delay factor = 1, an accurate static DC IV measurement is not obtained for this device. However, obtaining the set of curves for DF = 100 takes on the order of three to five minutes.

The same experiment was repeated for the Si MOSFET. In this case, a large difference was not noticed between the results. The NDU comparing the DF = 1 to DF = 100 IV curves is a mere NDU = 0.011, while the average instrument repeatability

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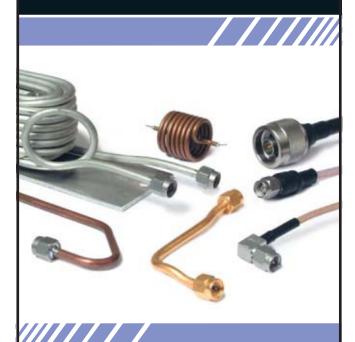
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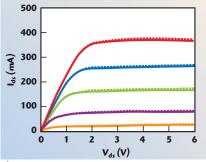


Fig. 4 Comparison of the Si MOSFET IV curves for DF=100 (solid curves) and DF=1 (dashed curves) at NDU=0.011.

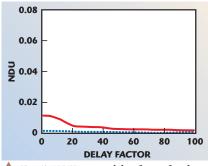


Fig. 5 NDU versus delay factor for the MOSFET device.

NDU is 0.00278 for the MOSFET. The DF = 1 and DF = 100 curvesare shown in Figure 4. It is evident that the curves show no large difference. In fact, the dashed curves, which represent the DF = 1 setting, are actually lower than the DF 100 curves, which should not be the case according to observed results concerning MOSFET device self-heating.² The NDU versus DF plot is given in *Figure* 5. It can be seen that while a decrease is observed with increasing DF, the

magnitude of the NDU is low for all DF settings, just above the repeatability level. Therefore, it is concluded that this difference may be due to measurement conditions (such as, "How warm is the device from the last measurement?"). The measurements for the LDMOS FET were made in order from DF = 1 to DF = 100. To gain insight into this, it could be advantageous to repeat the experiment, randomizing the order in which these measurements are taken, and observing whether the NDU versus DF graph changes. It appears from the results of this experiment that measuring with too small of a delay factor would have the largest detriment in the GaAs MESFET measurement, while little compromise in accuracy would occur in the case of the Si MOSFET.

CONCLUSION

The use of a sufficiently long sweep rate may be necessary to achieve an accurate static DC IV measurement. If the sweep rate used is too fast, thermal and trapping processes, if present, might not reach steady state in the region of measurement for each measurement point. However, in device operation at a quiescent bias point or at a low frequency, steady-state thermal and trapping conditions are generally held at the conditions that exist at the bias point. From the results presented in this article, it is apparent that for the case of Keithley 4200 DC IV measurements a delay factor of 20 or so was sufficient for accurate measurement results on the Si MOSFET device example, while for the GaAs MESFET example, a delay factor of greater than about 80 was required. The presented NDU metric is a useful tool to use in comparing IV curves in simple studies like this one to help confirm the appropriate instrument settings to use for a given device

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ACKNOWLEDGMENTS

The authors would like to thank Lee Stauffer of Keithley Instruments for his very helpful suggestions. It is also gratefully acknowledged that this work was sponsored in part by a fellowship grant from the Automatic RF Techniques Group (ARFTG).

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Gali ;;; 51F	DC-4000	18.0	15.9	3.5	32	78	50	4.4	1.29
Gali ;;; 55	DC-4000	20.4	15.7	3.5	31.5	103	50	4.3	1.29
Gali ;;; 55	DC-4000	21.9	15.0	3.3	28.5	100	50	4.3	1.29
Gali ;;; 52	DC-2000	22.9	15.5	2.7	32	85	50	4.4	1.29
Gali	DC-4000	12.2	18.2	4.5	35.5	93	70	5.0	1.49
	DC-4000	14.4	17.5	4.0	34	93	65	4.6	1.49
	DC-4000	18.1	18.0	3.5	35	78	65	4.5	1.49
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In the past, RF test engineers would either develop unique software for each product using rapid development tools, or develop a generic software platform that could be used on all products through a robust configuration mechanism. The advantage of using rapid development tools to come up with a unique program was that the tools were easy to use and the test program development could be handled by the test engineers themselves. Unfortunately, maintaining the software configuration is difficult and re-usability is often limit-

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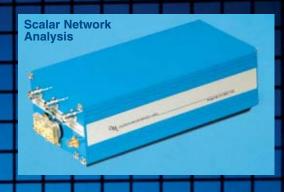


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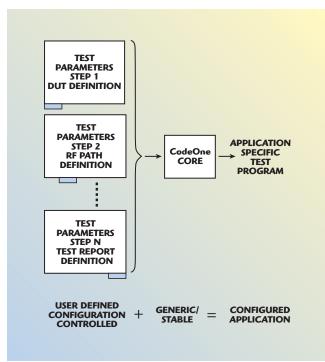


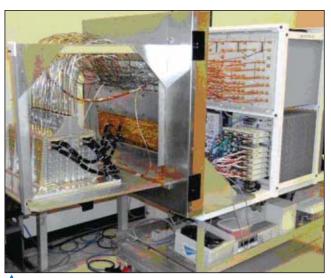
Fig. 1 The CodeOne platform.

ed. Also, this approach does not favor standard data management.

Conversely, the generic software platform can be reused on all products and projects through a robust configuration mechanism. Although this capability sounds attractive, its implementation is often difficult since it requires specialized resources (software developers) that are often not RF specialists. As a result, the software definition can take a long time to converge and be much more expensive than planned. Also, it leads to two extremes — it is either too simple (the platform never actually does what is required and needs endless additions and modifications); or it is too complex, designed to fulfill every possible requirement. Thus, it becomes a behemoth that takes more time to learn than to use and is very expensive to maintain.

The CodeOne platform takes the approach that, providing one can standardize the test process (which is under the test engineer's control), it must be possible to organize and bound the list of variables required for each test application. It is designed to allow the test engineer to describe the variables of any test application in a simple, but powerful and flexible way (a variable being a number, a formula or a complex routine). It captures the generic aspects of the test engineering process in the software and finally finds a way to parameterize the generic software using a list of variables.

Initially this set of tasks was not simple; however, over a long period of time a stable solution was arrived at and ultimately the approach was applied to a very large variety of products (from simple RF passive components to very complex microwave active equipment, base station transceivers, space instruments and even SAW wafers). The tool has basically allowed test engineers to focus on what really matters — test specifications and test results, as opposed to writing software.



▲ Fig. 2 Calibrating a 14x36 switch matrix.

HOW DOES IT WORK?

Users of the CodeOne platform first define the process parameters using ExcelTM The parameters are organized by configuration sheets, each of which parameterize a particular aspect (or step) of the test process. One sheet, for example, would describe all the test phases, another all of the RF paths used during the tests, and so on. The parameters define the behavior of the CodeOne core software at run time. They are stored with the test data to ensure full traceability.

The core software has been extremely stable over the past few years. However, a number of doors have been opened in the core software to allow users to "connect" their own software. In particular, user-specific post-processing routines can be coded using Matlab, for instance. Similarly, users can design their own device-under-test (DUT) control and monitoring software, or their own thermal chamber control software. *Figure 1* shows a simplified diagram of the CodeOne platform.

The CodeOne platform is designed to handle one application from project definition to test reports. This feature is essential to ensure consistency and traceability. The same test platform is used to:

- Define a new project
- Manage user access
- Import/export data
- During test: perform calibration, acquire data, calculate and retrieve data, and issue test reports and test summaries

In a multi-port configuration, performing the calibration can be tedious and prone to costly mistakes. Acquiring error terms, ensuring that the measurements are using the correct calibration set and storing the data are all critical to the success of the testing scenario. All aspects of advanced calibration techniques are embedded in the software structure to avoid these errors and ensure correct measurements.

CodeOne-based systems are designed around high performance, broadband switch matrices. A patented calibration technique that reduces the number of connections and disconnections during calibration has been developed and is employed. For example, the calibration of a 14×36 switch matrix (see **Figure 2**) only requires the measure-

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FPD1500P100	16	31	42	1.5	12.5	31	44	1.6	8	490
FPD750P100	14	27	40	0.7	8.5	27	41	2.5	8	225
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FPD2250SOT89*	15.5 ²	29	44	1.0	N/A	N/A	N/A	N/A	5	700
FPD1500SOT89*	17 ²	27.5	42	0.9	N/A	N/A	N/A	N/A	5	465
FPD1500DFN*	18²	27.5	42	0.9	7.0	27	40	N/A	- 5	465
FPD1050SOT89*	17.5 ²	25	40	0.9	N/A	N/A	N/A	N/A	5	325
FPD750SOT89*	18²	25	39	0.6	10.0	N/A	N/A	N/A	5	230
FPD750DFN*	20²	24	39	0.5	11.0	24	38	N/A	5	230
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FPD2000AS	14	20	33	46	10	1150
FPD4000AF	10.5	19	36.5	49	10	2300
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FMA411	Gain Block	8.5-14	18	17.5	2.6	+6	SB	120	64x58

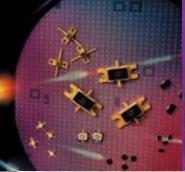
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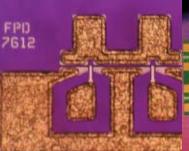
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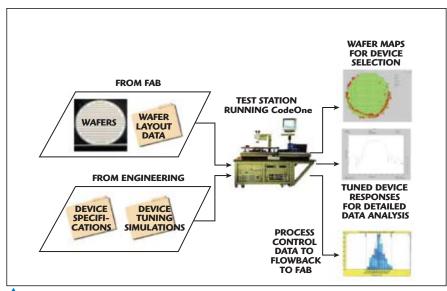


Fig. 3 A wafer test station running CodeOne software.

ment of 50 paths, as opposed to many thousands of isolation paths under normal techniques.

TEST ENGINEERING SERVICES

COM DEV is now offering its CodeOne platform as part of a Test Engineering Service Package. The test software platform can be deployed on a stand-alone basis or as a complete enterprise solution (networked test stations). Depending on the requirements, the company can design and deliver turnkey solutions, including training and post delivery maintenance and support, or license the CodeOne platform and train the test engineering team to deploy its own CodeOne-based solutions.

As an option, the CodeOne platform can include a "Special Test Equipment (STE) Toolbox," which is a combination of hardware and software that operates the DUT (power, telecommand, telemetry). STEs are often application/equipment specific, and the Toolbox is designed to enable the efficient design of such equipment. It is based on a generic input/output card that can be programmed to emulate almost any protocol (serial or parallel) and has been designed to easily interface with the CodeOne-based solution.

EXAMPLES OF CODEONE SOLUTIONS

The following three test systems were designed to test three different levels of assembly of an RF processor. All of the test racks used the same traceable software and the same rack architecture. The racks were part of a common network and the test data was accessible to all individuals involved in the project at all times.

Component Level: SAW Wafer and Package Testing

The requirement was to test up to 8000 SAW devices on a wafer and process the data in quasi-real time. The tests included S-parameters to determine bandwidth, loss and phase. The solution was to design an automatic feed and probe system using the CodeOne platform (see Figure 3). The resulting test time per SAW device was reduced to less than a second including the probe station movement time. Statistical analysis of the various parameters was performed to enhance the manufacturing process. Test data was then ported to the next higher assembly level.

Subassembly Level: Amplifier-SAW-Amplifier

The requirement was to measure the Amp/SAW/Amp subassemblies by batches in a thermal environment using a multi-port RF system, while maintaining calibration during a two-week cycle. The solution was to design a test system using high performance switch matrices. Each CodeOne test station had a throughput of 25 assemblies and included measurements of gain, phase, return loss, third-order intermodulation, isolation and spurious, without disconnection.

Final Assembly Level: The RF Processor

The requirement was to test a complex active RF processor (12×8 ports at L-band) for phase noise, phase and amplitude tracking, group delay, gain and gain monitoring, IM3 and isolation. Each test could generate up to 2 Gb of data. The solution was a multi-port test system using the same switch matrices as before and the same core software.

CONCLUSION

A versatile common test software platform has been described that has been borne out of COM DEV's extensive heritage in manufacturing equipment for space applications. The challenges faced in testing space hardware are typically those of low volume, high mix, high performance and high reliability. Similar requirements are faced by the aerospace and medical industries. The CodeOne platform has been designed to address the requirements of a large number of tests under difficult testing conditions with full traceability and low product standardization. The CodeOne solution provides flexibility, high reliability and high performance in automatic testing, thus minimizing cost and lowering capital expenditures.

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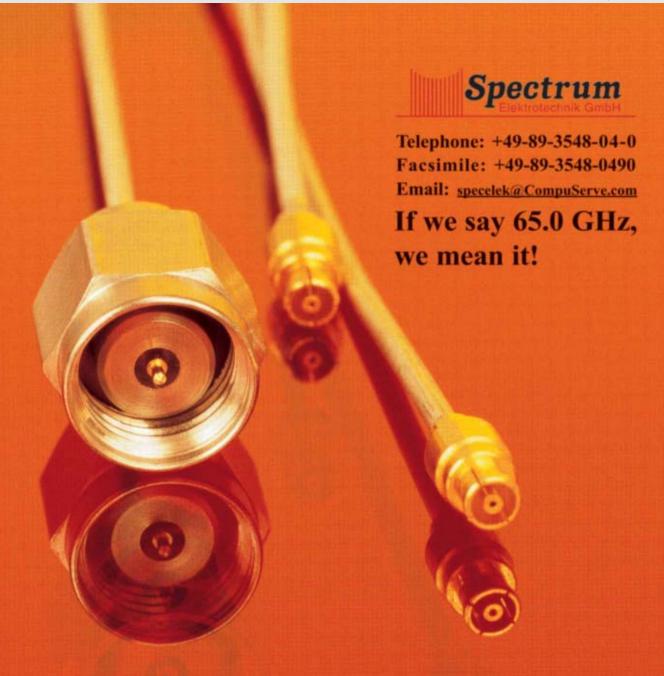
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Product Feature



SATELLITE IN-ORBIT GROUP DELAY MEASUREMENT USING A MICROWAVE SYSTEM ANALYZER

Typical established satellite transponders are often configured with channel bandwidths of between 26 and 72 MHz depending on the satellite system, although bandwidths between 5 and 120 MHz are not uncommon. This bandwidth was considered to be more than acceptable when the satellites were launched, but with the increasing demand for Internet traffic, digital TV and other digital services, operators are being forced to fill the available bandwidth to the limit. The consequence of this is that as signals occupy more of the available bandwidth they deteriorate because the transmission path, including the satellite transponder, uplink and downlink, degrades the signal. It becomes necessary to apply compensation for this degradation if the data rate is to be maintained; in order to do this effectively, the impairments must be measured.

Satellite in-orbit testing is carried out for several reasons. In its basic form it is to verify the integrity of the communications payload and the antenna platform following launch and prior to the release of the satellite to the customer. Regular checks are also carried out for the purpose of acceptance testing or anomaly resolution. Measurements can then be compared with forecasted values or previous results.

GROUP DELAY

One parameter that has proved difficult to measure is group delay over frequency, particularly through frequency conversion. Group delay is of prime importance in today's communication systems. 1 The requirement for distortionless transmission through a linear time invariant system is a flat amplitude response and a linear phase response. The components in a typical satellite link, shown in Figure 1, can only approximate these conditions. Group delay is a measure of the phase linearity. Flat group delay versus frequency implies linear phase. Figure 2 shows linear and parabolic group delay, which are typical of delays experienced in satellite networks. Parabolic delay is usually associated with bandpass filters found in satellite transponders and communication equipment. The sinusoidal delays are often caused by impedance mismatches in the system. Ideally, the group delay is flat, a straight line with no slope, so that all frequencies across the carrier bandwidth experience the same time lag through the link. If not, the recovered digits interfere with one another, making them difficult to distinguish and errors occur.²

AEROFLEX INC. *Plainview*, *NY*

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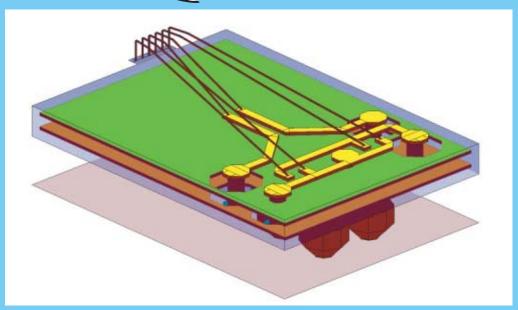
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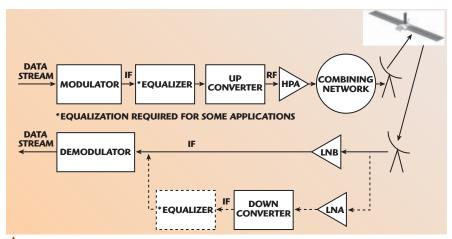
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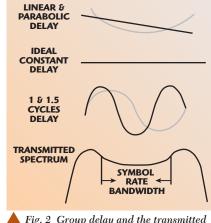


Fig. 2 Group delay and the transmitted spectrum.

Fig. 1 Schematic of a typical satellite link. **MICROWAVE SYSTEM ANALYZER**

The Aeroflex 6840 series Microwave System Analyzer (MSA) has become established as the ideal product for the measurement of group delay through frequency conversion components and circuits.1 It comprises a swept frequencymodulated source and a receiver, as shown in *Figure 3*, and measures group delay with the envelope or modulation delay technique. Since the group delay is derived from the modulation envelope and not the carrier frequency, the technique can be applied to measure frequency-converting networks. No external frequency converting hardware is needed be-

cause the source and receiver frequencies are independent.

Figure 4 shows a typical amplitude and group delay response of a downconverter. The MSA can also carry out spectrum analysis, gain compression, third-order intercept, return loss/VSWR and cable fault location.

It is rapidly becoming the instrument of choice in the measurement of group delay and other transfer characteristics of satellite links from ground stations, either co-located or remote, through the in-orbit transponder. A setup screen facilitates the selection of the input, output and/or conversion frequencies and levels (see *Figure 5*).

TRANSIT TIME

The transit time to and from a satellite can be considerable even for one in low earth orbit. For a geostationary satellite it is in the region of 250 ms. In practical terms this can mean that, since the source and receiver frequencies are synchronized, the receiver, which will have an aperture of perhaps 1 MHz, has moved beyond the received signal. It is necessary therefore to further offset the source and receiver frequencies to take account of the transit time.

The offset should be increased by

 $F_{offset}(MHz) = Sweep (MHz/ms) \times Transit time (ms)$

For example, the uplink (source) frequencies are 14,000 to 14,500 MHz and the downlink (receive) frequencies are 11,200 to 11,700 MHz; the satellite is in a geostationary orbit; the MSA is set to a sweep time of 10 seconds and an aperture (resolution bandwidth) of 1 or 3 MHz.



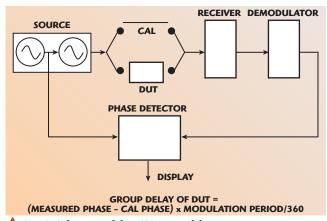


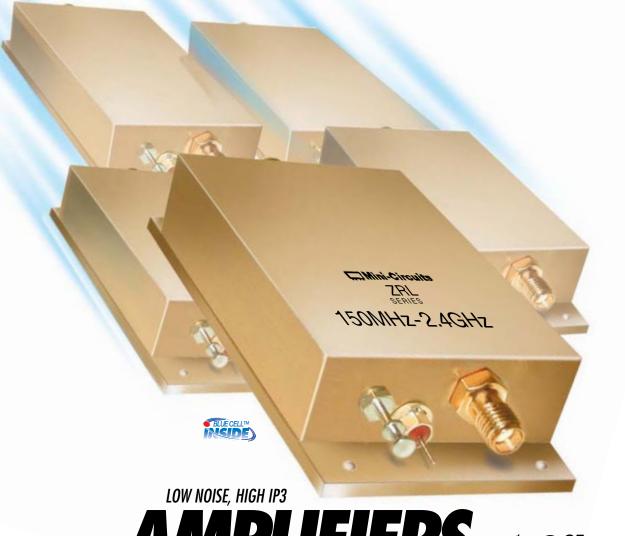
Fig. 3 Schematic of the MSA group delay measurement system.

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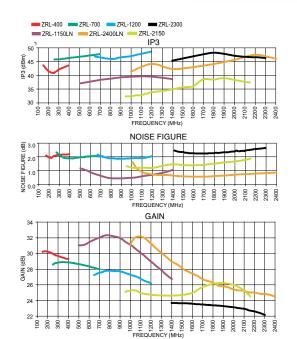












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ZRL-1200	650-1200	27	2.0	46	24.3	119.95
ZRL-2150	950-2150	25	1.5	33	22.0	119.95
ZRL-2300	1400-2300	24	2.5	46	24.6	119.95
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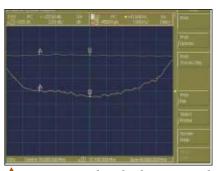


Fig. 4 Measured amplitude response and group delay of a downconverter.

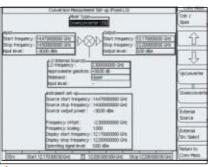
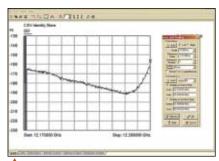


Fig. 5 Set-up screen for a downconverter measurement.



▲ Fig. 6 Relative group delay of an in-orbit satellite transponder displayed using MiPLOT™ (courtesy of Loral Skynet).

Transit time is 285 ms; sweep rate is 0.5 MHz/ms; F_{offset} = 14.25 MHz.

The receiver should therefore be set to sweep between 11,185.75 and 11,700 MHz and the source to 14,000 and 14,514.25 MHz. The display will show the receive frequency range and the received frequency will be well within the resolution bandwidth.

IN-ORBIT MEASUREMENT

Figure 6 shows the measured group delay characteristic of a satellite in geostationary orbit measured through a single ground station. Input (uplink) frequencies are 14.47 to 14.5 GHz and the output (downlink) frequencies are 12.17 to 12.2 GHz. Calibration was carried out at the input frequencies bypassing the antenna. (It is normal to calibrate at the

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source frequency rather than the receiver frequency to remove the delay changes inside the instrument through band switching and the frequency modulation hardware.) The setting up of the instrument and carrying out of group delay measurements are discussed in detail in Reference 3. In this case the sweep time was $10~{\rm s}$ and the sweep rate was therefore $3~{\rm kHz/ms}$. The transit time offset is less than $1~{\rm MHz}$, so with an aperture of $3~{\rm MHz}$ it can be ignored.

