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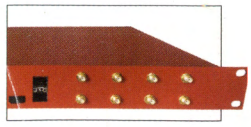

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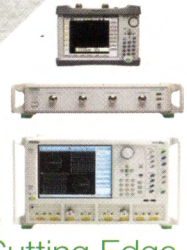

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