REMOTE GROUND STATIONS

This group delay test can be carried out across links where the ground stations are not co-located. The MSA acting as the source is located with a controlling PC running dedicated software at the link provider's main station. A second MSA acting as the receiver is installed at the receiving end that could be anywhere in the world where the satellite has a transmission footprint. Using the GPIB interface to the local MSA and a serial connection via modems to the remote MSA, the instruments are configured to obtain a relative group delay measurement across the section of the link to be analyzed. The two instruments are synchronized over the frequency sweep. GPS receivers can be used at either end of the system to obtain a common time and frequency reference. Measurement data are then returned from the remote end to the local PC for review and storage of the results.

CONCLUSION

The Aeroflex 6840 series Microwave System Analyzer is the ideal single box solution for in-orbit measurement of group delay across satellite links because all units will readily cover all of the currently required bandwidths and any future increased bandwidths within a single unit. Models cover 10 MHz to 20, 24 and 46 GHz, and are priced from \$67,000.

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- A. Jones and J. McManus, "The Measurement of Group Delay Using a Microwave System Analyzer," *Microwave Journal*, Vol. 43, No. 8, August 2000, pp. 106–118.
- S. Back and M. Weigel, "Degradation of Digital Satellite Signals by Group Delay," World Broadcast News, November 1999, http://206.223.8.10/linksite/manuals/datasheets/delaydeg7.pdf.
- "Measurement of Group Delay Using the 6840 Series Microwave System Analyzer with Option 22," Aeroflex Application Note.

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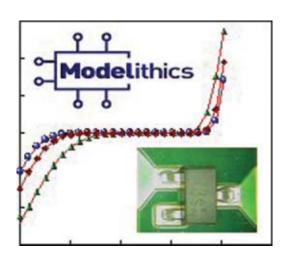








PRODUCT FEATURE



NONLINEAR DIODE MODELS FOR ENHANCED SIMULATION ACCURACY

library of robust models featuring substrate scalability and temperature dependence is now available for surfacemount diodes. The Modelithics Nonlinear Diode (NLDTM) Library contains a compilation of measurement validated nonlinear diode models developed from I-V, C-V, smalland large-signal S-parameter characterization data. Over-temperature testing, combined with Modelithics' patent-pending substratescalability features, extends the accuracy of nonlinear simulations over a wide range of assembly and operating conditions. No other set of diode models contains the same high levels of validation, accuracy, range of multi-variable applicability and documentation. The NLD Library is currently available in design kit format for Agilent's Advanced Design System (ADSTM).

The range of validity for any model used in electronic design automation (EDA) software depends on the internal topology and the types of characterization data from which it is extracted. Models in the NLD Library use proprietary, physically-motivated equivalent circuit topologies that correctly emulate device performance over DC bias, RF drive level and temperature. Extensive IV and CV data sets acquired using an automated Keithley 4200-SCS test system are used in conjunction with broadband S-parameter measurements made with an Anritsu Lightning VNA. Different novel intrinsic models are used to represent the Schottky, varactor and PIN diodes included in the NLD library.

Accuracy in developing an equivalent circuit model is contingent on representing the intrinsic characteristics of the device and also accounting for the extrinsic effects that arise due to the circuit environment in which the part is mounted. In addition, package-to-substrate coupling effects are included in order to capture variations in performance parameters such as impedance and resonant frequency due to different mounting configurations.

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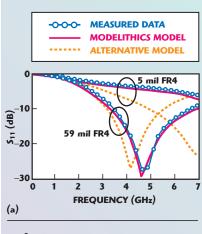
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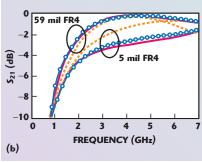
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igtheq Fig. 1 S_{11} (a) and S_{21} (b) for a Schottky diode biased at 16 V on 5 and 59 mil thick FR4 substrates.

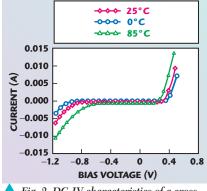


Fig. 2 DC-IV characteristics of a crossover quad Schottky diode at different temperatures (markers indicate measured data, solid lines are model results).

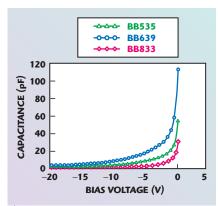


Fig. 3 Capacitance of varactor diodes at 1 MHz (markers indicate measured data, solid lines are model results).

ACCOUNTING FOR SUBSTRATE EFFECTS

The presence of substrate-dependent parasitic effects in the frequency response of surface-mount (SMT) components typically becomes evident

above a few- to several-hundred megahertz. These effects are attributable to complex interactions between the part, the package, board and solder pad stacks, and depend on the physical size of the component and the internal package configuration. (For a discussion of such effects on RLC passive SMT components see "Comprehensive Models for RLC Components to Accelerate PCB Designs," *Microwave Journal*, May 2004.)

An accurate model of an SMT diode must account for these parasitic effects as well as representing the intrinsic nonlinear behavior of the diode. The models should be capable of scaling all circuit parameters with changes in the substrate height and dielectric constant to increase the versatility of the model. This capability becomes increasingly important in nonlinear simulations involving multiple high frequency harmonics, where the impedance presented to a harmonic can change significantly as a function of substrate type (see *Figure 1*).

COMPLETE MODEL VERIFICATION

In addition to providing unique substrate-scaling features, each Modelithics model is provided with datasheets to document the model development process, to define each model's range of validity and to provide typical measured-to-modeled comparison graphs. These datasheets fill an important and all too common void in the EDA simulation community — in general a designer has access to little or no information regarding the conditions under which a given model can be used. In this situation the designer may find it necessary to perform his own model verification, or at the very least have less confidence in trusting the model, especially over bias, temperature or power level variations. The Modelithics datasheets specify the test conditions for each model and provide representative measurement-to-model comparisons, such as those shown in *Figures 2* and 3.

ACCURATE NONLINEAR PREDICTIONS

Extracting a nonlinear model using a wide set of characterization data types results in a versatile, robust simulation model. In the case of a diode model, I-V, C-V and S-parameters (small- and large-signal) are the most common test data types. If these data sets are fitted appropriately, accurate prediction of power compression (see *Figures 4* and 5) is an example of how the model can be applied.



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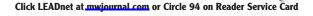
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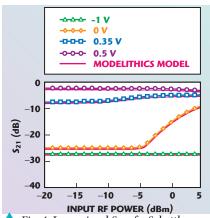








PRODUCT FEATURE



igwedge Fig. 4 Large signal S₂₁ of a Schottky diode at different bias conditions at 1 GHz (markers indicate measured data).

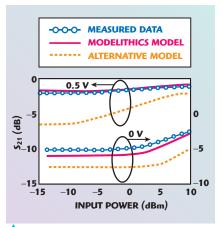


Fig. 5 Large signal swept power characteristics of a PIN diode at 1 GHz.

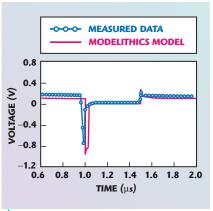


Fig. 6 Measured and simulated output voltage waveforms for a PIN diode at an input bias of 0 V.

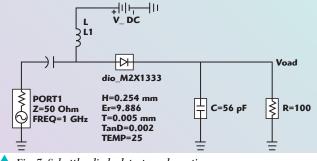
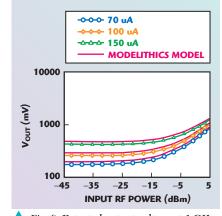


Fig. 7 Schottky diode detector schematic.



▲ Fig. 8 Detected output voltage at 1 GHz at different bias conditions (markers indicate measured data).

The accuracy obtained with nonlinear frequency domain simulations also extends to transient (time domain) simulations. Validation of a PIN diode tested at zero-bias with an input frequency of 1 MHz and input amplitude of 0.5 V is shown in Figure 6. An accurate prediction of the reverse recovery time, de-

fined as the time taken to switch between the off and the on states, is illustrated.

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DIODE DETECTOR EXAMPLE

A simplified schematic for a diode detector circuit, configured for a nonlinear simulation in ADS, is shown in *Figure 7*. The combination of C1 and L1 acts as a bias tee and provides a DC return path for the diode. The 56 pF output capacitance presents a low impedance to ground for transmitted RF harmonics. *Figure 8* illustrates the excellent fit between predicted and measured output DC voltage under different bias conditions.

CONCLUSION

A nonlinear diode library that provides designers with new levels of accuracy and flexibility has been described. For the first time, designers can take advantage of substrate and temperature effects in performing linear, nonlinear and time domain simulations for a wide range of commercially available Schottky, varactor and PIN diodes. For further information or to request a free demonstration trial, visit http://www.modelithics.com/diodes_yend.shtml.

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Ke Wu Ecole Polytechnique de Montreal <u>ke wu@ieee.org</u> The IEEE Radio and Wireless Symposium (RWS 2006) continues the evolution of the successful Radio and Wireless Conference (RAWCON), most recently held in Atlanta, GA, September 2004. This conference maintains a focus on interdisciplinary aspects of wireless and RF systems and technology with an emphasis on how pieces fit together to shape the latest developments in communications technology and enable the convergence of applications. In addition to oral presentations and posters, RWS includes workshops, panels, and a major exhibition. The inaugural RWS 2006 will be held in San Diego, CA, 17-19 January 2006 as part of a week-long major technical event – MTT Wireless. Also participating in MTT Wireless are the *Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF)* and the *IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)*.

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- 802.16/LMDS Broadband Fixed Wireless and Last-Mile Access Techniques
- Bluetooth/Personal Area Networks
- Wireless Sensors and Ad Hoc Networks
- 802.15/Ultrawideband (UWB) Communication
- Low-Power/Low Noise RF/Analog IC and System-On-Chip Solutions

Sessions will cover systems and enabling technologies in the areas of:

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- Digital/Analog Adaptive/Collaborative Signal Processing
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- Signal Generation/Power Amplification, Linearization, and Active Components
- Front-End Antenna/Subsystems and Passive Components
- Cross-Layer Design

Workshop Proposals

Proposals for workshop topics are solicited, and must be received by **6 June 2005**. Details on the process and requirements can be found at www.radiowireless.org.

Paper Submission Instructions

Authors must submit a summary (not more than 4 pages including figures) electronically using the www.radiowireless.org web page by 7 July 2005; this date is firm, no extensions can be granted. Please indicate your preference for oral or poster presentation format. The preferred file format is pdf; for additional options go to www.radiowireless.org.

Submissions will be evaluated for originality, significance of the work, technical soundness, and interest to a wide audience. Authors will be notified by 29 August 2005. Final manuscripts of accepted papers (4 pages in length) must be received by **1 November 2005** to be included in the published Proceedings.

Late News Papers

There will be limited space for Late News Papers, which may be submitted up to 7 September 2005. Submission requirements are the same as above, but the selection criteria are more rigorous. Accepted Late News Papers will appear in the Proceedings, but can not be listed in the Advance Program.

Major Exhibition

RWS 2006 is part of MTT Wireless which also includes a major commercial exhibition of technologies & services for radio and wireless development. See www.horizophouse.com for details.











Product Feature



A VECTOR SIGNAL GENERATOR FOR PRODUCTION APPLICATIONS

Recognition that the key requirements of test equipment used in an automated production environment are high throughput and reproducibility has led to the development of the R&S SMATE 200A vector signal generator. Designed as an optimum solution, this instrument features short setting times for frequency and level changes plus high signal quality.

As an automatic test equipment model, the instrument is based on the company's R&S SMU 200A vector signal generator and, like that model, can accommodate two independent signal generators in four height units. This means that it occupies only 50 percent of the rack space required by conventional instruments with similar functionality. This can be a major advantage in crowded production areas.

The RF range can include up to two paths. For this reason, the modules cover a frequency from either 100 kHz to 3 GHz or 100 kHz to 6 GHz for both paths. If the two-path option is implemented mixed installation is possible. Also, up to two internal baseband generators produce signals that can be digitally added together if required. As a result, the hardware components are optimally matched to one another and require no external cabling, allowing a level and a frequency offset to be applied.

Baseband generators with digital signal processing (DSP) and a coprocessor field-programmable gate array (FPGA) enable the calculation of complex signals in real time and signals for all common mobile radio standards are possible. A wide selection of modulation types are available — ASK, FSK, MSK, PSK

(including 8 PSK EDGE) and QAM (up to 1024 QAM). The vector signal generator can also handle all common coding types and baseband filters. GSM/EDGE, 3GPP FDD including HSDPA, GPS, CDMA2000 and IEEE 802.11 a/b/g are supported.

Furthermore, the application of the company's WinIQSIM simulation software facilitates the generation of signals for additional standards (cdmaOne, 3GPP TDD or TD-SCDMA, for example). It is also possible to independently feed in external analog I/Q signals for both paths of the instrument.

Since the vector signal generator is modular in design, it can be used for numerous applications that previously required multiple signal generators. For example, when equipped with two baseband generators and one RF path, it can add together real time signals of various standards such as GSM/EDGE and 3GPP FDD, generate multicarrier signals with real time components or simulate antenna diversity. An R&S SMATE 200A equipped with one baseband path and two RF paths enables the generation of a modulated signal on one path and a continuous wave interference signal on the other.

HIGH THROUGHPUT

As was mentioned previously, production environments demand high throughput to keep costs down. This vector signal generator meets this need by providing short settling times of less than 2 ms for frequency and level. In List mode,

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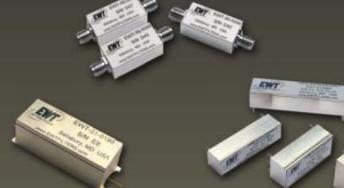






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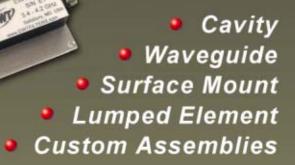
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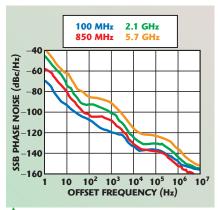
where frequency variations have previously been stored in a list, these times can typically fall to 400 µs. The flexibly addressable Fast Hop mode also operates at such short settling times. The baseband generators either provide complex signals in real time or output precalculated waveforms from the internal, 64 Msample arbitrary waveform generator, and the generated signals can be stored on the built-in, 20 Gbyte hard disk.

Claimed to be a unique function is the Multi Segment Waveform, which also enables high speed operation. In the baseband, this function makes it possible to rapidly switch between the various test signals in just a few microseconds. Rapid switching between the different waveforms becomes truly important in view of the increasingly numerous standards combined in mobile radio chips. For example, the single-chip solutions with GSM900, GSM1800 and GSM1900 technology will soon be supplemented with additional standards such as IEEE 802.11 a/b/g as well as EDGE or UMTS. Rapid switching cycles reduce dead time, thus contributing to high throughput.

SIGNAL QUALITY

Another significant feature of the instrument is its extremely low single sideband phase noise of typically –135 dBc (carrier offset 20 kHz, frequency 1 GHz, measurement bandwidth 1 Hz). *Figure 1* shows typical phase noise performance. A further improvement of 5 dB to a typical value of –140 dBc (under the same operating conditions) can be achieved by implementing the Low Phase Noise option.

Since multiple elements that cause attenuation are often located be-



▲ Fig. 1 The R&S SMATE 200A typical phase noise performance.

tween the signal generator and the device under test, especially in production environments, a vector signal generator must have enough reserve power to compensate for the resulting loss. When equipped with the High Power Output option, the R&S SMATE 200A provides output levels of typically +26 dBm. The high power level makes external amplifiers unnecessary and the High Power Output option does not involve replacing the electronic attenuator.

In addition to speed, the reproducibility of measurements is crucial in production. A temperature-controlled RMS detector means high precision level setting independent of the signal characteristic. The output level typically varies no more than ±0.01 dB over a period of five days. The detector thus contributes to very high measurement repeatability and keeps test conditions constant over time.

Optimum values for phase noise, noise floor and the high linearity of the I/Q modulator leave sufficient leeway for adjacent channel leakage ratio measurements on base station amplifiers. In the case of a 3GPP single-carrier signal (3GPP test model 1, 64 DPCH), the vector signal generator typically reaches 70 dB in the adjacent channel and 74 dB in the alternate channel. This leaves enough room for more demanding future requirements. Notably, however, no compromises need to be made in error vector magnitude measurements. Consequently, this combination makes it possible to determine the two important parameters when testing power amplifiers without any changes to the instrument's set-up.

PRODUCTION-ORIENTED OPERATION

The external interfaces of the vector signal generator have been designed with production in mind. Owing to the instrument's reduced operating concept, the front panel provides just the



Fig. 2 The rear panel of the vector signal generator, showing all interfaces and connectors.

elements needed — a power switch and four LEDs labeled Ready, Busy, Error and Remote that indicate the instrument's current status. All connectors are located at the rear of the instrument (see *Figure 2*) and it is designed for remote control.

The generator therefore contains interfaces for GPIB (IEC 625/IEEE 488) and for Gigabit Ethernet. The latter is also ideal for handling the rapid measurement cycles common in production during remote control operation. The vector signal generator can be operated via a monitor and keyboard. The rear panel offers a VGA connection as well as USB interfaces for a mouse, keyboard or memory sticks, and remote operation via Remote Desktop is also possible. The trigger interfaces, which are combined on two standard SCSI connectors, also contribute to easy installation.

FUTURE-PROOFING

The R&S SMATE 200A's design and characteristics not only make it suitable for use in today's production lines, but also ready for tomorrow's requirements. While the internal baseband generator supports a bandwidth of 80 MHz, which is sufficient for all currently relevant standards, a modulation bandwidth of up to 200 MHz is available with externally supplied signals. Thus, the instrument is prepared to handle the next generation of broadband systems, too. Also, to ensure a long instrument lifespan when used in a rack, several fans cool the internal components and as a result, the vector signal generator's mean time between failures is high. Finally, another benefit is the instrument's three-year calibration cycle, which contributes to its low cost of ownership.

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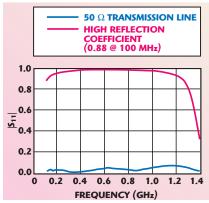


A HIGH POWER, HIGH SPEED 100 MHZ PROGRAMMABLE TUNER

In 2003 Focus Microwaves introduced its iTuner computer-controlled electro-mechanical microwave tuner product line. At the time it featured a frequency range of 0.2 to 18 GHz, and was completely self-contained and fully calibrated as a result of the powerful internally housed micro-controller. This innovative new device revolutionized production testing of microwave devices that traditionally had been tested under matched conditions

Fig. 1 The 100 MHz tuner's typical performance vs. frequency at minimum (50 Ω) within relatively narrow VSWR ranges using and maximum reflection.

| Fig. 1 The 100 MHz tuner's had been tested under matched conditions to embed the systems.



isolators to embed the systems. These mechanical tuners were able to maintain constant VSWR settings over a wide frequency range without operator intervention and are automatically calibrated in order to deembed the test results to the device reference plane.

A new iTuner mechanical tuner has now been introduced that is capable of handling power levels up to 300 W and covering the frequency range from 100 MHz to 1 GHz. This new mechanical tuner is comprised of a 64" long high power, low loss slab line with a 0.235" wide by 0.800" high stripline center conductor that has been machined with less than a 1 mil overall tolerance. The slab line is machined from a solid 3" \times 3" piece of 7075–T6 aluminum with a 0.9" wide and 2.5" deep slot. The tuning carriage travels on an ultra-high precision rail guide and is driven by a high speed micro-stepping motor, thus allowing a full 360° phase sweep at 100 MHz in less than 15 seconds. **Figure 1** shows the new tuner's typical return loss vs. frequency at minimum (50 Ω) and maximum reflection.

Other features of the new 100 MHz tuner include an internal microprocessor with 512K random access memory (RAM) and 512K Flash memory with a TCP/IP and RS232 interface. Its firmware is field upgradeable via its serial port and it has a 64M Flash card to store calibration data. The unit contains an electronically eraseable programmable read-

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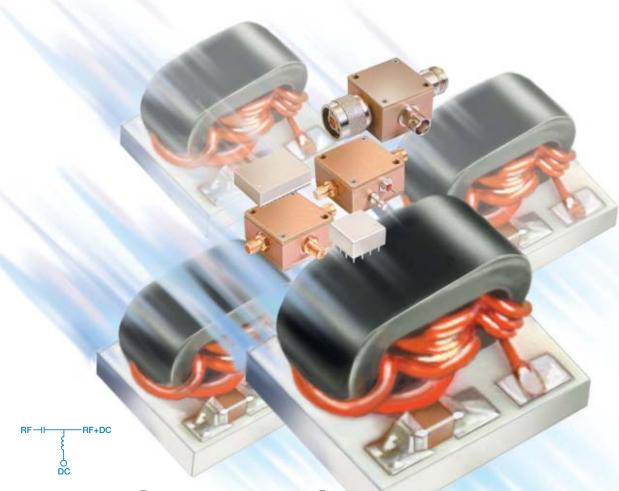
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TCBT-2R5G TCBT-6G NEW	20-2500 50-6000	0.35 0.7	44 28	1.1	8.95 * 11.95	
TCB Patent Pending	T Actual Size	.15"×.15" <i>LTC</i>	CC			
					Qty.1-9	
JEBT-4R2G JEBT-4R2GW	10-4200 0.1-4200	0.6 0.6	40 40	1.1 1.1	39.95 59.95	
PBTC-1G PBTC-3G PBTC-1GW PBTC-3GW	10-1000 10-3000 0.1-1000 0.1-3000	0.3 0.3 0.3 0.3	33 30 33 30	1.10 1.13 1.10 1.13	25.95 35.95 35.95 46.95	
FBT-4R2G FBT-6G FBT-4R2GW FBT-6GW	10-4200 10-6000 0.1-4200 0.1-6000	0.6 0.6 0.6 0.6	40 40 40 40	1.13 1.13 1.13 1.13	59.95 79.95 79.95 89.95	
FBT-4R2G-FT FBT-6G-FT FBT-4R2GW-FT FBT-6GW-FT	10-4200 10-6000 0.1-4200 0.1-6000	0.6 0.6 0.6 0.6	N/A N/A N/A N/A	1.13 1.13 1.13 1.13	59.95 79.95 79.95 89.95	
ZNBT-60-1W	2.5-6000	0.6	45	1.10	82.95	

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Product Feature

only memory (EEPROM) to store tuner configuration and operation parameters such as speed, acceleration/deceleration profile and motor current. There is an ASIC chip for the stepper motor control with a programmable acceleration/deceleration profile. Its microstepper control is capable of high phase resolution (0.1° at 100 MHz) and the tuner carriage is belt driven for fast tuning (15 seconds for 360° at 100 MHz).

OPERATION

The new high power, high speed 100 MHz tuner operates no different than its higher frequency counterparts. It is a self-contained unit requiring only a computer interface and appropriate test measurement equipment. When the tuner is initialized it has very low loss and behaves like an ordinary transmission line, thus only the phase of the test signal going to the test equipment is modified. The additional loss, caused by the tuner, is taken into account when performing the system calibration. Mechanical slide-screw tuners, such as this one, are low pass and very wideband, and do not interfere abnormally with out-of-band signals, such as intermodulation products and spurious oscillations that may have to be detected and measured.

The iTuner is controlled via a TCP/IP connection to the host computer. The TCP/IP interface is compatible with almost any operating system (Windows, Unix, Linux, MAC) and programming language (MS C++, Borland Builder, Delphi, Lab-View, Agilent VEE). No additional hardware beyond a network card in the controlling computer and a RJ-45 network cable is required to operate the tuner. Each tuner has its own user-settable IP address, thus multiple tunes can be controlled simulta-

are generally defined in the device under test (DUT) input or output reference plane, and the test setup is calibrated to allow correction of the raw test results measured with standard microwave test instruments, such as a power meter.

Although the iTuner is fully calibrated with respect to its input and output port, the VSWR reference plane for testing is located at the output of the DUT. The iTuner firmware has been extended to allow such reference plane shifting. Further, a nonperfect load impedance is also taken into account when adjusting the VSWR value in the DUT reference

neously by using an Ethernet hub. Specifications and test conditions

plane.

CONCLUSION

This new high power, high speed 100 MHz tuner brings the same testing capability that the previous iTuner instruments offer at the higher microwave frequencies to a lower frequency range and the higher power capability makes testing high power transmitting devices possible below 1 GHz. Additional information and availability may be obtained from the company's Web site.

Focus Microwaves, Dollard-des-Ormeaux, Quebec, Canada (514) 684-4554, www.focus-microwaves.com.

Circle No. 302

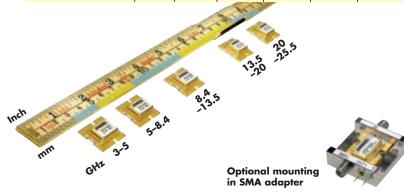
MICROWAVE JOURNAL ■ MARCH 2005

SIVERS

VCO 3-25.5 GHz

Ultra wide band oscillators

Tuning range	GHz	3 -5	5 - 8.4	8.4 - 13.5	13.5 - 20	20 - 25.5
Tuning sensitivity	MHz/V	50 - 300	100 - 600	100 - 600	100 - 600	100 - 600
Freq. vs temp.	MHz/°C	3.0	3.0	3.0	3.0	3.0
FM noise@100kHz, max	dBc/Hz	- 90	- 85	- 65	- 65	- 65
FM noise@1MHz, max	dBc/Hz	- 110	- 105	- 95	- 95	- 95
Bias current@ 15V, max						
14 dBm Pout version	mA	200	200	250	200	200
21 dBm Pout version	mA	300	300	300	300	300



The oscillators cover the range 3-25.5 GHz with a guaranteed frequency overlap. They are all fundamental frequency versions and have built-in regulators, buffer amplifiers and output filters.

Sivers IMA also offer a variety of oscillator based products such as, Low Phase Noise VCO, YIG-Oscillators and FMCW Micro Wave Modules. Our products are available in both off the shelf and customized versions.

Sivers IMA AB Box 1274 Torshamnsgatan 9 SE-164 29 Kista/Stockholm

Phone: +46 (0)8 703 68 04

Sivers IMA AB U.S. Office 164 Old Country Rd New Ipswich, NH 03071 USA

Phone: +1 603 878 4566

info@siversima.com www.siversima.com •

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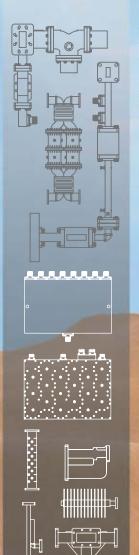
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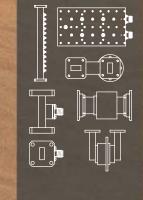
116 West 23rd Street, Suite 500 New York, NY 10011 Fred Gonzales

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Korea: Hun-JOONG PARK, 82-31-201-7512
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● Microwave & RF Components and Subsystems

This Web site features the Weinschel division's components and subsystems. It is updated often and offers a complete library of downloaded data sheets for a wide variety of RF and microwave components and subsystems. New items include on-line quote forms, keyword search, expanded information on subsystem capabilities and easy to use drop-down menus allowing the location of the desired products.

Aeroflex/Weinschel Inc., 5305 Spectrum Drive, Frederick, MD 21703-7362

> www.aeroflexweinschel.com



Ceramic Materials and Packages for RF and Microwave

AdTech Ceramics is a domestic supplier of multiplayer co-fired electronic packages, including AlN and HTCC applications. The Web site contains a company profile, including design and engineering capabilities, materials expertise, available products, and area rep and contact information. A detailed, downloadable design guide is also available.

Advanced Technical Ceramics Inc., 511 Manufacturers Road, Chattanooga, TN 37405

www. adtechceramics.com



MMIC Products

This Web site features an expanded product line, increased access to company information and includes a search engine and dropdown menus for simplified navigation. It contains the company's gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) products and includes the full line of standard product data sheets in .pdf format, application notes, white papers and reference designs. Users can request product samples and purchase information.

MIMIX Broadband Inc., 10795 Rockley Rd., Houston, TX 77099

www. mimixbroadband.com



RF, Microwave and Optical Components

This Web site describes the many types of products and services for RF, microwave and optical frequencies available. The products are geared to optical and microwave communications applications. Standard products include oscillators (VCOs and DROs), phase shifters, frequency doublers, bias tees, filters and receivers (optical). Data sheets can be downloaded for the standard items while design services are available for custom requirements.

Milli Optics Inc., 3391 Route 27, Franklin Park, NJ 08823

www.millioptics.com



MMIC and MIC Amplifiers

This Web site lists many standard amplifiers in the following families: narrow band (low noise), octave band (low noise), broadband (low noise), ultra-broadband, special function, high power (≥ 0.5 W), narrow band (medium power), octave band (medium power), broadband (medium power), variable gain and integrated hybrid. Custom design and research and development projects are also undertaken.

Planar Electronics Technology Inc., 5715 Industry Lane, Frederick, MD 21704

www.planarelectronics technology.com



Modular Digitally Tuned RF Filters and Preselectors

This Web site contains an extensive library of tunable filter subsystems as well as data on a DRTM controller and limiter/LNA. The families of filters are the Micro-Pole $^{\text{TM}}$ series, the Mini-Pole® series, the Maxi-Pole® series, the Power-Pole® series, the Track-PoleTM series and the MAXI/4RTM series. The types of filters and their applications are included.

Pole/Zero Corp., 5530 Union Center Drive, West Chester, OH 45069

www.polezero.com

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WEB UPDATE



DC to 40 GHz Solid State Control Components

This Web site describes the company's offerings in the standard product line as well as its history and future goals. The products include microwave solid-state switches, electronically variable attenuators (AGH and AGT technologies), detector log video amplifiers, bias tees and integrated assemblies.

American Microwave Corp., 7311–G Grove Road, Frederick, MD 21704

www.american microwavecorp.com



Microwave Components and Subsystems

The general Web site describes the company as a whole and allows detailed browsing through its various divisions worldwide. The products covered are microwave components including attenuators, modulators, oscillators, synthesizers, phase shifters, power amplifiers, switches and subsystems from RF to millimeter-wave frequency ranges.

Herley Industries 101 North Pointe Blvd., Lancaster, PA 17601

www.herley.com



RF Product Search

The company's comprehensive portfolio of RF products, including cables, connectors, adaptors, lightning protectors and resistive components can now be easily accessed via a new on-line product search engine. By using product attributes as search criteria it scans the database in seconds and automatically provides matches based on user selections. Instant access is available as no registration is required.

Huber+Suhner AG, CH-9100, Herisau, Switzerland

www.hubersuhner.com



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RF and Microwave Connectors

This newly re-designed Web site has enhanced capabilities. This allows the user to search an extensive library of connectors by part number or connector type. Specifications, photos, pricing and stock levels are available. The types include BNC, C, HN, LC, MHV, N, SC, SHV, SMA, TNC, UHF, 7/16 and adapters for between series.

San-Tron Inc., 4 Newburyport Turnpike, Ipswich, MA 01938

www.san-tron.com



RF & Microwave Components and Systems

This Web site highlights the products and services available from the new Spectrum Microwave. Complete details, specs and datasheets are on the site for the company's three groups – integrated microwave systems, filter and antenna products, and amplifier, mixer and oscillator products. These are proven designs for low cost commercial applications as well as high performance military requirements.

Spectrum Microwave Inc., 6798 Oak Hall Lane, Columbia, MD 21045

www.specwave.com



Solid-state Power Amplifiers

This Web site highlights the next generation solid-state power amplifier (SSPA) technology that enables emerging SATCOM mobility markets. This SSPA product line utilizes innovative miniaturization techniques to produce the highest output power in small, lightweight configurations. New product development to be released next year includes transceivers covering the Q-band to E-band, each designed to offer an enabling solution to the RF system integrator.

Sophia Wireless Inc., 14225-C Sullyfield Circle, Chantilly, VA 20151

www.
sophiawireless.com



Microwave and Millimeterwave Packages

This redesigned Web site features complete product information of microwave and millimeter-wave packages that operate from DC to 50+ GHz, stripline filters and assembly and test services. The new site is a powerful tool for researching, locating and specifying products. Datasheets, design guides, application notes and photos are available for all package accessories, including lids and test fixtures.

StratEdge Inc., 4393 Viewridge Avenue, San Diego, CA 92123

www.stratedge.com



MIC/MMIC-based Microwave Components and Subsystems

This Web site contains an extensive array of hybrid microwave monolithic circuit (HMMIC)-based components and subsystems. Amplifiers (low noise, power, log. buffer), detectors, attenuators, frequency and polar discriminators, frequency synthesizers, receiver front ends, ECL/ITL and TTL/ECL converters, mixers (image reject and balanced), I/Q vector modulators, limiters, monopulse comparators, phase shifters, power dividers as well as other standard and specialty subsystems are featured.

Planar Monolithics Industries Inc., 7311-G Grove Rd., Frederick, MD 21704

www.
planarmonolithics.com



Components and Subsystems

This redesigned and updated Web site provides comprehensive information on the company's latest initiatives for the electronics and communications market. Solutions in the SATCOM field, particularly converters and other subsystems are highlighted. Standard and state-of-the-art MMIC VCOs are featured, together with information on the company's offering of customized VCOs to meet specific customer needs.

WORK Microwave GmbH, Raiffeisenstrasse 12, D-83607 Holzkirchen, Germany

www.work-gmbh.de

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WEB UPDATE



Specialty Filters and Switch **Filter Banks**

This site contains details of many types of filters from DC to 40 GHz. Design types are cavity, combline and interdigital. Items found on the site are quick turn filters (30-60 day deliveries), standard filter housing drawings, switch filter bank data sheets and test reports, as well as filter data sheets and test reports.

Planar Filter Co., 5715 Industry Lane, Frederick, MD 21704

www.planarfilter.com



Cable Installation Videos

On-line instructional videos are available at this Web site covering LMR® EZ connectors and LMR® accessories, including ground kits, weatherproofing kits, hangers and supports for the LMR® wireless products line. The videos, which provide a foolproof way to install the LMR® connectors and accessories, can be viewed either directly online or downloaded for viewing at a later time.

Times Microwave Systems, 358 Hall Ave., Wallingford, CT 06492

www. timesmicrowave.com



Test Probe Quotes

This Web site has been updated to include a facility for requesting quotes for the company's Z probes on-line. The order form can be found under www.suss.com/hfprobing. This page provides information about the range of SUSS test equipment for high frequency applications and offers the possibility to download brochures as well as jump to other areas of interest such as a page dedicated to SussCal calibration software.

SUSS MicroTec Test Systems GmbH, Suss Strasse 1, 01561 Sacka, Germany

www.suss.com

www.pulsarmicrowave.com

PULSAR

SW5RD-3

MICROWAVE CORPORATION

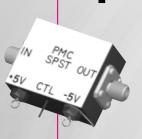
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broadband

pin diode switches



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New Waves: Test, Measurement & CAD MMM/////

High Frequency Circuit Simulator

NexximTM is a circuit simulation tool that combined with Ansoft DesignerTM targets the next generation of analog/mixed signal applications, including high performance RFCMOS, GaAs/SiGe RF ICs and gigabit computer and communication backplanes. With a multitude of algorithmic innovations in transient and harmonic-balance analyses, Nexxim achieves robust convergence and simulation speeds while improving accuracy and dynamic range. Nexxim addresses a major industry concern by running frequency and time-domain analyses using the same circuit netlist and the same library models, thus guaranteeing consistent results from two different domains.

Ansoft Corp., Pittsburgh, PA (412) 261-3200, urur.ansoft.com.

Circle No. 215

13 GHz Oscilloscope

The Infiniium DS081304A oscilloscope provides 13 GHz, real-time bandwidth, which translates into higher signal fidelity, more accurate and repeatable measurements, and improved test margins. This instrument also allows previously hidden high speed signal components to be seen. The DS080000 series instruments have included the Infinimax II series probing system that is based on the InfiniiMax probing architecture. This makes it possible to measure 13 GHz signals from the high impedance probe tip to the highly responsive oscilloscope display. Price of this model is \$122,500; 1169A 12/13 GHz Infiniimax II probe amplifier is \$9000.

Agilent Technologies Inc., Santa Clara, CA (800) 829-4444, <u>ımmr.agilent.com</u>.

Circle No. 216

LTCC Simulation and Optimization Tool

The LINMIC design suite linear is the new entry level to the LINMIC design suite. It offers integrated tools for efficient EM-based simulation, design optimization and layout of linear distributed RF and microwave circuits such as couplers, filters and matching networks. Optional extensions include nonlinear and multilayer circuit simulation/optimization and active device modeling. LINMIC LTCC is a new compact simulation and optimization tool for the design of multiplayer components like LTCC inductors, baluns or multilayer laminate components. It is based on a partial element equivalent circuit (PEEC) approach and therefore offers high computation speed compared to 3D planar or even full 3D simulators. Results are n-port S-parameters and a SPICE netlist, both for export to circuit simulators. Both tools are available as demo versions for download at www linmic com.

AC Microwave GmbH, Aachen, Germany +49 241 879 3022, www.linmic.com

Circle No. 217

Analog and RFIC Design System

Analog Office™ 2004 is a software tool for analog and radio-frequency integrated circuit (RFIC) designs. This version is an IC design system that is specifically architected and optimized for designers of analog and RFICs. It has been enhanced to provide an open, unified design environment, offering full interaction with a comprehensive and powerful set of integrated tools. The Analog Office 2004 toolset spans the entire IC design flow, from systemlevel to circuit-level design and verification, for complete top-to-bottom and front-to-back high frequency design. It supports the Linux platform, a significant extension of the AWR intelligent NetTM (iNet) technology to handle arbitrary layout geometries; automatic and "on the fly" connectivity extraction in layout; support for Verilog-A analog behavioral language; integration of an additional SPICE circuit simulator and electromagnetic (EM) simulators; and support for industry standard physical verification flow for final chip tape-outs.

Applied Wave Research Inc., El Segundo, CA (310) 726-3000, www.mwoffice.com.

Circle No. 218

Self-contained Simulator for RF **Conducted Immunity Testing**

The CWS500D compact simulator is suited for ISO 11452-4, SAE J1113-4 and GMW3097



BCI testing. It is also used for testing to the avionics specification DO-160 conducted susceptibility test. It is capable of

testing to the highest levels of the DO-160 spec. that are categories R, S, T, W and Y. The simulator includes the signal generator, bi-directional coupler, power amplifier, 3-channel power meter, controller and Windows-based operating software. Selecting the standard to be tested is sufficient to perform both calibration and testing. A complete test report is available, which can be exported to an RTF file or Excel for editing.

AR Worldwide, Souderton, PA (215) 723-8181, provinario rldivide.com.

Circle No. 219

Wafer Probe Stations

The S300 wafer probe stations for 300 mm wafer probing and summit 1200 series probe



stations integrate with the Agilent 4100 series, or integrated parametric analysis and characterization environment (iPACE). 4100 series uses

advanced switching matrix technology and supports a new atto sense and switch unit (ASU) that enables automation of parametric instruments without compromising measurement performance. The integration of these capabilities into one product allows the semiconductor industry to speed wafer characterization and lower the cost of testing, while enhancing test flexibility and performance. The atto sense mount allows easy integration with the new parametric analyzer. The S300 and summit series probe stations provide a complete measurement environment for on-wafer parametric tests.

Cascade Microtech Inc., Beaverton, OR (503) 550-3279, www.cascademicrotech.com.

Circle No. 220

EM Field Solver

An electromagnetic field solver FEKO for the Intel® extended memory 64 technology (EM64T) is available. EM64T is an enhancement to Intel's IA-32 architecture allowing the processor to run 64-bit code and access larger amounts of memory. The main advantage being that it supports both 32- and 64-bit applications, with the result that all the components of FEKO can run on the same system, with the kernel accessing more than 2 Gbytes of memory, thereby increasing the number of unknowns that can be solved for Incore. Also, native 64bit versions of the kernel for EM64T are available for both Linux and Microsoft Windows 64-bit edition (Windows XP or Server 2003).

EM Software & Systems-SA (Pty) Ltd., Stellenbosch, South Africa +27 (21) 880 1880, www.emss.co.za.

Circle No. 221

Process Design Kit

A new process design kit (PDK) supports Agilent's RF design environment (RFDE) electronic design automation (EDA) software. It contains the full frequency range for its 0.18-micron mixed-signal/RF CMOS processes, from DC through baseband and into the RF range. This broad frequency range allows designers to simulate the entire system-on-chip design, ensuring correct operation at all frequencies. At the 0.18micron node, these frequencies typically range from the audio and video frequencies in the baseband to 5 GHz in the RF band.

Magnachip Semiconductor, Korea 82-43-270-2102, www.magnachip.com.

Circle No. 222

MATLAB Programmer **Productivity Tools**

MATLAB® 7 is a new release that enhances programmer productivity with new tools that enable rapid, iterative program creation. In addition, MATLAB 7 offers built-in support for integer and single-precision floating-point math, as well as language features for managing and analyzing larger data sets. A large number of optimizations across data types, operations, functions and hardware result in improved computational performance of end user applications. Also new in the MATLAB family of products is an enhanced MATLAB compiler that now supports the full MATLAB language, enabling developers to deploy many more MATLAB applications for use outside of MATLAB.

The MathWorks Inc., Natick, MA (508) 647-7427, www.mathworks.com

Circle No. 223



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Radar/Microwave Monitoring Receiver



The RMR-818-77-NRL is an 8.0 to 18.0 GHz radar/microwave monitoring receiver for labo-ratory applications. The receiver uses an extended range detector log video amplifier (DLVA), a preamplifier and RF bandpass filtering. It also has a dynamic range of 75 dB with a typical TSS of -80 dBm. It can be supplied with either individually removable bandpass filters or various witched filter bank options. The basic model offers a log video output for analysis through external equipment. These microwave monitoring receivers are available in frequency ranges from 0.5 to 20.0 GHz.

Planar Monolithics Industries Inc., Frederick, MD (301) 631-1579, www.planarmonolithics.com.

Circle No. 224

Dual-band Signal Strength Measurement System



This system is available in either AMP/PCS (310-010062-001) or GSM/DCS (310-010062-001) configuration. This easy to use system is ideal for making path loss measurements. The dual-band test set includes the receiver with portable antenna, transmitter, cable and adapters, as well as an inline attenuator for setting the transmitter output power using the receiver. The transmitter and receiver are also available separately. The receiver can be connected to a PC to log signal level data. The receiver is also compatible with Wireless Valley's Infielder® software. The system is packaged in a foam-lined case suitable for use as a shipping container.

Praxsym Inc., Fisher, IL (217) 897-1744, www.praxsym.com.

microwave

Circle No. 225

Hand-held 5 MHz DSO/DMM

Model S2405 is a battery operated, lightweight, dual channel multifunction DSO/DMM. It has



a 5 MHz bandwidth, 50 MS/s sampling rate (single) and 50 mV sensitivity. This portable scope/meter has a DSO section that features an 8-bit resolution with a record length of 512 bytes for single

shot/glitch capture along with 256 bytes for other modes. It is capable of saving up to 16 waveforms and setups in memory, and its vertical sensitivity ranges from 50 mV in 1-2-5 order with 600 VDC or AC RMS maximum input voltage. Standard equipment includes an RS232 port with software. Selling price for the S2405 is \$399 (US) list. It is complete with a 4.8 V NiMh battery pack with a 120 V to 9 V at 1 Amp DC battery, both standard, RS 232 cable, software, test leads, holster, AC/DC charger and carrying case. Weight is 1.5 lbs and size is 3.5 \times 7.5 \times 1.57".

Protek, Allendale, NJ (201) 760-9898, www.protektest.com.

Circle No. 226

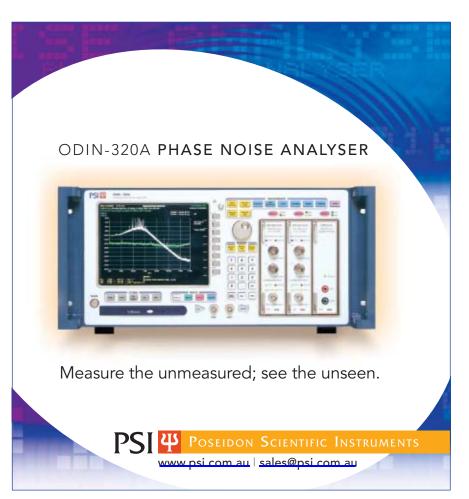
WCDMA Base Station Tester



The FSMU-W combines the vector signal generator SMU200A with the vector signal analyzer FSQ. Preconfigured for WCDMA, with one RF path and an analyzer frequency range up to 26 GHz, both instruments together test WCD-MA base stations in line with the 3GPP standard. The FSMU-W can be upgraded at any time with a second RF path, a fading simulator and options for other 2G or 3G standards.

Rohde & Schwarz, Munich, Germany +49 89 4129-13779, www.zvb.rohdeschwarz.com.

Circle No. 227



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New Products

COMPONENTS

100 kHz to 40 GHz Solid State Switch

This single-pole single-throw solid-state switch features high speed, high isolation and very broad band. The frequency range is $100~\rm kHz$ to $40~\rm kHz$



GHz and useful operation can be obtained to 50 GHz. Over this bandwidth the isolation is greater than 60 dB, while switching speed delay is less than 7 ns and the rise and fall times are less than 5 ns.

American Microwave Corp., Frederick, MD (301) 662-4700, www.americanmicrowavecorp.com.

Circle No. 228

DC to 2.5 GHz 2 W SMA Attenuators

The 660 series SMA coaxial attenuators cover all commercial wireless bands from DC to $2.5~\mathrm{GHz}$ and are available in attenuation values from



0 to 40 dB in 1 dB increments. Standard attenuation values of 3, 6, 10 and 20 dB are in stock. These attenuators dissipate 2 W max. average RF/microwave power (500 W peak), and feature gold-plated brass connectors and contact pins and virgin electrical grade PTFE insulation within the connectors.

MECA Electronics, Denville, NJ

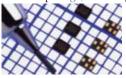
(973) 625-0661, <u>www.e-meca.com</u>.

Circle No. 235

Model 3100 Modular HF Receiver Sets new performance standards with: Phase Coherence No Local Oscillators 10 kHz to 30 MHz coverage -130 dBm to +10 dBm input level 400 Mbps Firewire Output Connection For more information on Interad surveillance, intercept, aviation, communications, and cellular products go to www.interadlimited.com call us at 757-787-7610, or Fax 757-787-7740 Insertal Ltd. Accomack Airport Industrial Park Melfa, VA 23410 Email: sales@interadlimited.com

Miniaturized SAW Filters

Two new product families are available in CSSP3 (third-generation chipsize SAW package) technology. Product family 1411 has a footprint of 1.4



 \times 1.1 mm and an insertion height of 0.4 mm. It supersedes current standard 2014. The second product family, 1513, has a footprint of 1.5 \times 1.3 mm and an insertion height of less than 0.6 mm. It supersedes the current standard 2016.

EPCOS UK Ltd.,

Berkshire, England +44(0) 1344 396689, www.encos.com.

Circle No. 230

DC to 6 GHz Fixed Attenuator

This miniature low cost fixed attenuator operates from $\,$ DC to 6 GHz. It has a HEX body and offers excellent VSWR, good attenuation accuracy



and a wide operating temperature range of -65° to $+125^{\circ}$ C. It is capable of handling 2 W average power.

JFW Industries Inc., Indianapolis, IN (317) 887-1340, www.jfwindustries.com.

Circle No. 231

■ 1 GHz to 10 GHz High Pass Filter

Utilizing suspended substrate technology, this filter's (p/n 9SH10-1000/T10000-0/0) passband performance holds out to 10X the cut-off



frequency. Other specifications include 3.0 dB cut-off at 1.0 GHz, insertion loss: <1.0 dB at 1.1 GHz to 10 GHz, stopband: >50 dB at DC to 0.5 GHz and VSWR: 2.0 at 1.1 GHz to 10 GHz. The package size is $1.3 \times 1.0 \times 0.5$ ".

K&L Microwave Inc., Salisbury, MD (410) 749-2424, www.klmicrowave.com

Circle No. 232

■ Dual-band Surface-mount Diplexer

The model 3DP9-1227/1575-M is a GPS dual-band diplexer. The filter provides a $0.5~\mathrm{dB}$ relative bandwidth over the center 30 MHz, with $1.5~\mathrm{dB}$



VSWR over the pass band. The 3 dB bandwidths are 100 MHz typical. The insertion loss at center frequency is 1.2 dB (low band) and 1.65 dB (high band) max. The physical size is $1.25 \times 0.5 \times 0.38$ ".

Lorch Microwave, Salisbury, MD (410) 860-5100, www.lorch.com.

Circle No. 233

■ High Precision RF and Microwave Connectors

These high precision 7/16 RF and microwave connectors feature super low passive intermodulation (PIM). Configurations include type NF and SMA connectors, which are in stock and available for quick delivery.

Microwave Communications Laboratories Inc., Saint Petersburg, FL (727) 344-6254, www.mcli.com.

Circle No. 234

■ Reciprocal X-band Ferrite Switch

The Tandem-rotator Reciprocal ferrite switch uses 0° and 90° total Faraday rotation states to achieve reciprocal connections to the desired ports.



This structure operates at moderate isolation and power levels (peak and average) compared to bridge-switches, but is smaller and less expensive. It operates from 8.5 to 9.5 GHz, peak power is 50 kW, average power is 100 W, isolation is 25 dB, insertion loss is 0.5 dB, return loss is 17.7 dB, switching speed is $< 25 \,\mu s$, operating temperature

is -30° to +60°C and weight is I.6 lbs. Microwave Applications Group, Santa Maria, CA (805) 928-5711, www.magsmx.com.

Circle No. 236

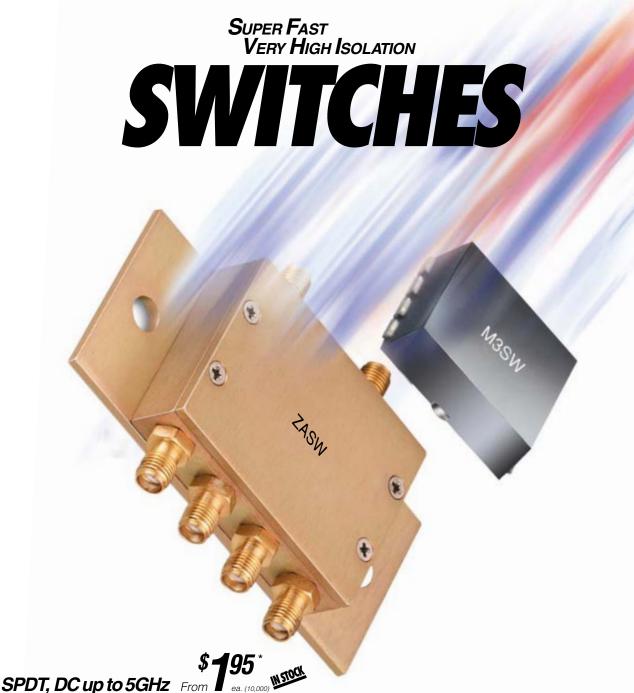
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Mini-Circuits wideband SPDT switches offer very high isolation up to 90dB at 1GHz, built-in TTL driver with blazing fast 10nsec switching speed, and the ability to withstand severe operating temperatures. But that's not all! Reflective and absorptive models are available to suit your design requirements; M3SW's 3x3mm MCLP™ surface mount package with exposed metal bottom for excellent grounding and heat dissipation and ZASW's tough built coaxial design with SMA-F connectors. No matter which model you choose, you'll get strong performance and rugged reliability at a price that crushes the competition. So look no further. You'll find just the right switch for your commercial, industrial, or military application right here at Mini-Circuits!

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SPECIFICATIONS (@ 1GHz)

	Model	Freq. (GHz)	In-Out Isol. dB(typ)	Ins. Loss dB(typ)	1dB Comp. dBm(typ)	Price \$ea (Qty. 10)
	M3SW-2-50DR M3SWA-2-50DR	DC-4.5 DC-4.5	60 65	0.7 <i>0.7</i>	25 25	4.95 *
	ZASW-2-50DR ZASWA-2-50DR	DC-5 DC-5	90 90	1.7 1.7	20 20	(Qty.1-9) 89.95 89.95
•	Supply voltage +5V, Switching time 10ns Reflective Absor	sec (typ).	control.		3x3mm Mini-Circuits Low Profile (MCLF	отм)

Detailed Performance Data & Specs Online at: www.minicircuits.com/model



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379 Rev H



See our 244 page RF/IF Designer's Guide in EEM (Electronic Engineers Master)



New Products

■ Surface-mount Relay



The GRF172 Centigrid® surface-mount relay is an ultraminiature hermetically sealed armature relay for 2.5 GHz applications. Its low profile height (0.330") and 0.100" grid-spaced terminals make it suitable for extreme packaging density and close PC board spacing. The ground shield feature isolates and shields each lead providing an insertion loss of < 0.3 dB, a VSWR of 1.10 and a pole-to-pole isolation of 45 dB. It is available with a choice of DC coils, DPDT contacts and an optional coil transient suppression diode.

Teledyne Electronics and Communications, Quickborn, Germany +49 (0) 4106 7684-0, www.teledyne-europe.com.

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DC Block to 18 GHz

These coaxial BLK-18 DC blocks operate from 10 MHz to 18 GHz and provide very low inser-



tion loss (less than 1.0 dB up to 18 GHz) and a return loss of 24 dB typical. The units have SMA (F) to SMA (M) connectors and are 1.18" long.

They operate from -55° to 100°C. Pricing is \$21.95 ea. in 1 to 9 piece quantity.

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.

Circle No. 237

Detector/Coupler/Switch

The model TDCS-4T-10F-HP is an integrated threshold detector, $17~\mathrm{dB}$ coupler and a SPDT



PIN diode switch. The device operates from 9 to 10.5 GHz (other frequency ranges are available), with an insertion loss of 2 dB maximum, VSWR of 1.5 maximum, 2 W average RF input pow-

er handling capability and TTL threshold output. The TDCS-4T-10F-HP is designed to operate in harsh environments with stability over temperature and frequency. Size: $1.5 \times 1.2 \times 0.40$!

Planar Monolithics Industries, Frederick, MD (301) 662-4700, www.planarmonolithics.com.

Circle No. 238

■ New BNC Connector Material

A right angle circuit board BNC jack connector manufactured using a metal molded technolo-



gy – Zamak – has been introduced. Available with an impedance of $50 \, \Omega$, the Zamak BNC connector features a very low return loss of 28 db at up to 1.5 GHz. These con-

nectors are also highly solderable through selective tin plating on the legs and the center contact. Exhibiting the same electrical and mechanical performance as the standard material units, they are less expensive.

Radiall,

Rosny Sous Bois, France 33 1 49 35 35 35, www.radiall.com.

Circle No. 239

WiFi Surface-mount Isolators/Circulators

Model 2W6NB is a surface-mount microstrip isolator designed for WiFi IEEE 802.11a wire-



less-local-areanetwork (WLAN) applications operating from 5.15 to 5.35 GHz. It occupies a footprint of 12 × 12 mm and is for use in

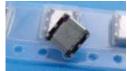
PCMCIA cards. The isolator has port-to-port isolation of 17 dB with an insertion loss of 0.4 dB. It is designed to handle power levels to 1 W and exhibits a VSWR of 1.3. Circulator versions and frequencies of 2.4 GHz are also available. Price is less than \$5.00 in large production quantities.

Renaissance Electronics Corp., Harvard, MA (978) 772-7774, www.rec-usa.com.

Circle No. 241

Surface-mount Lumped Element Isolator

The RLEI series is a surface-mount lumped element isolator that covers 19 specific fre-



quencies ranging from 800 to 2500 MHz. This isolator is designed for tape and reel high speed applica-

tions for high volume projects. This low cost unit is 5 mm square and is supplied at 2000 pieces per reel.

Raditek,

San Jose, CA (408) 266-7404, www.raditek.com.

Circle No. 240

■ 200 to 2000 MHz Bi-directional Coupler

The model C6600 is a low loss, bi-directional 20 dB coupler that covers the entire 200 to



2000 MHz frequency band. It is rated at 200 W CW, with an insertion loss of 0.25 dB, VSWR of 1.2 and directivity of 20 dB. It

is suitable for both military and commercial applications.

Werlatone Inc., Brewster, NY (845) 279-6187, www.werlatone.com,

Circle No. 243

DC to 6 GHz SMA Attenuator

Model 2082-6346-XX is a fixed passivated stainless steel attenuator with gold plated



beryllium copper center conductor. It covers the frequency range of DC to 6 GHz with standard attenuation of 0 to 12, 15, 20 and 30

dB. VSWR is 1.15 up to 2.5 GHz and 1.35 at the high end. Power handling is 2 W average and 200 W peak. Operating temperature is -65° to +125°C. Length is 0.86" and weight is 0.21 oz. Price for 1 to 99 pieces is \$11.99 each. **XMA Corp.**,

Manchester, NH (603) 222-2256,

www.xmacorp.com.

Circle No. 244

AMPLIFIERS

■ Broadband RF Power Amplifier

Part number SSPA 0.4-2.2-10 is a high power broadband amplifier that operates from 0.4 to

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For additional information,

contact Synergy's sales and application team. 201 McLean Boulevard, Paterson, NJ 07504 Phone: (973) 881-8800 Fax: (973) 881-8361

E-mail: sales@synergymwave.com

World Wide Web: www.synergymwaye.com



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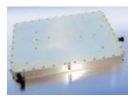


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New Products



2.2 GHz. It is packaged in a modular housing that is approximately 6.5 × 10.0 × 1.0. The minimum output power at P1dB is 10 W at

room temperature; saturated power is 20 W across the band; small signal gain is 45 dB typical; input VSWR is 2.0 typical and output VSWR is 3.0 worst case.

Aethercomm Inc., San Marcos, CA (760) 598-4340, www.gethercomm.com

Circle No. 245

■ Wideband Cascadable Gain Block Outputs +24 dBm

The high linearity HMC482ST89 SiGe HBT MMIC amplifier covers the frequency range of



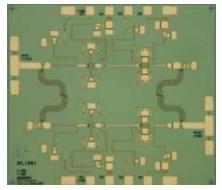
DC to 5 GHz. This gain block is fully matched to 50 Ω , provides 19 db of gain and can be used as a

cascadable gain stage in various RF and IF applications. With +22 dBm of output P1dB and +36 dBm of output IP3 at 1 GHz, this unit can be also used as an LO buffer amplifier or as a PA pre-driver. It consumes 110mA from a single positive supply of +6 V and requires no matching components. It is housed in an industry standard SOT89 surface-mount package.

Hittite Microwave Corp., Chelmsford, MA (978) 250-3343, www.hittite.com.

Circle No. 248

17 to 35 GHz MMIC Low Noise Amplifier



The XL1001 is a self-biased , MMIC two-stage low noise amplifier that covers 17 to 35 GHz. It has a small signal gain of 14 dB with a noise figure of 2.5 dB across the band. It includes simple, single supply bias with no need for negative voltages or active bias circuits. Due to its balanced design it has good input and output matches. It is suited for wireless communications such as millimeter-wave point-to-point radio, local multipoint distribution services (LMDS) and SATCOM.

Mimix Broadband Inc., Houston, TX (281) 988-4600, www.mimixbroadband.com.

Circle No. 249

Ultra Wideband Low Noise Amplifier

This LNA, part number AF00120243A, covers the entire frequency range of 0.1 to 20.0 GHz with a single unit; minimum gain is 24 dB, maximum noise figure is 3.0 and maximum gain flatness is ± 1.5 dB. Bias is $\pm 5~\mathrm{V}$ at 90mA. Both connectorized and drop-in versions are available.

Herotek Inc., San Jose, CA (408) 941-8399, www.herotek.com.

Circle No. 247

Ultra Low Noise Amplifier

Model PE2-30-610-1R2-15-SFF LNA operates from 6 to 10 GHz with a typical noise



figure of 0.8 dB, 1.2 dB maximum. The gain is 30 db, VSWR in/out is

1.75, power output at 1 dB compression point is 2 dBm and gain flatness is ±0.75 dB. Bias levels are 15 V at 45 mA.

Planar Electronics Technology, Frederick, MD (301) 662-5019, www.planarelectronicstechnology.com. Circle No. 250

Dual-band UMTS Power Amplifier Module

The TQM7M60001 is a dual-band UMTS power amplifier module in a small $4\times4\times1.1$ mm form factor. It is designed to support costeffective GSM, EDGE, UMTS and HSDPA (high speed download packet access) compressed mode phone architectures with only one antenna. Its biasing circuit is optimized for low idle current consumption (below 30 mA). The output power is 27.5 dBm with a linearity that provides a 7 dB margin for the UMTS ETSI requirement. This allows sufficient margin for applying additional transmit channels for large-scale data transmission rates, enabling next generation 3G phones for HSDPA.

TriQuint, Hillsboro, OR (503) 615-9000, www.triquint.com.

Circle No. 251

Power Amplifier Module

The ECM168 is a 1.9 GHz high efficiency power amplifier module utilizing InGaP HBT technology. It has 33.5 dBm output power, a single 10 to 12 V supply, 33 dB typical gain and a good ACPR2 at 600 kHz offset. The device operates over a frequency range of 1800 to 1920 MHz. No negative voltage is required and the efficiency is 20%. It is housed in a flange mount package measuring $29\times13\times4$ mm.

WJ Communications Inc., San Jose, CA (408) 577-6200, www.wj.com.

Circle No. 252

DEVICES

High Q, Low Cap Ceramic Trimmer Capacitor

The model 0538-099A0.8-20 is a ceramic trimmer capacitor that exhibits high Q and a capacitance as low as 0.8 pF. It is 0.375" in diameter and 0.275" high, operates effectively at -55° to +125°C with a torque resistance of 1.0 to 6.0 oz-ins. The silver electrodes are intimately bonded to the top surfaces of the base rotor.

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The terminals and other metal parts are nonferrous and silver-plated to provide excellent conductivity and trouble free soldering.

Tusonix, Tucson, AZ (520) 744-0400,

www.tusonix.com.

Circle No. 257

Zero Bias SMT Schottky Diodes

The MA4E2200 zero bias surface-mount Schottky diode series is silicon medium barrier





manufactured using a planar-BCB foundry process and are offered in single, single tee, series tee reverse and unconnected pair configurations. They are suitable for circuits requiring lower tangential sensitivity (TSS) values as in RF envelope detection with temperature compensation, as well as in limiter circuits where lower flat leakage power is required (< +10 dBm). They can operate from DC to 4 GHz and up to a peak RF incident power of +20 dBm. Pricing is \$0.17 for the SOD-323, \$0.21 for the SOT-33 and \$0.23 for the SOT-143 packages.

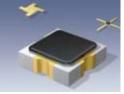
M/A-COM Inc.,

Lowell, MA (800) 366-2266,

www.macom.com/microwave_ic_products. Circle No. 253

Ring Quad Schottky Surfacemount Ceramic Package

These low, medium and high barrier Schottky ring quads are manufactured using an in-house



epitaxial process. The CS-17 are square ceramic surface-mount packages with an epoxy top. The dimensions are 0.06 \times 0.06 \times 0.025"

with four bonding pads on the bottom, making them suitable for high volume manufacturing. They are available in "sleeves" or tape and reel. The monolithic design makes them useful for double balanced mixers, modulators and doublers.

Micrometrics Inc., Londonderry, NH (603) 641-3800, unumicrometrics.com.

Circle No. 254

2.4 GHz Transceiver Chip

The nRF24Z1 is a single chip 2.4 GHz 4 Mbit/s solution for CD-quality wireless audio



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streaming with extremely low latency. It uses the company's latest 4 Mbit/s Mega-ZtreamTM platform embedding a state of the art quality of service subsystem with an

ultra low power robust 4 Mbit/s wireless 2.4 GHz transceiver and all appropriate digital audio interfaces to create a complete digital wireless streamer solution in a 6 × 6 mm package. This configuration ensures that there is bandwidth enough to stream and transmit 16-bit 48 Kspls/s CD quality audio without using compression. In addition to streaming audio the chip also boasts a digital control information channel for transfer of control

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information such as volume, balance, track and display information.

Nordic Semiconductor ASA, Oslo, Norway +47 22 51 10 50, www.nordicsemi.no.

Circle No. 255

SOURCES

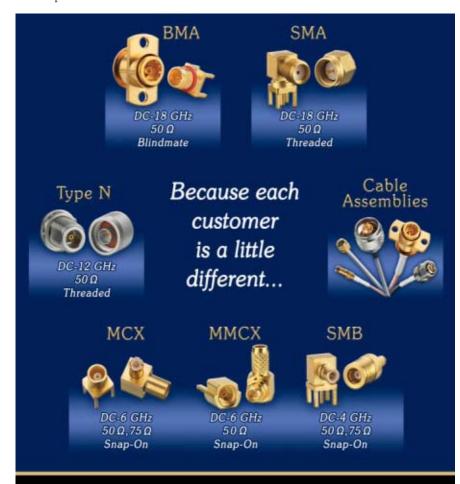
Low Noise PLOs

Operating at fixed frequencies in the 300 MHz to 22 GHz range, the APL-02 series of fundamental frequency phase-locked oscillators provides a low noise and stable local oscillator input for frequency converters for multiple uses. The compact oscillators are either coaxial res-

onator based for frequencies up to 3.0 GHz, using low noise silicon bipolar active devices or dielectric resonator based for frequencies above 3.0 GHz, using GaAs FETs or MMICs. The use of fundamental frequency architecture drives down phase noise and minimizes physical size. For example, a 4 GHz unit achieves considerably better than -110 dBc/Hz phase noise at 10 kHz offset from the carrier with a typical floor close to -140 dBc/Hz. Using an internal reference the "close in" phase noise is better that -64 dBc/Hz at 100 Hz offset and can be improved further by the use of an external ultra low phase noise OCXO reference.

Atlantic Microwave Ltd., Braintree Essex, UK +44 00 1376 550220, www.atlanticmicrowave.co.uk

Circle No. 258



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New Products

Low Power OCXO

Part 1412 is an AT cut crystal oscillator with a sine wave output. It requires 175 mW at a sup-



ply voltage of 5 V and at 0° to 50°C exhibits stabilities down to 15 ppb. Frequencies available are 10, 16, 19.44 and 20 MHz. Packaging is European standard and it mea-

sures 36.0×27.2×19.0 mm. Pricing is \$90.00 ea. in quantities of 100 pcs.

ILSI Âmerica, Reno, NV (775) 851-8880, proprilsiamerica.com.

Circle No. 259

■ PECL VCXOs to 300 MHz

PECL (positive emitter coupled logic) voltagecontrolled oscillators (VCXO) are available with frequency ranges up to 300 MHz. They utilize inverted mesa and AT strip crystals to achieve pull ranges of up to ±200 ppm at 300 MHz, operating in the fundamental mode, and provide a low jitter in the 2 to 5 nanosecond range. When ordered with an extended operating temperature range they can operate in temperatures of -55° to +125°C. Operating voltages are 5 V, 3.3 V or 3 V. Size is $5 \times 7 \times 1.5$ mm. Pricing is \$12.00 ea. in quantities of 1000 pcs.

MMD Components (Monitor & Quartztek), Rancho Santa Margarita, CA (949) 709-5075, www.mmdcom

Circle No. 260

Low Phase Noise MMIC VCOs

This new line of GaAs monolithic microwave integrated circuit VCOs with integrated buffers



covers the 4.8 to 12 GHz frequency range in several bands. It delivers more than 10 dBm of output

power and exhibits outstanding phase noise behavior. These HBT MMICs integrate an active device, resonator, varactor and buffer amplifier on a chip, thus no external elements are necessary. All VCOs are housed in a standard 4×4 mm QFN plastic package and provide identical footprint assignments.

Work Microwave GmbH, Holzkirchen, Germany +49 8024 64080, www.work-gmbh.de.

Circle No. 261

Low Cost Coaxial Resonator VCO

The coaxial resonator VCO, model CRO2985A, covers 2955 to 3014 MHz in 0.5 to 4.5 V of



tuning. It delivers a clean spectral signal of -82 and −Ĭ10 dBc/Hz at 1 and 10 kHz offsets, respectively, while covering the 59 MHz bandwidth with an average tuning sensitivity of 22 MHz/V. The CRO2985A is designed to operate off a 5 V supply while drawing 20 mA of current, and provides 6±3 dBm of output power into a 50 Ω load over the temperature range of -40° to +85°C. It suppresses the 2nd harmonic to better than -15 dBc and is further heightened by pushing less than 1 MHz within 5 percent of the nominal supply voltage and pulling less than 1 MHz with a 14 dB return loss, any phase. Size is $0.5 \times 0.5 \times 0.22$ ".

Z-Communications Inc., San Diego, CA (858) 621-2700, www.zcomm.com.

Circle No. 262

RF Transceiver

The MICRF505 transceiver operates from $850\ \mathrm{to}$ 950 MHz, and supports frequency-shift keyed (FSK) modulation at data rates up to 200 kbps. Many functions are user programmable, including the frequency synthesizer, making the MI-CRF505 ideal for frequency hopping applications. It is 5×5 mm and is designed to accommodate low cost, low accuracy crystals. To address this, a frequency error estimator has been added to determine frequency mismatch between communicating transceivers and an internal crystal tuning mechanism to enable automated crystal tuning on-the-fly. It also incorporates an internal clock recovery circuit to reduce the burden on its companion baseband device enabling the use of a lower cost microcontroller. Prices start at \$4.50.

Micrel Inc., San Jose, CA (408) 944-0800, www.micrel.com.

Circle No. 263

THALES



Thales MESL (www.thales-mesl.com) is the re-branded name for Racal-MESL. With a commercial presence in 50 countries and industrial plants in 28 countries, the Thales group is among the world leaders in professional electronics for commercial and defence applications. On-going investment in design, production and test facilities allows us to concentrate on continuous improvement. Here at Thales MESL we design components and systems for wireless telecommunications equipment.

The market for wireless telecommunications never stands still. Our fast design and development times allow our customers to put products on the market quickly in order to maximise market opportunities. Heavy investment in production facilities ensures our capability to produce a high volume of products of maximum quality.

Due to continued growth, we have a requirement to recruit at our facility in Newbridge near Edinburgh, Scotland.

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We are looking for a minimum of a college qualification and at least 5 years' experience in the design of Ferrite/passive components. Alternatively you may be degree qualified and have at least 3 years' experience in Ferrite components. Specifically, you must have experience in circulators, phase shifters, diplexers and test jig design and integration. Experience in Autosketch, HFSS 3-D and any filter package would be an advantage.

Our central Scotland location is close to beautiful countryside, yet equally close to excellent transportation links via rail and air. Shops, restaurants and leisure facilities are set amongst some of Britain's most breathtaking architecture, with a cultural diversity and lively atmosphere that makes this an ideal environment to work and live in. To find out more about living and working in Scotland visit www.scottish-enterprise.com

We offer a competitive remuneration package and the opportunity to work in a challenging and dynamic environment with a

To apply please forward your CV and covering letter to our retained consultant Scott Shields, Managing Consultant, The Resource Group, 105 West George Street, Glasgow, Scotland, G2 1PD Tel: +44 (0) 141 566 4967. Fax: +44 (0) 141 248 6782 or email scott shields@trgrecruitment.net

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■ Transceivers for Cellular Radios

These POLARIS 2 transceivers are designed using direct digital polar architecture and support up to four frequency bands (850, 900, 1800 and 1900 MHz). They perform all the radio functions of GSM, GPRS and EDGE cellular handsets. The receive sensitivity is –109 dBm and –108 dBm in the low and high bands, respectively. The transceiver implements both very low IF (VLIF) and direct conversion receive (DCR) architecture and provides selectable analog I/Q and digital baseband interfaces. Additionally, VCOs and loop filters are integrated. Production pricing is \$8.50 ea. in volumes of 100,000 units.

RF Micro Devices, Greensboro, NC (336) 664-1233, www.rfmd.com.

Circle No. 264

■ Microwave Switch Platform

The 1260-67 M, six position, single-slot, VXI, modular, microwave switch platform allows



users to specify up to twelve combinations of various 18 GHz and/or 26 GHz switches, enabling them to mix and match while keeping the size to a single VXI slot. The platform provides a choice of eight

switch types, including 18 GHz and 26 GHz 1×2 , multi-throw and transfer switches. This modular approach means there is no need to purchase separate C-size cards for each type of microwave switch needed in a system.

Racal Instruments Group Ltd., Wimborne Dorset, England, UK, +44 (0) 1202 872800,

www.racalinstrumentsgroup.com.

Circle No. 265

PROCESSING EQUIPMENT

Laser PCB Prototype System

ProtoLaser 100 is an easy-to-operate high performance laser structuring system for printed



circuit board prototyping that combines the milling, drilling and contour routing capabilities of an advanced LPKF Protomat* PCB plotter. The Proto-Laser 100 is ideal for producing high

quality RF and microwave boards on a variety of materials from FR4 to PTFE-based substrates, as well as for structuring, cutting and drilling. A board can be structured at speeds up to 6 sq. cm (1 sq in.) per minute, producing circuit paths as small as $50~\mu m$ (2 mils).

LPKF Laser & Electronics, Wilsonville, OR (503) 454-4200, www.lpkfusa.com.

Circle No. 266

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Circle 1



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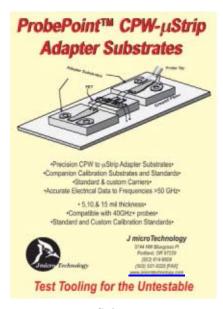
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(Octave/Multi-octave) 35Khz-50GHz; 2db for 0.5-2GHz; 3db for 0.5-18GHz; 2db for 2-8GHz; 3db for 2-20GHz; 4db for 2-26.5GHz; 2.5db for 6-18GHz; 3db for18-26.5GHz; 4db for 18-40GHz

Narrow-Band Low Noise Amplifiers

0.5-110 GHz

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Broad-Band High Power Amplifiers

0.1-30.0 GHz (Octave & Multi-octave) 0.1-0.5GHz(30W), 0.5-2GHz(20W), 1-2GHz 50W 2-4GHz(50W), 2-8GHz(15W), 3.7-12GHz(5W), 4-8GHz(15W), 5-15GHz(5W), 6-18GHz(15W), 8-12GHz (15W), 18-26.5GHz (5W)

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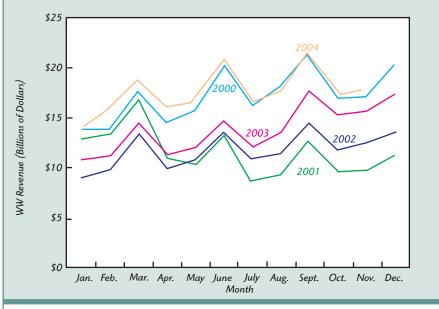
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MICROWAVE METRICS



Monthly Worldwide Semiconductor Revenue

In 2003 the worldwide semiconductor market was \$166.4 B made up of \$140 B in ICs and \$26.4 B in discretes. For 2004 IC Knowledge expects the total semiconductor market to end at approximately 29% growth with ICs showing similar growth.



Source: IC Knowledge LLC, PO Box 20, Georgetown, MA 01833 (www.icknowledge.com)

Worldwide Test and Measurement Revenues to Reach \$6.7 B in 2008

In the aftermath of the telecommunications market collapse, equipment, software and service providers are rededicated to test and measurement solutions that will ensure availability and reliability for the entire network life cycle. This renewed commitment will result in worldwide test and measurement revenues growing to \$6.7 B in 2008, an 11% compound annual growth rate (CAGR) from 2003 to 2008, according to a new report from IDC.

The opportunities for network test and measurement vendors continue to expand with the evolution of next-generation wireless networks. Those vendors with broad wireless strategies (beyond 3G test) will be best positioned to gain market share. Although the most compelling tests remain user-centric, such as drive test or response time, handset testing is becoming increasingly important as well. Add to that a blurring of lines between traditional handsets and consumer electronics devices, and an even larger pool or opportunity begins to emerge. Other key findings from the new IDC study include:

- Test and measurement players are under tremendous pressure to deliver tools based on open standards
- The research and development (R&D) market feeds the network lifecycle and supports a long-term revenue stream for network test and measurement vendors
- · Today's network test and measurement market is made up of 25 to 30 vendors
- Emerging areas for wireless test include wireless LAN, WiMax, consumer devices and RFID

Source: Worldwide Network Test and Measurement 2004–2008 Forecast IDC, 5 Speen St., Framingham, MA 01701 (<u>www.idc.com</u>)











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Smart Antennas

Lal Chand Godara **CRC Press** 464 pages; \$139.95, £85.00 ISBN: 0-8493-1206-X

Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones and hydrophones. They have applications in the areas of radar, sonar, medical imaging and communications. The smart antenna field has been a very active area of research for

"Smart antennas involve processing of signals induced on an array of sensors such as antennas, microphones and hydrophones."

over four decades. During this time, many types of processors for smart antennas have been proposed and their performance studied. Currently, the use of smart antennas in mobile communications to increase the capacity of communication channels has reignited research and development in this field. After some introductory material in Chapter 1, the detail work on smart antennas starts in Chapter 2, where various processor

structures suitable for narrow band field are discussed. Adaptive processing is presented in Chapter 3, with details on the sample matrix inversion algorithm, constrained and unconstrained least mean square (LSM) algorithms, recursive LSM algorithm, recursive least square, constant modulus algorithm, conjugate gradient method and neural network approach. Smart antennas suitable for broadband signals are discussed in Chapter 4. Processing of broadband signals can be carried out in the time domain as well as in the frequency domain. Chapter 5 presents models for a correlated field in a situation of multipath signals. In Chapter 6, various direction of arrival (DOA) estimation methods are described, followed by performance comparisons and sensitivity analyses. In Chapter 7, a brief review of fading channels is presented, distribution of signal amplitude and received power on an antenna is developed, and analysis of noise- and interference-limited single antenna systems in Raleigh and Nakagama fading channels is presented by deriving results for average bit error rate and outage probability. Chapter 8 presents a comprehensive analysis of diversity combining, which is a process of combining several signals with independent fading characteristics to reduce large attenuation of the desired signal in the presence of multipath signals.

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THE BOOK END

Introduction to Microelectromechanical Microwave Systems, Second Edition

Hector De Los Santos Artech House Inc. 234 pages; \$99, £66 ISBN: 1-58053-871-1

his book provides an update on the development of the microelectromechanical systems (MEMS) field over the last five years, and continues to be a timely resource for workers already involved in, or interested in using the potential of RF MEMS to revolutionize wireless portables, base stations and satellite communications. Chapter 1 starts by reviewing the origins, impetus and motivation of the MEMS field, putting into perspective its development up to the present and describing the fundamentals of the technology. Chapter 2 deals with the fundamental physics of electrostatic, piezoelectric, thermal and magnetic actuation, which are the principles on which most MEMS devices applied to RF and microwave systems operate. This chapter also introduces the rudiments of computer-aided design (CAD) numerical and analytical simulation techniques, which are crucial for the rapid prototyping, development and commercialization of MEMS.

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"...an update on the development of the MEMS field over the last five years..."

mission lines and lumped passive elements, are discussed, with emphasis on the interplay between fabrication process and microwave performance. Finally, Chapter 6 presents the fundamentals of wireless communications systems and the application of MEMS-based devices and techniques in these systems. Since the intended readership of the book includes materials, process and device scientists and engineers who may not be familiar with RF and microwave electronics, the presentation follows a semi-intuitive, common-sense approach, complete with the fundamentals and MEMS applications to a variety of important RF and microwave circuits, namely phase shifters, resonators, filters and oscillators.

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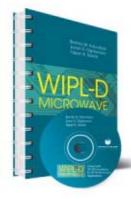
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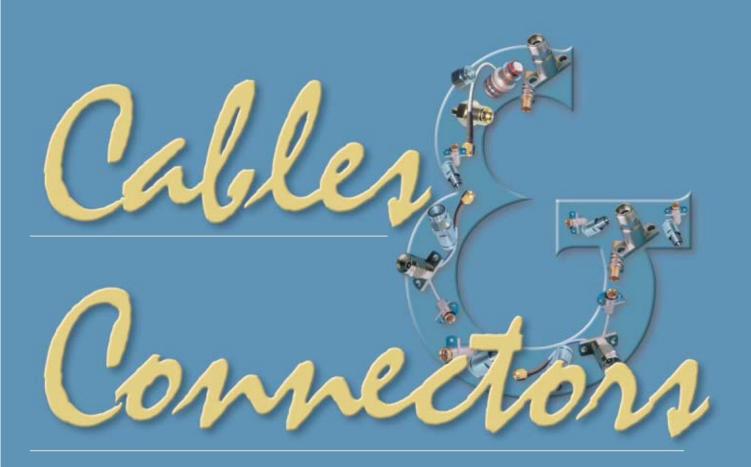












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Cables & Connectors Supplement

2005 Connector, CABLE AND CABLE ASSEMBLY SURVEY

This is the third survey of connectors, cables and cable assemblies sponsored by Microwave Journal. We plan to update it annually with continued industry support and participation.

e are very pleased to offer this updated survey of companies providing connectors, cables and cable assemblies. Sixty-seven companies responded to our request for information this year, which is an increase from the 56 companies in last year's survey. Many of last year's participants have updated their information as well, so this survey represents the most comprehensive listsing of companies offering RF and microwave cable and connector products.

There is clearly a large overlap of similar products being produced by the 67 companies included in the survey, particularly the standard connectors. However, careful examination of the information shows that virtually all of the companies have at least one unique, proprietary or patented product that addresses some niche market and which forms the core of their business, as well as customized products to meet specific requirements. These special products and services seem to be the principal reason for the diversity of suppliers. In addition, some companies specialize in different markets such as Hi-Rel, military and base stations as opposed to low cost commercial and consumer. Thus, in reality, the overlap is not as great as it seems.

Every manufacturer has provided an address for its Web site. Most of these sites contain either full catalog information or selected data sheets. We have also provided phone and e-mail points of contact for each company where available. In some cases, both foreign and domestic contacts have been provided.

I would like to thank the many people who responded to our request for information. Because of limited space, we were not able to use some detailed information that was sent in addition to the specific survey answers, however, we were able to use some of that information to expand on the brief answers to the questions. The data are presented in table format on the following pages. Readers are encouraged to use the Web information and contact points to gain additional insight on the products, services and capabilities of a company of interest.

[Table begins on page 8]

HARLAN HOWE, JR. Editor, Microwave Journal











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Dynawave designs, develops & manufactures RF & microwave interconnect solutions. Our product diversity includes connectors, terminators, test adapters, attenuators, delay lines, harnesses and low cost test & system cable assemblies.

DYNAWAVE'S CONNECTOR INTERFACES: SMA, SMA Polarized, SSMA, SMB, SMC, SMP, SMPM (SMP miniature), SMPSM (SMP sub-miniature), SMT, BMA, BMAM, MCX, MMCX, TNC, KTNC, N, HN, SC, 7/16, 2.4mm, 2.92mm and 3.5mm.

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COMPANY	STANDARD CONNECTOR TYPES	SPECIAL CONNECTORS	Raw Cable Manufacturing
Aeroflex/Weinschel	Planar Crown® and Planar Blind-mate® systems, which are compatible with N, TNC, GPC-7, 3.5 mm, 2.92 mm and 2.4 mm series	Planar Crown® and Planar Blind-mate® allow connector interfaces to be changed for custom applications or for damage replacement	Do not manufacture cable
Aliner	MMCX, MCX, SSMB, SSMA, MC card, SMP, SMA, QMA, SMB, SMC, TNC, BNC, N	MMCX switch connector, MCII, SSMCX, board-to-board connectors, ACX board-to-board	Do not manufacture cable
Amphenol RF	MMCX, AMC, MCX, SMB, SMC, SMA, 1.0/2.3, QMA FAKRA, BNC, TNC, Mini BNC, Twin BNC, Triax, UHF, Mini UHF, N, F, 7/16	smp, afi, qma, fakra, amc	Yes, please visit <u>www.amphenol.com</u>
Anritsu	K series (2.92 mm), V series (1.85 mm), W1 Connector (1 mm)	Over 300 special or custom designed connectors	Do not manufacture cable
Applied Engineering Products	SMA, SMB, SMC, SLB, SSMB, SSMC, SSLB, SSMA MCX, 75 Ω MCX, MMCX, 75 Ω Snap-on, 75 Ω Screw-on, BNC, TNC, N, adapters between series and over 100 styles of MIL-PRF-39012 QPL connectors	Water-proof and weather-tight, special leg configurations for PCBs, special plating and finishes, custom contact configurations, special cable types, connectors with internal functions like switches, unique captivation, reverse polarity, special testing	Do not manufacture cable
Astrolab Inc.	N, SMA, SMP, SMPM, TNC, ATNC, 3.5 mm, 2.9 mm, 2.4 mm, 1.85 mm, BNC, 7 mm, 7/16, BMA, TK, SC, HN, M39029 coax contacts in various forms such as straight, right angle, swept bend, bulkhead and flanged	SMA designs up to 27.5 GHz, SSMA designs up to 40 GHz, low IM space qualified TNC, multipaction resistant designs, Flouraloy dielectric, M39029 contacts up to 12 GHz, phase shifter/fine stretchers up to 26.5 GHz, HF hermetically sealed	0.041 to 0.310 diameter from 70% VP to 82% VP, semi-rigid to highly flexible with capability up to 90 GHz
Atlantic Microwave	SMA, SMP, SSMP, 2.9 mm, 2.4 mm, 1.85 mm, N, TNC, BNC, MCX, MMCX, SMB, SMC	Special body lengths, special PCB connections moisture ingress protection, special cable types	Do not manufacture cable
Aviel Electronics Div. of RF Industries	low	special designs for non-standard types such as hermetically se PIM, polaraized special interface for compliance with FCC lind mate, hermetic rt. angle, 45°, custom make to order capa	15.203,
Belden Inc.	Do not manufacture connectors	Do not manufacture connectors N	fil-Spec RG type coax for high frequency applications as well as 50 Ω antenna coax for wireless communications applications including base stations, wireless LANs and other in-building wireless applications
BTC Electronics Inc.	BMB, BNC, C, G874, GHV, HN, LC/LT, MCX, MHV MMCX, MQD, N, QDS, QMA, SC, SMA, SMB, SMC, T TPS, TRB, TW34, TWBNC, UHF, 1.0/2.3, 7/16		Do not manufacture cable
Cable Experts Inc.	No standard connector products	No special connectors	Do not manufacture cable
CE Precision Assemblies Inc.	No standard connector products	Special designs for specific customer problems such as a 600 W version of the SMP connector. The company also but radiation hardened connectors, high temperature and higl power connectors as well as low IM and waveguide connectors.	llds h
Compel Group	1.0/2.3 and 1.6/5.6 – 50 or 75 Ω, SMA, SMB, SMC, BMA, SMP, MMCX, MCX, N, 7/16, BT-43, adapters	Special designs are available using a wide variety of materials and processes	Do not manufacture cable but does re-sell under some circumstances
Corning Gilbert Inc.	$\label{eq:GPO} \begin{split} \text{GPO (DC to 26.5 GHz), GPPO (DC to 65 GHz),} \\ \text{GMS (DC to 23 GHz)} \end{split}$	Custom versions of the GPO, GPPO and GMS designs for backplane mounting, waveguide launches and group mating configurations	Do not manufacture cable
Delta Electronics Mfg. Corp.	N, QDS, SC, MMCX, MCX, BNC, 75 Ω BNC, C, G874, GHV, HN, LC/LT, MHV, SMA, BMA, SMB/SMC, TNC, TPS, TRB, TW34, TWBNC, UHF, 7/16	QDS, slide-on, BMA, pressmounts, Mini QDS, G874	Do not manufacture cable
Deutsch Advanced Interconnect	DPP series of connectors in N and SMA configurations with push-pull coupling, 7/16, circular multi blind mate, environmental power connectors, fiber opti		Do not manufacture cable
Dynawave Inc.	SMA, SSMA, SMB, SMC, MCX, MMCX, BMA, BMA miniature, SMP, SMPM, SMPSM, SMT, 2.4 mm, 2.92 mm, 3.5 mm, 7 mm, N, TNC, SC, HN, BNC.	Custom designs for cables, field replaceable, PCB mount, edge mount, hermetic connectors and seals, tabbed contact, adapters	Semi-rigid and flexible as well as custom designs
ESM Cable Corp.	Do not manufacture connectors	Do not manufacture connectors	Do not manufacture cable
EZ Form Cable Corp.	MCX, MMCX, BMA, SMA, SMB, SMC, N, TNC, BNC, SSMA, SSMB, 7/16, DSB	EZ Quick-Connect™ plug (SMA compatible), standard series to stripline and microstrip transitions, standard series for low loss and custom cables	Semi-rigid cable from 0.020 to 0.325 inch in copper or aluminum at impedances from 25 to 100 Ω. Custom cables from special materials, flexible cable such as EZConformable in diameters from 0.034 to 0.250 inch at 50 and 75 Ω, EZFlex 401, 402 and 405 flex
Flexco Microwave Inc.	LC, LT, GPO, BNC, EIA, HN, precision N, precision SMA, SC, SMC and TNC	Special connectors for use on cable assemblies such as GPPO, SSMA and ZMA types	Custom cable is manufactured for use in Flexco cable assemblies
Florida RF Labs Inc.	Do not manufacture connectors	Do not manufacture connectors	Do not manufacture cable
Florida RS Technology	SMA, TNC and N with special strain relief	Special SMAs in plug, jack and bulkhead	Do not manufacture cable
Gigalane Co. Ltd.	2.4 mm, 2.92 mm, SMA, high performance SMA, SMB, MCX, MMCX, N, GPO	Customer specific designs are available	RG cable types, semi-rigid and special types
Harbour Industries	Do not manufacture connectors	comm	types of MIL-C-17 QPL approved RG cables, SB strip braid, CN nunication network, LL low loss, SS spiral strip, SC sureform, HPF formance foam, HIS high strength, TRX triaxial, LN low noise, plenum
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Cable Assemblies	Unique Products	Web site and Contact Information
Do not manufacture cable assemblies	US and international patents on both Planar Crown®	www.aeroflex-weinschel.com
	and Planar Blind-Mate® systems	Technical: Jimmy Dholoo, Sales: Thomas Steidel, <u>sales@aeroflex-weinschel.com</u>
General purpose and military for RG178, RG174, RG316, Filotex, LMR, Belden, flexible, semi-rigid	Specials and cable assemblies	www.aliner.com.tw Technical: Victor Chou, <u>victor@aliner.com.tw</u>
Flexible, semi-rigid, conformable, harnesses, phased matched, time delay	AFI Interface to compensate for axial and radial misalignment, which is available in both 50 and 75 Ω	www.amphenolrf.com Technical: Tom Aubin 203-796-2059, haubin@amphenolrf.com, Sales: Greg Straiton 203-796-2079, estraiton@amphenolrf.com
Cable assemblies with APC, N, K, V and W1 connectors, mostly semi-rigid. Test cables both armored, semi-rigid and flexible	The new W1 connector, which can be used up to 250°C, VP series Blind Mate up to 65 GHz	www.us.anritsu.com 1-800-Anritsu
Flexible, conformable, semi-rigid, phase matched and delay lines	SLB/SA patented self aligning PCB to PCB system	www.aep.us. Technical: Dave Critelli at <u>deritelli@aep.us.</u> Sales: Dennis Flanders at <u>dflanders@aep.us.</u> General: <u>sales@aep.us</u>
Mini-bend flexible, convoluted semi-rigid for superconducting temperatures down to 4°K, high flexcables for gimbles and phase stable cables up to 60 GHz	Mini-bend cable assemblies, ever-flex cable and the Cobra-flex line	www.astrolab.com Mary Ceres 732-560-9570
Laboratory and test, general purpose, flexible, semi-rigid, phase stable, phase matched, high temperature	Ultra flexible high frequency, reformable, semi-rigid and flexible test cable are in stock	Joanna Bolton www.atlanticmicrowave.co.uk
Both standard and non-standard types, phase matched, semi-rigid, general purpose, commercial and military	Special fabrication for unique customer applications	<u>www.avielelectronies.com</u> Jack Kaufman 702-739-8155, <u>avielecnn@aol.com</u>
Do not manufacture cable assemblies	Conformable $^{\ensuremath{IM}}$ coax for semi-flexible replacement of rigid-coax	www.belden.com Technical Support: 1-800-belden1
Do not manufacture cable assemblies	Special configurations and quick samples	www.btcelectronics.com Technical: Robert Barnett at.rbarnett@htcelectronics.com, Sales: Audra Starling at astarling@btcelectronics.com, 800-526-2:
A large array of RF cable assemblies	CXP1318FX series, low loss RG8/U assemblies	www.cablexperts.com – Marc Abramson, Chuck Abramson
A wide range of custom cable assemblies including build-to-print and custom standard and low loss assemblies from DC to 65 GHz with limited capability to 110 GHz. Cable assemblies are available from commercial grade to space qualified, radiation hardened	All products are unique to the individual customer's requirements. Many are not available for export without government permission	www.cepaine.com. Technical: Henry Richards 480-940-0740 x222, hrichards@cepaine. Sales: Kathy Kennard x219, kkennard@cepaine.com
Coaxial, multi-pin, fiber optic, semi-rigid, conformable, corrugated, flexible, multi-strand for commercial, military, laboratory and medical applications	Patented plastic flange 7/16 (available in pms colors)	www.compel.it or www.compelna.com. Americas: Peter Alfano at palfano@compelna.com. Europe: Mauro Colleoni at mauro.colleoni@compel.it Asia: Antonella Colombo at antonella.colombo@compel.it
Laboratory and test, general purpose, semi-rigid, flexible	The GPO and GPPO push-on interconnects were created by Gilbert and are patented	www.coming.com/cominggilhert Technical and Customer Service (US and Canada): 800-651-886 (International): (01)623-845-5613_push-info@coming.com
Do not make cable assemblies	Heli-grip, QDS, mini QDS, G874	www.deltarf.com Corinne Rose (Application Specialist), <u>crose@deltarf.com</u> and Terry Hannan, <u>thannan@deltarf.com</u>
Laboratory and test for push-pull N and SMA, assemblies to customer specs, test jumper cables with DPP on both ends	DPP series is unique as it does not require a special receptacle	www.deutschai.com Chief Engineer is Bryan Harrington, Customer Service Manager is Clyde Farren, Sales & Marketing is Ted Linder 909-791-2600, Fax 909-791-26
Instrumentation, laboratory and test, semi-rigid, formable, flexible, delay lines, phase stable, phase matched, low IM, high power, rigid	Internal R&D	www.dynawave.com Brian Nothum 978-469-0555, <u>hnothum@dynawave.com</u>
Laboratory and test, general purpose, flexible, rigid, semi-rigid, phase stable, phase matched, high temperature	Specializing in RF and high frequency	www.esmcablecom.com Greg Garno or David Doo at 209-892-3347
Custom cable assemblies using all of the EZ Form cables	EZ Quick-Connect $^{\text{TM}}$ is patented	www.ezform.com Technical: Tom Ricard at <u>tricard@ezform.com</u> Sales: Jeff Buccitti at <u>jhuccitti@ezform.com</u>
Cable assemblies using Flexco cable for commercial, test and military with emphasis on assemblies with very low phase and amplitude changes during flexure. See next column.	Flexco's cable assemblies are unique due to a combination of connectors and special cables with a wide range of jackets, braids and protective armoring. These are extremely rugged, while providing excellent phase and amplitude stability	www.flexcomw.com Bill Bright, Larry Cagno and Dan Beene at 908-850-5800 or <u>dbcene@flexcomw.com</u>
Laboratory and test, general purpose, flexible, semi-rigid, hand formable, phase stable, phase matched, high temperature, space level and custom	$ \begin{array}{c} Lab\text{-}Flex^{TM} \text{ cables DC to 46 GHz with 2.4 mm,} \\ 2.9 \text{ mm, 3.5 mm SMA, precision type N \& TNC as well as low cost assemblies for specific frequency ranges with 40% lower loss and shielding greater than 90 dB} \end{array} $	www.rflabs.com Jim Walker 772-286-9300 or <u>iwalker@rflabs.com</u>
40 GHz test cables, low loss assemblies, semi-rigid configurations, Flex cables both standard and armored, sizes from 0.019 to 2 inches in diameter	Many of our assemblies are made on patented production equipment	waaw first com. Technical: Tim Spacek & Al Ragl, Sales: Sandy Struthers, 772-221-8188
Low loss assemblies up to 40 GHz, semi-rigid	VEREND high performance and launch connector	www.øigalane.com Richard Song at <u>sales@øigalane.com</u>
and semi-flexible types, RG types		









COMPANY	STANDARD CONNECTOR TYPES	SPECIAL CONNECTORS	Raw Cable Manufacturing	
HoSung Technics Co. Ltd.	MMCX, MCX, SMA, SMB, SMC, BNC, TNC, N, 7/16 DIN, ada	pters Special products as requested	Do not manufacture cable	
Huber + Suhner	1.0/2.3, 7/16, BMA, BNC, BNO, BNT, MCX, MHV, MMBX, MMCX, N, PC2.4, PC3.5, PC7, QLA, QMA, QN, SHV, SK, SMA, precision SMA, SMB, SMC, SMS, TNC, adapters	Custom MMBX, SUHNER QUICK-FIT, ARC series for automotive applications, quick lock connectors and adapters, phase trimmers	Standard RG types (58, 174, etc.), low loss RF cables, high temperature and flame-retardant, low noise for test applications, triaxial, twisted pair, multiple cables in the same jacket, radiation hardened	
IMS Connector Systems GmbH	SMA, SMB, SMC, SMS, SSMB nano, SMP, SMM, MMCX, MCX, coaxial inserts DIN 41612, coaxial inserts sub-D, high power inserts, high voltage inserts FME, BNC, TNC, N, 7/16, 1.6/5.6, SMBA (FAKRA Std.)	Customer specific designs are available	Do not manufacture cable	
Insulated Wire Inc.	SMA, TNC, N, SC, 1.85 mm, 2.4 mm, 2.9 mm, 3.5 mm, 7 mm	Custom designs including MIL 38999 Ove multi-pin contacts, custom flange mounts, special interface connectors	er 150 types ranging in size from 0.050 to 0.500" with impedances from 10 to 125 \Omega\$. A wide variety of outer braids, shields and jacket materials. Multiple cables in common jackets and armored types as well as semi-rigid and reflex cables	
Isotec	SMA, SSMA, SMB, SMZ, SSMB, SMC, SSMC, BNC, TNC MCX, MMCX, N, 7/16 DIN, field replaceable SMA, reverse polarity and reverse thread, adapters	, Slide-on, waterproof, special leg or board, cable types	Do not manufacature cable	
Jyebao Co.	SMA, K, SMB, SSMB, SMP, FME, 7/16, SMC, MMCX, MCX, BNC, TNC, N, HN, C, SC, SHV, MHV, plus reverse polarity versions	Custom designs can be made	Semi-rigid and flexible, 0.034, 0.047, 0.085 and 0.141 with various platings	
M/A-COM (Tyeo)	SMP, 2.4 mm, SSMA, 2.92 mm, 3.5 mm, SMA, TR, TNC, BNC, GPPO, ETNC, N, 7 mm, SC, C, 7/16 IEC, HN, LC, LT, MLT, 7/8 EIA, 1 5/8 EIA (types N, TNC and 7/16 IEC available with low PIM)	MTNC – A multipactor free variant of TNC for high powe space applications, size 8 and 12 contacts for low loss, low VSWR, high frequency performance for MIL-C-87104 and MIL-T-81490 in standard MIL-C-38999 housings, SL family of connectors	er Hundreds of cable types from 0.05 to 1.40" with a variety of materials. Military airborne, space satelllite, mobile mast, general lab, gimble, lightweight military, commercial aircraft, kapton and halogen free, custom designs	
Maury Microwave	1.85, 2.4, 2.92, 3.5, QT3.5, 7 mm, MPC8, N, TNC, BNC, HN, SC, C, LCP/OSP, 14 mm, 7-16, precision and high precision grades, 75 Ω N and BNC	Quick test 3.5 connectors in different sizes, turns and nut configurations, improved LCP/OSP for high repeatability		
MegaPhase Inc.	Do not manufacture connectors	Special adapters for test applications	Groove Tube™ coaxial cable but do not sell raw cable	
Meggitt Safety Systems	SMA, TNC, ETCN, N, 2.4, 2.92, 3.5, GPO, SMP, SC	Custom high frequency e.g. 50 GHz 2.9 mm, special military e.g. multiport, extreme environment e.g. non-magnetic, high temperature e.g. special alloy	Semi-rigid silicon dioxide dielectric cables	
Micro-Coax Inc.	Manufacture connectors to support in-house cable assembly business only	Special connectors for multi-paction sensitive applications and low PIM requirements	Semi-rigid, aluminum jacketed, hand-formable-tin dipped, low loss and ultra-low loss flexible, miniature low loss, ultralight flexible	
Micro-Mode Inc.	MSMA compatible to SMA 2.92, MBMB compatible to BMB, MMSP compatible to SMP, MSSP compatible to SMP, MSSP compatible to MSMP, MSSS™ MM4S, TNC, SMA, SSMA, 2.92, 2.4, SMP, SMPM	Special applications with interface to SSMA, BMA, 2.4, SMC and TNC as well as customer interfaces	Do not manufacture cable	
Microstock Inc. (Distributor)	SMA, SMB, SMC, MCX, MMCX, MMBX, 3.5 mm, 2.9 mm, 2.4 mm, 1.85 mm, BMA, QMA, SHV, MHV N, 7/16, 1.0/2.3, 1.6/5.6, 4.1/9.5, TNC, BNC, UHF, plus between series adapters	Special SMAs for low loss 0.047 diam. semi-rigid , cables such as UT-47-LL and UT-47-LL-TP, special SMA for 25 Ω 0.090 diam. cables such as UT-90-25 and UT-90-25-TP	Do not manufacture cable, but do distribute it	
Microwave Distributors Co. (Midisco)	SMA, SMB, SMC, CMS, SSMA, SSMB, SSMC, MMCX, N, UHF, C, HN, 7/16 and others	Specials and custom products with reasonable minimum lot sizes	Semi-rigid (SNAKE and hand-formable) (Ultra-Flex) as well as distribution of cable from other manufacturers	
Midwest Microwave	SMA, SSMA, SMM, BNC, TNC, TNC-A, N, BMA, QPL, 7 mm, 3.5 mm, SC, HN, SMB, SMC, 2.9 mm, BSAs and in-series adapters	Engineering and design support for specials	Do not manufacture cable	
Molex Inc.	MMCX, MCX, SMB, SMA, SMA field replaceable, SMP, 2.92, BNC, TNC, F, FAKRA, N, 7/16, between series adapters	Catalog derivative for special requirements such as: solderless edge mount, 45 degree SMB plugs, MCX custom coaxial headers	Do not manufacture cable	
Radiall	BNC, BMA, coaxipack 2, coaxi-kit, DIN 1.02/2.3, DIN 1.6/5.1 DTF, FME, FAKRA II, HN, mini UHF, microswitch, MC-CAI MCX, MMCX, N, N7/16, PR, SMA, SSMA, SMB, SSMB, SM SMB carlock, triax, twinax, TNC, UHF, USCar, adapters	RD, MiniQuick, non-magnetic	Low loss and ultra low loss raw cable	
RF Industries Inc.	3.5 mm (DC to 34 GHz), MHV, reverse polarity N, BNC, TNC, SMA, SMB, SSMB, MMCX, (FCC Part 15 compliant) reverse thread N, TNC, SMA (FCC Part 15 compliant), 7/16 D 75 Ω BNC, TNC, Mini-SMB and SMB, F, FME, mini-bayonet, MCXMMCX, N, NEC P300, RCA, SMA, SMB, TNC, UHF, mini-UHF, unidapt, 1.0/2.3		Do not manufacture cable	
RF TEC Mfg. Inc.		Snap-on SMA, Push-on N, M18 male and female, 50/75 Ω TNC, thumbnut SMA plug for #195 cable, long sleeve thumbnut SMA male-TNC male adapter, MA male-F female adapter, connectors for 1.32 mm doub shield and 0.8 mm single shield for hirose U.FL connector		
Rhophase Microwave Ltd.	No standard connector products	Custom connectors for special applications such as SMA 10 Ω for a laser application	Do not manufacture cable but are UK agents for Insulated Wire Inc., Harbour Industries Corp. and Haverhill Cable and Manufacturing Corp.	
Rosenberger Hochfrequenztechnik GmbH & Co.	SSMB, SSMC, SMP, mini-SMP, MCX, 1.0-2.3, coax inserts for mir D-sub coax, DIN 41626, high voltage inserts, DIN 41626 power in SMB, SMG, SMC, QLR-A, FME (SAP), 1.6-5.6, BNC, TNC UHF, mini-UHF, N, 7/16, microdot, F, high voltage SHV-SHV-N high voltage 4-10, IEC antenna, C, high voltage HN, twinax, 3.5-12 BNC-twinax, adapters, RF-FAKRA, RPC-N, R-TNC, RPC-7, RT-S RPC-3.5, RCP-2.92, RCP-1.85, RCP-1.0, RCP-2.4	nserts, custom products on request ;, SIM, /CATV,	Do not manufacture cable	

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	Cable Assemblies	Unique Products	Web site and Contact Information
	Flexible, semi-rigid and jumper cables	Quick delivery on specials within one week	www.hstens.com - Anthony Ham at 82-32-683-8007 x216
	Flexible RF, form stable, semi-rigid, hand formable, flexible MW	MMBX board-to-board, Sucoflex, TM LSFH (low smoke halogen free), enviroflex cables, low noise cables, triaxial, twisted pair (up to $100~\Omega$)	www.hubersuhner.com Local sales offices in 60 countries
	Semi-rigid, semi-flexible, flexible, corrugated, coilcord, GPS cable, GSM cable	Press-fit and press-in as well as MIM manufacturing technology	www.imscs.com Technical: Roland Baumgartner +49-7654-901-182 <u>rhaumgartner@imscs.com</u> Sales: Christian Bitzer +49-7654-901-130, <u>sales@inscs.com</u>
	Low loss cable assemblies up to 65 GHz, general purpose and laboratory, medical and military applications	Proprietary dielectric of laminated, expanded or full density PTFE. Dielectric constant can be tailored anywhere from 1.3 to 2.0. Patented connector design for full captivation on large cables up to 18 GHz	www.iw-microwave.com Cable assemblies: 203-791-1999 or iwsales@iw.com Raw cable: 631-981-7424 or iw-microwave.com
	Flexible, semi-rigid, semi-flex, corrugated UFL cable general purpose, commercial, phase matched, delay lines		www.isoconnector.com Edward Lee at 408-351-3450, i <u>sotec@unitel.com.kr</u>
	RG types, Japanese types, semi-rigid, handbendable, low loss, phase matched	Almost the only manufacturer of semi-rigid cable in Southeast Asia. Standard connectors are stocked and can be shipped within one week	www.ivebao.com.tw Jyebao.Sales – <u>pol-heyns@ivebao.com.tw</u>
	Laboratory, general purpose, airborne EW, phase stable, phase and amplitude matched, small diameter, radiation resistant, cable sets with interchangeable ends and replaceable heads	All products designed and produced in-house	www.macom.com, Technical: Ray Schwartz at 978-442-5487 or Gorden Robertson at 978-442-5486 Sales (Americas): 800-366-2266, (Europe, Middle East, Africa): 44 (1908) 574200, (Asia/Pacific): 81-44-844-8296
	Semi-rigid assemblies in general purpose type N as well as precision 2.4 mm, 3.5 mm, SMA, 7 mm, and N in 0.25, 0.141 and 0.085 diameter cables. Test port adapters and between series adapters as well as test cable kits	Quick test connectors and assemblies	www.maurymw.com/mme_catalog/mmecatalog.htm Technical: Brian Wolf at hwolf@maurymw.com Domestic Sales: Shawna Johnson at sjohnson@maurymw.com Int'l Sales: Anita Luther at ahuther@maurymw.com
	Flexible and semi-rigid assemblies for test and system cable applications from 2 to 65 GHz. There are 5 product lines for test and measurement and 8 product lines for system and general purpose cables	GrooveTube™ is unique to MegaPhase	www.megaphase.com Joe Carbonara at 570-424-8400 sales@megaphase.com
tem	Semi-rigid silicon dioxide dielectric cables and assemblies – phase stable from near 0K to 2400 F, phase matched, high perature, harsh environments and precision configured assemblies	Meggitt is the only company to produce space qualified ${\rm SiO_2}$ cables and assemblies	www.stablecable.com Cyril Berg at 805-584-4100, <u>cherr@safetysystem.com</u>
	Test, general purpose, flexible, semi-rigid, phase stable, phase matched, high temperature, low loss, ultralight, space qualified	Flexible Ultralight UTiFLEX cable assemblies using DuPont's ARACON™ metal clad fibers	waw.micro-coax.com, Sales: Bruce Ash at 610-495-4225 Technical: John Lewis at 610-495-4326
	Flexible, semi-rigid and rigid phase matched assemblies	$\rm MSSS^{TM}$ series, which is 20% smaller than MSMP and 40% smaller than SMP. Over 500,000 parts produced	www.micromode.com Technical: Mark Perry 619-449-3844 v25 <u>mperry@micromode.com</u> Sales: Brian Peckham 619-449-3844 v46 <u>brian@micromode.com</u>
	Laboratory and test, general purpose, flexible RG, semi-rigid formed to specification, phase stable, low loss rigid assemblies	No unique products	www.microstock-inc.com Technical contact: Dr. Bob Schafer, Sales: Scott Frobese_micrstok@ix.netcom.com_215-699-0355
	Standard RG cables, LMR,™ semi-rigid, ultra-flex, and phase stable assemblies	Unique configurations and combinations supported by a large inventory	www.microwavedistributors/idisco.net Technical: John Summerville, Sales: Mark Laurenti, <u>instock@microwavedistributors.com</u>
	Test and measurement, general purpose, mil/aero applications, low loss, std. RG-type patch cords, semi-rigid and semi-flex, phase matched, delay lines Flexform I & II	Flexform I and Flexform II are proprietary cable designs	www.midwest-microwave.com Contact: Ruth Fawson, f <u>awson@midwest-microwave.com</u> 781-894-8787 or sales@midwest-microwave.com, 734-429-4773
	Laboratory, test and general purpose applications using flexible, semi-rigid and triax cable	Solderless Edge Mount is a patented Molex design. Supplied in panels up to 30 BNC receptacles	www.molev.com Technical: Don Gould, Dwaine Robison Sales: Roger Kauffman 317-834-5600 rf@molev.com
ult	Flexible RG, flexible low loss ECO friendly (zero halogen and sulphur), semi-rigid, handformable, corrugated, SHF ra low loss for general purpose lab and test, outdoor and air frame	QMA and QN (quick lock formula), IMP, UMP, MMT and MMS are patented by Radiall	www.radiall.com Technical: <u>info@radiall.com</u>
	General purpose, WiFi and antenna pigtails, wire harness, flexible, semi-rigid, phase matched, pull/tensile tested, Hi pot, sweep tested	Unidapt adapters, pigtails, adapter kits, quick disconnect BNC, F, mini-UHF, N, RCA, SMA and TNC, MB and mini-bayonet, cellular interface adapters and connectors	www.rfcoaxconnectors.com www.rfcables.com www.rfneulink.com Technical: Connie Jones, Dave McReynolds, Ronnie Rice Sales: Rosa Reynolds, Jesse Fuller all at <u>rfi@rfindustries.com</u>
	Laboratory and test, general purpose, flexible, semi-rigid, rigid, phase stable, phase matched	Snap-on and push-on SMA, push-on N up to 14 GHz, long sleeve thumbnut SMA, connectors for 1.32 mm and 0.8 mm cables for hirose U.FL connectors and cable assemblies	www.rftec.com Kiyoshi Endo 770-251-2235 or k4st@rftec.com
	Laboratory and test to 50 GHz, medical, defense, general purpose, flexible, semi-rigid, phase stable, phase matched	No unique products	www.rhophase.co.uk Technical: Byron Putt & Nick Lewis, Sales: Jodie Di-Orio & Bob Davis
	Flexible, semi-flexible, semi-rigid, corrugated, UTIFLEX cable assemblies, test cables	QLR-A (Quick Lock Rosenberger-SMA), SMCC-surface-mount coaxial connector is patented coax to planar technology	www.rosenberger.de US: Kevin LaRue 717-290-8000 info@rosenbergerna.com Europe: Harry Rausch (+49 8684-180) <u>info@rosenberger.de</u>











COMPANY	STANDARD CONNECTOR TYPES	SPECIAL CONNECTORS	Raw Cable Manufacturing
S.G. McGeary Co.	1.85 mm, 2.4 mm, 2.9 mm, 3.5 mm, PGM, SSMA, SMA, TNC, N, 7 mm	Custom designs are available on request, including 1.0 mm (DC-110 GHz), 2.9 spark plug over 1-1/2" long special sraight and angle flange mounts	Do not manufacture cable
Sabritec Inc.	SCX, Micro-D, SMP, SMPM, high frequency D-sub size 8 coax contacts	Custom designs are available on request	Do not manufacture cable
San-tron Inc.	N, 7/16, SMA, BNC, TNC, C, HN, LC, MHV, SC, SHV, UHF, 1.0/2.3 and adapters	Extended insulators and contacts, custom flanges, custom cable sizes, custom designs based on standard interface designs	Do not manufacture cable
Semflex Inc.		High power/high temperature, environmental sealed, eustom interfaces, push-on, blind-mate, phase trimmers	High performance 50 Ω, low loss, high power, s low density PTFE dielectrics, RG cable types, communications cable, custom cable
Sources East	SMA, SMB, SMC, SMK, SMP, SMZ, SSMA, SSMB, MCX, MMCX, BMA, BNC, TNC, N, 7-16 (L29), CCWX, DSB, DSD, ISMA, 2.92, SMB-75, SSMB-75, SMC-75, MCX-75, SMZ-75, SAA-75, TNC-75, BNC-75, reverse polarity SMA, MCX, TNC and BNC	Special connectors from modified standards with special pin length, shape or termination. Special housings and finishes	Do not manufacture cable
Southwest Microwave Inc.	SMA, enhanced high temperature SMA, N, TNC, SSMA, OPS/BMA, 2.92 mm, 2.4 mm, adapters between series, end-launch adapters, field replaceable accessories, new SSMA to 40 GHz and SSMA-to-2.4 mm adapters to 50 GHz	Custom designs are available on request. Wave guide launchers, mechanical switch connectors, special flanges, 50% of shipments are non-catalog specials	Do not manufacture cable
Special Hermetic Products	Hermetic SMP (MIL-STD-348)	Modified SMPs for special interface mounting	Do not manufacture cable
Spectrum Elektrotechnik GmbH	1.4/4.4 mm, 1.8/5.6 mm, 2/5.5 mm, 1.85 mm (V), 2.4 mm, 2.92 mm (K), 3.5 mm, 7 mm, 7/16, BMA, BNC, C, HN, N, SC, SMA, SMP, SPPO (SSMP), TNC, TNX, SBX, SBY, SMP, SMPM, SQ-8, SSMA	SPM (Spectrum power miniature), push-ons for 7/16, N, TNC, SMA and SMA reverse sex, SBX (Spectrum blind-mate X), SBY (Spectrum sub sub miniature push-on) phase adjustable connectors	0.141 semi-rigid cable using a seamless convoluted stainless steel copper composite tubing known as "Handy Form Type 33"
Spinner GmbH	7/16 (low PIM), N (low PIM), 4.1-9.5 (low PIM), TNC, BNC, N, HN, 1.6-5.6 EIA, between series adapters	Custom 7/16 panel mount and EIA connectors with a coupling nut	Do not manufacture cable
SRC Cables Inc.	Do not manufacture connectors	Do not manufacture connectors	Do not make their own cable, custom designed cables are made for them
SRI Connector Inc.	1.85 mm, 2.4 mm, 2.9 mm, 3.5 mm 7 mm, N, SMA, TNC, ZMA and between series adapters	Superites SMA right angle connectors with high performance, proprietary custom designs	Do not manufacture cable
SSI Cable Corp.	Do not manufacture connectors	Stainless steel connectors made to their specifications and specials at customer request	0.093, 0.145, and 0.240 stainless steel cable in regular and low loss types as well as stainless steel jacket over copper outer conductor, RTFE or medium loss dielectric
Storm Products Inc.	SMA, TNC, N, precision N, 3.5 mm, 2.4 mm, GPO, GPPO, GMS, 2.9 mm, 2.4 NMD	Custom designs for specific customer requirements	Semi-rigid, flexible, solid PTFE, low loss low density PTFE, microporous and expanded PTFE, ePTFE tape and foil wrapping, flat and round wire braiding, textile braiding, low and high temperature extrusion, semi-rigid die sizing
SV Microwave Inc.	SMA, SSMA, BMA, BMMA, BMZ, BZ, ZMA, MCX, MMCX, SMP, SMPM, TNC, precision TNC, N, precision N, SMB, SMC, 1.85 mm, 2.4 mm, SVK, 2.92 mm, 3.5 mr 7 mm, C, SC, HN, 7-16, QDS, LC/LT, EIA, multi-contact assembli		Do not manufacture cable
Telegartner Inc.	BNC, TNC, UHF, mini-UHF, N, 7/16 DIN, 1.6/5.6 DIN, FME, SMA, SMB, SMC, SMS, SSMB, MCX, MMCX, ASMB	Custom designs as well as surge protectors (both gas a for N and 7/16, low PIM types, special connectors for corrugated and non-standard cables	and stub) Do not manufacture cable
Tensolite Inc.	SMA, SSMA, SMP, SSMP, SSMT BMA, 2.92 mm, 1.85 mm, MCX, N, TNC, 7 mm, TK	HF connectors to 65 GHz, integrated connector block interface assemblies, custom angle designs	Netflight® high performance cable, ACCULITE™ miniature coaxial, balanced line, twisted pair multiconductor, low loss flexible cables
Thermax/CDT	Do not manufacture connectors	Do not manufacture connectors	MIL-C-17 cables, MaxForm hand formable, MaxFlex cables, high temperature, low loss cables with air expanded PTFE, seamless wrap PTFE tape dielectric cables
Times Microwave Systems Inc.	N, TNC, BNC, SMA, UHF, mini-UHF, 1.0/2.3 DIN, 7/16 DIN, 7/8 EIA, 7 mm, 3.5 mm, reverse polarity	Reverse polarity, self-locking, phase trimmed, non-solder (EZ)	Commercial, aerospace and shipboard high reliability RF & microwave
Trompeter Electronics Inc.	BNC, TNC, N (all 50 or 75 Ω), SMZ, F, mini-BNC (75 Ω), WECO and mini-WECO, TPS, TRB, TRT, TRS, TTM, TRC, TRN, TWBNC	Patching and distribution panels, custom designs, hermetic, radiation resistant, space rated to NASA Srec SP-R-022	Do not manufacture cable
TRU Corp.	2.4 mm, 2.92 mm, 3.5 mm, 7 mm, 7/16 DIN, MCX, MMCX, SMA, SMB, SMC, SMP, BMA, BMMA, BNC, N, TNC, ATNC, C, SC, HN, LC, LT, EIA, TRIAX	Custom high power/high voltage interfaces, polarized, environmental sealed, low PIM, precision adapters, swept high power right angle adapters	High performance, high power/temperature, flexible 50 Ω, low loss, low density PTFE dielectrics, RG cable types, cintru™ communication cable, general purpose RF/microwave
Vitelec Co.	BNC (50 & 75 Ω), insulated BNC, twin BNC, TNC, SMA, SMB, SMC, MCX, MMCX, N, N (high frequency), twinax, UHF, mini-UHF, FME, F, euro, adapters	Modifications of standard product as well as custom designs	Do not manufacture cable
W. L. Gore & Associates Inc.	7/16, N, TNC, TNCA, SMA, precision N, 7 mm, 3.5 mm, 2.92 mm, 2.4 mm, 1.85 mm, MVX, MMCX, BMA, BMMA, #8, #12, SMP, SMPM, adapters between series, blind mate adapters, PCB mount connectors	Special board mount footprints, custom cable connectors, replaceable interfaces	Broad capabilities including coaxial, RF/microwave, round, planar, ribbon, triaxial, and hybrid constructions, fiber optical, industrial, high flex
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Cable Assemblies	Unique Products	Web site and Contact Information
Do not manufacture cable assemblies	Swept right angle bends in all series plus the PGM series, which is intermateable with SSMA connectors up to 50 GHz and uses an air-dielectric interface. New 1.0 mm series extends the capability to 110 GHz	www.sgmcgeary.com Technical: Larry Herring Sales: Steve McGeary 321-409-0509, Jim Riter 973-224-451 Fax 321-409-0510
RG-316 flexible coax, RG-178 flexible coax, RG-405 semi-rigid, RG-402 semi-rigid, RG-58 flexible coax, SR.047 semi-rigid	SCX-Air dielectric interface	www.sabritec.com Technical: Mike Pohorecki at mpoho@sabritec.com Tony Cardino at teardino@sabritec.com Jeff Uhlack at jublack@sabritec.com Sales: Glenn Piper (West Coast) at gpiper@sabritec.com Phil Baynes (East Coast) at <u>phaynes@sabritec.com</u>
Do not manufacture cable assemblies	Reverse polarity types and unique 15 product line to meet FCC Part 15.203	www.santron.com Technical: Fred Hull 978-356-1585, f <u>red@santron.com</u> Sales: Chris Sanders <u>chris@santron.com</u>
Test and measurement, phase or delay matched, semi-rigid and conformable, rigid air/dielectric electroform assemblies, custom splitters and power dividers, 1553 databus, custom harnesses and corrugated jumpers	High power KW series cable, lightweight RG+ series cable, rigid air dielectric electroform assemblies	www.semflex.com Technical: Robert Thiel Sales: Doug Hartje at <u>doug hartje@semflex.com</u>
Flexible, semi-rigid, conformable, corrugated and other types	Wide variety with the ability to provide custom designs in small quantities	www.sourceseast.com, Wayne Pittman at 408-374-1031, <u>wavnep@sourceseast.com</u>
Semi-rigid and semi-flexible/conformable, field replaceable connectors, Hi-REL	All connectors are thermal tested, space qualified materials, high-rel, high temperature performance, lot control and material traceability, lead-free solder processing	Www.southwestmicrowave.com Technical: Dusty Leavitt 480-783-0201 x391 dusty@southwestmicrowave.com Sales: Sandy Feeney 480-783-0201 sandyf@southwestmicrowave.com
Do not manufacture cable assemblies	Robust series for aluminum and kovar as well as other housing materials are covered by US patents or patents pending	www.shp-seals.com Technical: Jack Pollock jack@shp-seals.com Sales: Wendy Cheney wendy@shp-seals.com 603-654-2002 Fax 603-654-2533
Flexible test and measurement, ruggedized, military, interconnect systems, power, commercial RG types, phase stable, hand formable, semi-rigid (0.034" to 0.50" diameter), radiation resistant, general purpose	CNCA-700 cable cutting and stripping machine, push-on 7/16, N, SMA, TNC and SNX, SBY, SSPO and SPM are unique, new MA2-line and SA2-line angle air connectors, new hermetic glass beads	www.spectrum-et.com Peter Von Nordheim +49-89-3548-040 pvnordheim@compuserve.com
Corrugated cables for base stations and low IM test, braided general purpose, semi-rigid, phase stable, phase matched	Jumper cables for corrugated copper cables	www.spinner.de info@spinner.de
All types of cable assemblies	Proprietary coax types SRC-316, SRC-402SF & SRC-405SF	www.src-cables.com President: Dan Hirschnitz, dan@src-cables.com Sales Coordinator: Kathy Badger, <u>kathy@src-cables.com</u>
Do not make cable assemblies	Superite series	waww.sriconnectorgage.com Mark Hiser 321-259-9688 hiser@sriconnectorgage.com
Semi-rigid (copper, stainless steel, aluminum), flexible, conformable, phase matched, delay lines, medium and low loss, wireless preps, wire harnesses, test, general purpose and cryogenic	Stainless steel cables are unique to SSI	www.ssicable.com Contacts: Bill Smith and Brek Sowers 360-426-5719 <u>hsmith@ssicable.com</u>
Semi-rigid, flexible, general purpose, laboratory and test, military, communications, miniature low loss, phase stable, high-rel, thermal pre-conditioned	Phase Master® – exceptional phase stability with temperature, True Blue® – low loss with durability and value, Storm Flex™ – superior electrical performance, trouble free, durable, compact, Accu-Test™ – calibration accuracy, repeatable phase measurement with flex	www.stormproducts.com/microwave Inside sales 888-347-8676
All types built to customer requirements		www.symicrowave.com Sales & technical 561-840-1800 sales@symicrowave.com
Laboratory and test, general purpose, flexible, conformable, semi-rigid, low loss, high power corrugated, multi-core coax	$\operatorname{SimFIX}\operatorname{Plus^{TM}}\operatorname{connectors}$ and low PIM telealloy plating	www.telegartner.com Technical: Allen Ehredt Sales: Jim Ziebka 630-616-7600 sales@telegartner.com
Flexible, semi-flexible, high density assemblies, test and measurement, precision harnesses, semi-rigid, delay lines, phase matched	QBC series for blind mating with standard series, Netflight™ cables, UCCULITE™ cables, Q-Flex,® Semi-Flex® and Workhorse® cable assemblies, high density application cable assemblies such as HDSI® and HDSI-DP®	wave tensolite com info@tensolite.com or 877-890-7483
Do not manufacture cable assemblies	Thermax LTE expanded PTFE dielectric is proprietary as is seamless wrap PTFE dielectric and jackets	<u>www.thermaxedt.com</u> Maria Neclerio 203-284-9610
Laboratory and test, general purpose, flexible, semi-rigid, phase stable, phase matched, high temperature	Miltech, blindmate, T-flex, stripflex, T-com, nu-trac, FlexRAD, testmate, phasetrack, LLSB, LSSB, and LMR cable and cable assemblies	www.timesmicrowave.com Technical: Joe Lamoue jlanoue@timesmicrowave.com Sales: Sue Reynolds graynolds@timesmicrowave.com
1553 data buss and ground support, broadcast head-end patching, Telco central office, medical MRI test, laboratory and test	Separable BNC connectors for PC mount, miniature normal-through patch jacks with true 75 Ω for HDTV performance	www.trompeter.com, Technical: Mark Borton 818-865-6534, <u>mark borton@trompeter.com</u> , Sales: Dale Re 818-865-6538, <u>dale reed@trompeter.com</u> or <u>sales@trompeter.</u>
High power/high voltage phase and amplitude matched, shipboard and aerospace, flexible, semi-rigid, corrugated and rigid line assemblies, general purpose, cintru™ broadband communication, customized cable/connector attachments	Quick-disconnect line (QD16™ QDL, QDM, QDS, QRM™ SQS™), safety interlock interfaces, high temperatuare and frequency dielectric interfaces, solderless right angle cable attachments	www.trucorporation.com Brenda Wheeler, 978-532-0775
$Semi-rigid, flexible \\ (with or without data for telecoms, datacoms, wireless, test)$	Gigaflex™ cable assemblies	www.vitelec.com.uk sales@vitelec.com.uk +44 (0) 1420 488661
Flexible, laboratory and test, phase and amplitude stable, performance options through 110 GHz, ruggedized, general purpose, phase matched, high temperature, low loss, long length, high power, spaceflight, high density, airframe/vapor sealed	Performance to 110 GHz, precision test adapters, excellent phase and amplitude stability, low loss/long length assemblies, industry standard performance	www.gore.com/electronics. 800-445-4673 or 302-292-5100

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Cables & Connectors Supplement

AN RF/MICROWAVE TEST SOLUTION FOR CABLE ASSEMBLY AND AEROSPACE **TESTING**

uilders and users of RF/microwave cable assemblies must specify and guarantee the performance of their cables for characteristics such as return loss, insertion loss, phase stability and VSWR. Cables must be 100 per cent tested in order to ensure specification compliance and optimum performance. Typically, critical measurements such as these require highly skilled engineers to operate complex vector network analyzers (VNA). The high cost of testing is a major challenge when considering tight budgets and margins. Utilizing DCM Industries' 30+ years of cable testing experience, the Model COAX-3000 Test System automates VNA measurements of RF/microwave cable assemblies. Automation is so complete that un-

skilled operators may now perform accurate, complex measurements, with minimal training.

AUTOMATED SOFTWARE

At the heart of the COAX-3000 system is DCM-developed software that turns a complicated, general-purpose VNA into an application-specific, plug-and-play measurement solution. The software provides complete system configuration, calibration management, test reporting and data base management, all with no user programming. The software can be used with most major VNAs and can be easily upgraded to include any VNA using the appropriate instrument drivers.

Unlike programming languages such as C++, VEE and LabVIEW, the COAX-3000 is a turnkey solution ready to perform RF measurements with no programming required. The COAX-3000 eliminates the extensive development time and costs associated with other methods by incorporating the company's expertise in VNA measurements, de-embedding techniques and application program development. The result is a plug-and-play test solution that is flexible, user friendly and ready to use.

System setup is a simple, one-time process using graphic user interface (GUI) panels (see **Figure 1**). Enter a few key parameters such as frequency range, number of test points, type of

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Fig. 1 A typical graphic panel that provides an easy interface for all measurements.



DCM Industries Inc. Union City, CA

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Electrically: There is almost no difference, compared to our straight connectors. We are having the most advanced tools available to always design state-of-the-art connectors.

Mechanically: They are small! And if we say small, we mean small! They are only as big as the connector series requires! We do not sell connectors by the pound! We design connectors

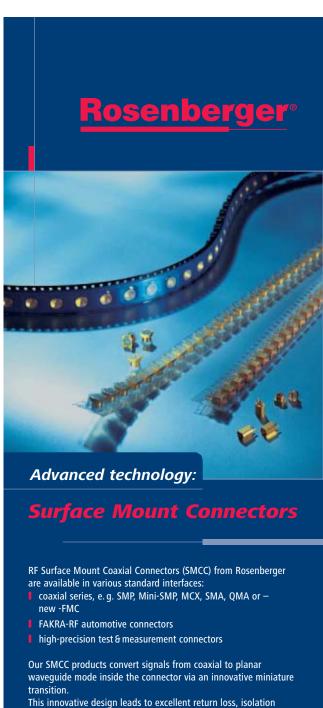
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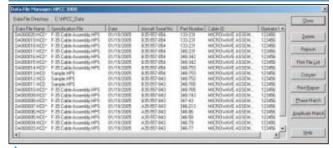
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▲ Fig. 2 Test data automatically stored in the database.

test and specification limits, and the program automatically sets up the pass/fail limits, determines the type of calibration needed and configures the VNA for optimum performance. The user is guided through the entire measurement process without having to touch a VNA button.

For system control and security, a three level password-protected login is included. Only qualified top-level users have authority to generate and edit specification files and manage data. Password protected login means that the time-consuming configuration files are protected from unauthorized changes.

The COAX-3000 software contains a number of advanced measurement capabilities and can be customized by the user through use of the Screen Editor. Data entry fields can be defined for specific customer parameters such as part identification, operator ID, batch number, etc. The Screen Editor also provides an easy method of customizing measurement fields for special device characteristics. As a result, the program can easily be re-configured by the user to accommodate nearly all possible measurement parameters for any type of two-port device.

COMPLETE DATA FILE MANAGEMENT

The Data File Manager within the COAX-3000 software stores a complete history of device measurement data (see *Figure 2*) and provides extensive analytical tools including cable matching capabilities, data exporting and printout options. Cable matching functions include the ability to match cables with respect to phase, insertion loss and electrical length. After measurements, complete test reports with data summary and multiple graphs are available (examples of some of the test report graphs are shown in *Figure 3*). With powerful database tools already

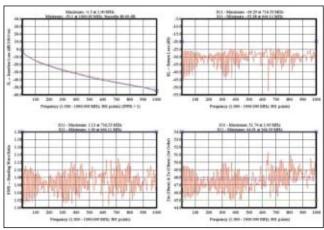


Fig. 3 Full range of graphs available in the test reports.







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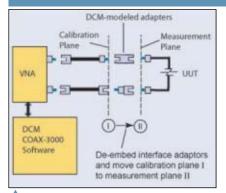








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▲ Fig. 4 A de-embedding function that provides error-corrected measurement data with adapter errors transparently removed.



Fig. 5 An HPCC-3000 system measuring aerospace cable assemblies.

integrated into the measurement program, it is no longer necessary to export files to an external database program, or to an external computer, for data analysis — a savings of time and added security. However, if data export is required, a one-button conversion program is also provided.

ADVANCED CALIBRATION AND DE-EMBEDDING

The COAX-3000 provides an automated calibration management system that guides the user to minimize the potential for operator errors. In addition, advanced calibration techniques solve the problem of adapters when measuring cable assemblies. Test engineers are well aware of the increase in measurement errors when adapters are used to measure non-insertable (male-tomale or female-to-female) devices. DCM has developed a system to easily remove adapter effects using mathematically compensated de-

embedding techniques.

The COAX-3000 software extracts adapter errors by utilizing modeled adapters during the measurement process, as shown in *Figure 4*. After calibration, the appropriate adapter is attached, the characterization file is downloaded, and the effects are mathematically extracted. The COAX-3000 software does this transparently, and measurement data is presented with the effects of the adapters automatically removed. The benefits of this technique include improved accuracy, fewer calibrations, fewer calibration kits and reduced operating costs.

The DCM de-embedding technique provides the ability to accurately measure cables with a mix of different connector types (see *Figure 5*). This situation is often found in the aerospace industry where cables with different connector types are used. A common practice is to use error-prone adapters to facilitate



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the measurement, thereby increasing measurement uncertainty. Including the appropriate DCM-modeled adapter with the COAX-3000 system solves this problem.

A final significant benefit of the DCM calibration solution is elimination of the need for multiple calibration kits. After calibration, converting the test port to a different connector type is as simple as adding the appropriate DCM-modeled adapter. With a single calibration kit, the measurement port can be re-configured without re-calibrating the system or purchasing additional calibration kits. Total impact is a reduction in calibration time, fewer calibration kits and minimized calibration errors.

FULLY INTEGRATED AEROSPACE PRODUCTION LINE AND FLIGHT-LINE TEST SOLUTION

The aerospace version of the COAX-3000 is the HPCC-3000, as shown in Figure 5. With the introduction of the HPCC-3000, the aero-

space industry now has a powerful solution for testing high performance coaxial cable (HPCC) assemblies on the flight-line, in the shipyard, or on the production line. The Model HPCC-3000 provides all required aerospace requirements including secure frequency operation, full data base functions, extensive cable matching capabilities, complete calibration management, and testing a wide range of cable assemblies with multiple connector configurations and supplies a comprehensive test report for each tested cable assembly. Because of the unique capabilities of the HPCC-3000 system, it has been chosen for use in the F-35 JSF Joint Strike Fighter program.

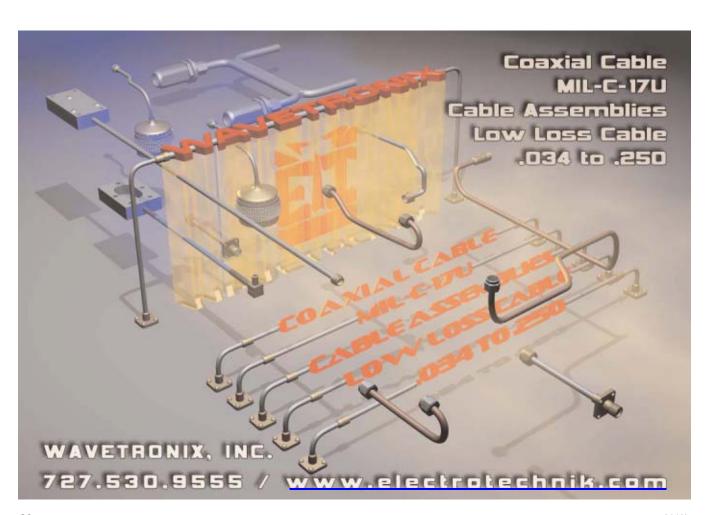
CONCLUSION

The COAX-3000 system is a complete test solution supporting the most demanding requirements for coaxial cables and cable assemblies used in the RF/microwave field. All RF measurement parameters are

supported with full frequency range support. The COAX-3000 can act as a stand-alone software automation solution or can be combined with adapters and fixtures to facilitate cable testing. For cable assembly manufacturers, the COAX-3000 provides an automation solution easily useable by unskilled operators, both reducing testing costs and providing more accurate results and better data archiving. For the aerospace industry, the HPCC-3000 offers an automation solution for providing highly accurate HPCC testing, secure frequency testing and better data archiving. All DCM RF/microwave test solutions can be custom packaged to meet customer needs.

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NON-MAGNETIC RF COAXIAL CONNECTORS

enerally speaking microwave and RF connectors tend to be viewed as simple, uncomplicated components. What is often overlooked, however, is that there are special applications requiring special connectors that have specific properties and characteristics. A prime example is Radiall's range of non-magnetic RF coaxial connectors that have applications primarily for magnetic resonance imaging (MRI) medical equipment.

imaging (MRI) medical equipment.

MRI is an advanced imaging technique that

is able to produce high resolution cross-sectional images of the inside of the human body by exploiting radio frequency pulses. The images produced are the visual equivalent of a slice of anatomy. Although MRI has been available for over two decades, there have been tremendous technological improvements.

available for over two decades, there have been tremendous technological improvements in recent years, a small part of which is due to

coaxial non-magnetic connectors.

To understand why, consider that MRI medical equipment consists of a computer, a large magnet that surrounds the patient and RF coils. The magnet creates a strong uniform static magnetic field (0.3 to 7 Tesla) in a chamber

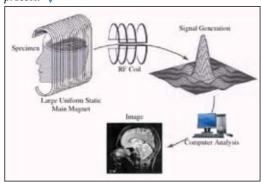
where the patients lies. The transmit coil produces the RF pulse of 20 to 300 MHz, which is only aimed at the affected area. The RF pulse is responsible for altering the uniform magnetic field and generating a signal that is picked up by the receiver coil. The process is shown in *Figure 1*.

The quality of the picture depends above all on the homogeneity of the magnetic field and on the signal-to-noise ratio. *Figure 2* is an example of an MRI brain image with poor spatial resolution and low signal-to-noise ratio, while *Figure 3* represents good spatial resolution and high signal-to-noise ratio. To avoid any interference in the field homogeneity, coaxial connectors and cables located in the magnetic field connecting the coils should be transparent relative to the field, meaning that their relative permittivity should be equal to 1.

Being able to meet this requirement, so called 'non-magnetic' coaxial connectors can provide MRI equipment with electromagnetic immunity. They are made from diamagnetic materials and plating. Such RF connectors offer a good 'non-magnetism' level when positioned inside the magnetic field. The field distortion they generate is so small that it meets the strict requirements of MRI type applications. Furthermore, the MRI image's spatial resolution is opti-

Radiall *Paris*, *France*

Fig. 1 The magnetic resonance imaging process.



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HIGH FREQUENCY

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Tech Bites

Ask the Professor

As a PCB designer assigned to reduce the overall size of electronic networking equipment that is currently defined by high

counts of BNC or sometimes F connectors, I'm stymied by the sheer size of these legacy interfaces that are so entrenched in the industry. Suggestions?

Answer: You're not the first confounded by this dilemma. One BNC supplier listened a few years back to their customer's struggle with Central Office equipment congestion issues, and suggested that a smaller connector could enable more devices - consequently more interconnects - per rack. In addition to requiring a substantial size reduction and retention of all other product attributes, a pivotal factor for the user was preservation of the cable installation process to allow continued use of their investment in fielded tooling and trained technicians. This M-BNC design is now being deployed in the telco/CO via network OEMs.

As previously reported, the BNC market is highly polarized in two segments with a corresponding variation in performance and price. Most are produced and marketed for cost-sensitive, low reliability, low frequency applications, and do not approach the telco standard in frequency response, mating cycle life, mechanical pull strength or service life characteristics. The M-BNC products now surfacing are subject to this same variation between "Carrier Class" and "hobby grade" quality. Be sure to match your need to the product you specify.

For example, the DS3 line is where the public switched network optical data streams are converted into electricity for routing and other signal management work. BNC connectors are used here to support highly shielded coaxial line rates and signal egress. These "Carrier Class" connectors are designed and built to a standard quite separate from those used for other applications. Another network that now needs "Carrier Class" long life reliability and high performance is CATV which is rushing to deploy high definition television (HDTV), an application that requires new attention to signal integrity issues.

New Products

Miniature BNC PCB-Mount Jack: 40% Smaller and 99.999% Reliability



The Trompeter 250 Series of M-BNC connectors has recently expanded with the addition of the UCBJ250S. A unique feature of this new 75-ohm pcb-mount jack is the robust, reinforced leg set that provides the mechanical strength necessary to compensate for the torque related to the jack's small footprint. This jack has undergone extensive reliability testing including mixed flowing gas, thermal cycling, thermal aging, and NEBS testing for telco grade compliance.

The M-BNC series enables a significant increase in connector density. The Trompeter products in this series retain all the product attributes of the classic telco grade BNC, making the series ideal for OEM equipment applications that involve high data rates, high bandwidths and/or high frequencies. The Trompeter product design, performance, material choices, installation tooling compatibility, and overall quality are consistent with network "Carrier Class" telco DS3 data rate applications.

Included in the 250 Series are straight and right angle plugs, bulkhead cable jacks, as well as straight and 90° pcb-mount jacks. Pcb-mount jacks are available in both nickel and gold plate.

Samples and information can be obtained by contacting Customer Service at 800-982-2629, or on the website at **www.trompeter.com**.

About Trompeter

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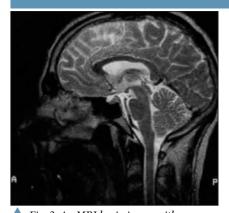






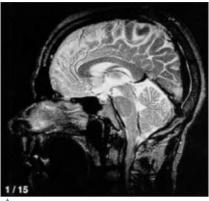


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▲ Fig. 2 An MRI brain image with poor spatial resolution and low signal-to-noise ratio.

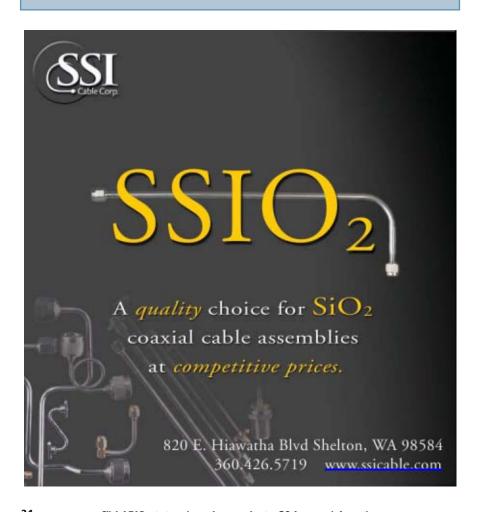
Brass/nickel connector



▲ Fig. 3 An MRI brain image with good spatial resolution and high signal-to-noise ratio.

≈ 10⁻²

≈ 10⁻⁴



mized, adjacent image details can be captured and there are fewer corrections to be made to the image.

CONNECTOR COMPARISON

With standard connectors, when an external magnetic field H_{ext} is applied, a magnetization M appears inside the material of the connector. This magnetization generates a ΔH disturbing field that distorts the flux lines of the H_{ext} magnetic field. As a result the quality of the picture is poor and many corrections have to be made.

The disturbing field generated by the connector depends on the distance between the connector and the point where it is calculated, the connector dimensions (as the connector gets larger, ΔH increases) and the magnetic susceptibility χ of the material of the connector.

In practice, under a $H_{\rm ext}$ external magnetic field, the material will get a magnetization equal to approximately

$$M=\chi H_{ext}$$

The weaker the magnetic susceptibility, the closer to 1 the relative permittivity μ_r of the material is, the more the material is transparent and the less it affects the magnetic field. So, as diamagnetic (brass, gold, silver, etc.) and paramagnetic (aluminum, palladium, etc.) materials have a magnetic susceptibility of around -10⁻² to -10⁻⁹, connectors made of such materials will be transparent relative to the external magnetic field. Conversely, the greater the magnetic susceptibility the more magnetic is the material. Superparamagnetic and ferromagnetic (steel, nickel, etc.) materials fall into this category and connectors made from them will distort the flux lines of the magnetic field.

Hence, Radiall non-magnetic RF coaxial connectors are manufactured from materials specially adapted to non-magnetism — with relative permittivity close to 1 and each raw material rod being selected on a direct measurement with a vibrating magnetometer. Center contacts are gold plated over a copper underlayer and bodies are plated with BBR, a diamagnetic alloy of copper-tin-zinc or with GBR, a diamagnetic alloy of copper-tin-zinc with a thin layer of gold. Their manufacture utilizes a special production process carried out in an environment where tools are specifically allocated







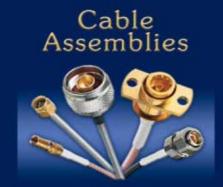








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and where all precautions are taken to avoid any contact with ferromagnetic materials during the machining and cleaning process.

A comparison of the relative distortion of different materials is shown in Table 1. The $\Delta H/H_{ext}$ relative distortion of a magnetic field of 1.5 T, generated by a Radiall non-magnetic connector, is only 5 10-7 maximum, at a distance of 10 mm from the surface of the connector. Moreover, these connectors meet the electrical and mechanical characteristics required for any reliable coaxial connector and also specific requirements of the medical environment such as durability. This technology is applicable for almost all of the company's coaxial connectors, and SMB, MMCX and SMA connectors are currently available.

SPACE APPLICATIONS

The medical market is not the only one to use non-magnetic RF coaxial connectors. They are also used in the space industry, mainly for satellites involved in scientific missions. Here, the compliance with ESA/SCC specification is a priority. Radiall has a range of SMA products, fully ESA qualified that meet the residual magnetism required by the ESCC 3402 generic specification and the ESCC 3402/001-002 & 003 detailed specifications. These connectors are made from beryllium copper, gold plated and copper underplated.

CONCLUSION

When incorporated in MRI equipment, Radiall non-magnetic RF coaxial connectors provide the electromagnetic immunity necessary to ensure that vital patient readings are not affected by outside magnetic distortions. To guarantee an exceptional level of non-magnetism and repeatability, each nonmagnetic connector is manufactured via a strictly controlled production process and in accordance with the company's quality assurance procedure.

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SMA AND QMA TWO-PIECE CONNECTORS FOR USE ON LOW LOSS COAXIAL CABLE

imes Microwave Systems has expanded the range of "EZ" style, two-piece coax connectors for its popular LMR240 low loss coax cable. It has also released a series of attachment tools to make field attachment of connectors on LMR-240 cable easy and

Fig. 1 The new EZ style two-reliable. piece SMA connectors.





Fig. 2 The EZ style QMA connectors.

LMR-240 is a 0.240" diameter, low loss coax that is ideal for system interconnects, short antenna feeders and other RF interconnect applications. The combination of a foam polyethylene (PE) dielectric and tape/braid outer conductor results in very low loss and very good flexibility, making this cable a candidate to replace stiffer cables such as 0.250" corrugated copper cables and cables that although larger have comparable loss, including RG-213 and RG-214.

Added to the already popular Type N and TNC is a new SMA straight plug, SMA right angle, QMA straight plug and

QMA right angle, as shown in *Figures 1* and **2**, respectively. The QMA series of coax connectors is the new snap-on version of an SMA interface. It is gaining popularity with OEMs for use on indoor interconnects where frequencies are below 6 GHz. In the spring of 2005 the company will announce the availability of an EZ style SMA bulkhead jack for LMR-240.

EZ connectors eliminate the need for soldering and are preferred because they exhibit a positive "snap," signaling that a solid connection to the cable center conductor has been achieved. A rugged beryllium copper spring finger design on the connector center contact allows the connector to be removed if necessary and re-installed. The outer conductor is attached with a crimp ferrule supplied with each connector along with strain relief tubing and instructions. The two-piece EZ design simplifies the parts count, eliminates material waste and reduces labor. Times also offers several models of crimping tools. The CT-240/200/ 195/100 results in fast, consistent

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Fig. 3 The DBT-02 deburring tool for LMR cables.

crimps when used with Times connectors and cable sizes from LMR-100 through LMR-240.

The DBT-02 debur tool, shown in *Figure 3*, is designed to make fast, accurate work of pointing the center conductor on LMR240. It also works with many of the smaller size LMR cables. The DBT-02 is small enough for a key chain yet the cutting edge is case-hardened carbon steel for a long service life. It can be used by hand or in a drill or screwdriver chuck. The design facilitates the removal of any chips after use.

Also available is the new ST-240EZ prep/strip tool for use with LMR-240



Fig. 4 The ST-240EZ prep/strip tool for use with LMR-240 cable.

cable. The lightweight, ergonomically designed ST-240EZ, shown in *Figure 4*, eliminates the need to measure and cut each layer of cable or use different tools to prep a cable for termination. Outfitted with case-hardened carbon steel blades for long life, the ST-240EZ tool makes a clean, sharp, 90° cut. It prepares the cable to the exact strip dimensions in one easy step, reducing labor and increasing both accuracy and consistency.

Times LMR-240 is the original foam polyethylene dielectric, 0.240" diameter low loss coax. LMR-240 standard has a UV resistant PE jacket for a 20-year outdoor life. Its size, su-

perior RF performance characteristics, ease of use and competitive price make it an attractive and popular alternative to solid Teflon, or solid PE cables of a similar (or in some instances) smaller diameter. Its high flexibility makes it a perfect alternative to corrugated cable without sacrificing low insertion loss. LMR-240 is available in "db" (direct burial), "FR" (fire retardant), "FR-PVC" (riser rated) and other configurations. When used in conjunction with Times connectors, LMR cable assemblies routinely and consistently exhibit lower attenuation and VSWR through 6 GHz as compared to other brands.

With the complete system of LMR-240 cable, EZ connectors and the cable prep tools, assemblies can now be fabricated in the field with high reliability and excellent performance previously achievable only in factory made assemblies.

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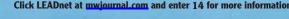




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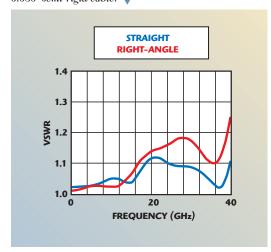






SMP MICROMINIATURE HIGH FREQUENCY CONNECTORS

Fig. 1 VSWR performance for a straight and right-angle female SMP connector soldered to 0.086" semi-rigid cable.



ith today's emphasis on small size and light weight, the coaxial RF connector is rapidly becoming one of the larger components in a modern electronic system. To help counter that trend, AEP has introduced a new microminiature SMP connector series that combines high performance and high frequency capability with small size, and adds blind mating to the mix as

well. Three detent configurations in the mating end provide a range of mating and retention forces to match specific applications.

Both the straight and the right-angle SMP connectors have gone through an extensive design phase to optimize electrical performance. Currently there are designs for both 0.047" and 0.086" semi-rigid cable. The

frequency range for this new series of connectors is DC to 40 GHz, and the cable connectors include an integrated EMI/anti-rock ring to reduce RF leakage and maintain mating alignment. The 0.086" straight female design exhibits very little insertion loss and a VSWR of better than 1.20 to 40 GHz. The right-angle version exhibits slightly more loss than the straight connectors and the 0.086" version currently has a typical VSWR of better than 1.20 to 36 GHz. Figure 1 shows typical performance vs. frequency for a straight female SMP connector direct soldered to 0.086" semi-rigid cable and a right-angle female (soldered center contact) direct soldered to similar 0.086" cable.

AEP right-angle connectors have stayed with the proven bifurcated slot on the connector center contact. This slot allows for the cable center wire to be soldered to the contact

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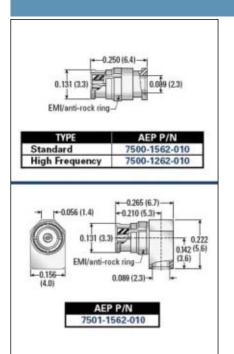
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▲ Fig. 2 SMP straight (top) and right-angle (bottom) female cable connectors for 0.086" semi-rigid cable.

providing lower contact resistance, a stronger joint during vibration and a longer service life by eliminating corrosion.

SMP body components are stainless steel or beryllium copper to ensure rugged performance and a service life of over 1000 mating cycles (dependent on the mating type) with no degradation of performance. The body finish is either gold plated or passivated, center contacts are gold plated and the insulators are PTFE for consistent electrical performance through a wide temperature range.

Current configurations include straight and right-angle cable connectors, panel shrouds for use with hermetic seals, several lengths of female-to-female "bullet" adapters and panel-mounted cable connectors (including snap-in types). *Figure 2* shows mechanical outlines for both the straight and right-angle female cable connectors for 0.086" semi-rigid cable.

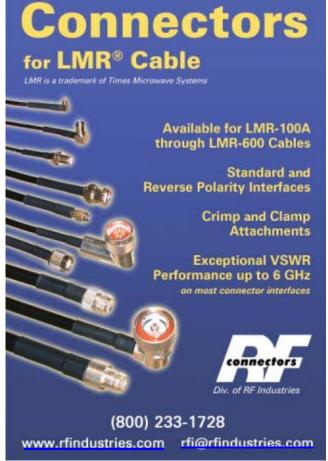
One of the advantages of these connectors is in blind-mate applications with multiple connector pairs. SMP connectors allow for as much as 0.010" radial and 0.010" axial misalignment of mating connectors without damage when engaging. An optional "Catcher's Mitt" configuration can extend the radial misalignment tolerance to 0.020".

A new eight-page SMP brochure is available from AEP that lists specifications, application notes and assembly tooling. The brochure, along with pricing and availability information, can be downloaded from the company's Web site.

Applied Engineering Products (AEP), New Haven, CT (203) 776-2813, www.aep.us.

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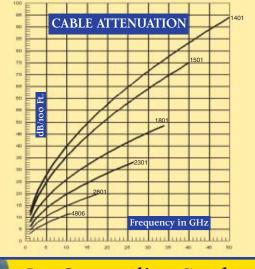




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recision test cable assemblies that provide low loss and high performance at 110 GHz are hard to come by. Now add the requirement for true flexibility and they become even more difficult to obtain. Gore, a producer of precision microwave cable and cable assemblies, has now introduced the GORETM PHASEFLEX® 110 GHz Test Assemblies, the newest addition to its PHASE-FLEX Microwave Test Assemblies product

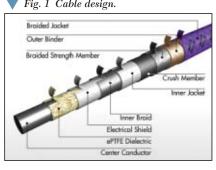
family. These new test cable assemblies feature torque and crush resistance, as well as stability with flexure and temperature, while operating at relatively low loss up to 110 GHz.

The GORE PHASEFLEX 110 GHz Test Assemblies provide excellent phase and amplitude stability with flexure over a wide range of temperature. At 110 GHz, a 16-cm long PHASEFLEX assembly bent 90° around a 1" diameter mandrel has a change in phase of 4.3° and a change in amplitude of 0.05 dB (typical). When the assembly is returned to its original configuration, its phase and amplitude return to their original values. This type of performance assures accurate and repeatable measurements are achieved without the need to repeat time-consuming calibrations between measurements.

Figure 1 shows a cross-sectional diagram of the cable's construction. In addition to being flexible, the cables exhibit virtually no springback, thus allowing for easy test setup and minimizing stresses on the device under test, probe tips and adapters caused by cable tension. The cable assemblies can be flexed, reformed or repositioned repeatedly without fear of damage or performance degradation.

W.L. Gore & Associates Inc. Elkton, MD

🔻 Fig. 1-Cable design.



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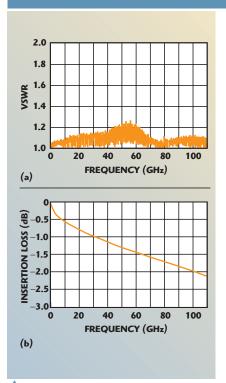


Fig. 2 Typical VSWR (a) and insertion loss (b) for a 16 cm assembly.

The cable's internal construction provides for a very rugged assembly that makes it crush resistant, while still maintaining a small outer diameter of 0.167" nominal. Even with this small size, the assemblies are still low loss. Typical insertion loss for a 16 cm assembly at 110 GHz is 2.1 dB. *Figure 2* shows typical VSWR and insertion loss performance.

The cable assemblies' specifications include a characteristic impedance of 50 Ω , a frequency range of DC to 110 GHz, a nominal cable outer diameter of 0.167" (4.2 mm) and an operating temperature of −55° to +125°C. Coupling torque is 4 ±0.5 in-lb and the assembly can experience 500 minimum mating cycles without degradation. The connectors are passivated stainless steel 303, with gold-plated BeCu center conductors and Ultem™ dielectric beads. If a connector is damaged it can typically be repaired for less than the price of a new cable assembly.

GORE PHASEFLEX 110 GHz Test Assemblies are available at varying lengths to suit specific applications and can be configured with 1 mm pin and/or socket connectors. Ordering information and additional details can be obtained by phone or on the company's Web site.

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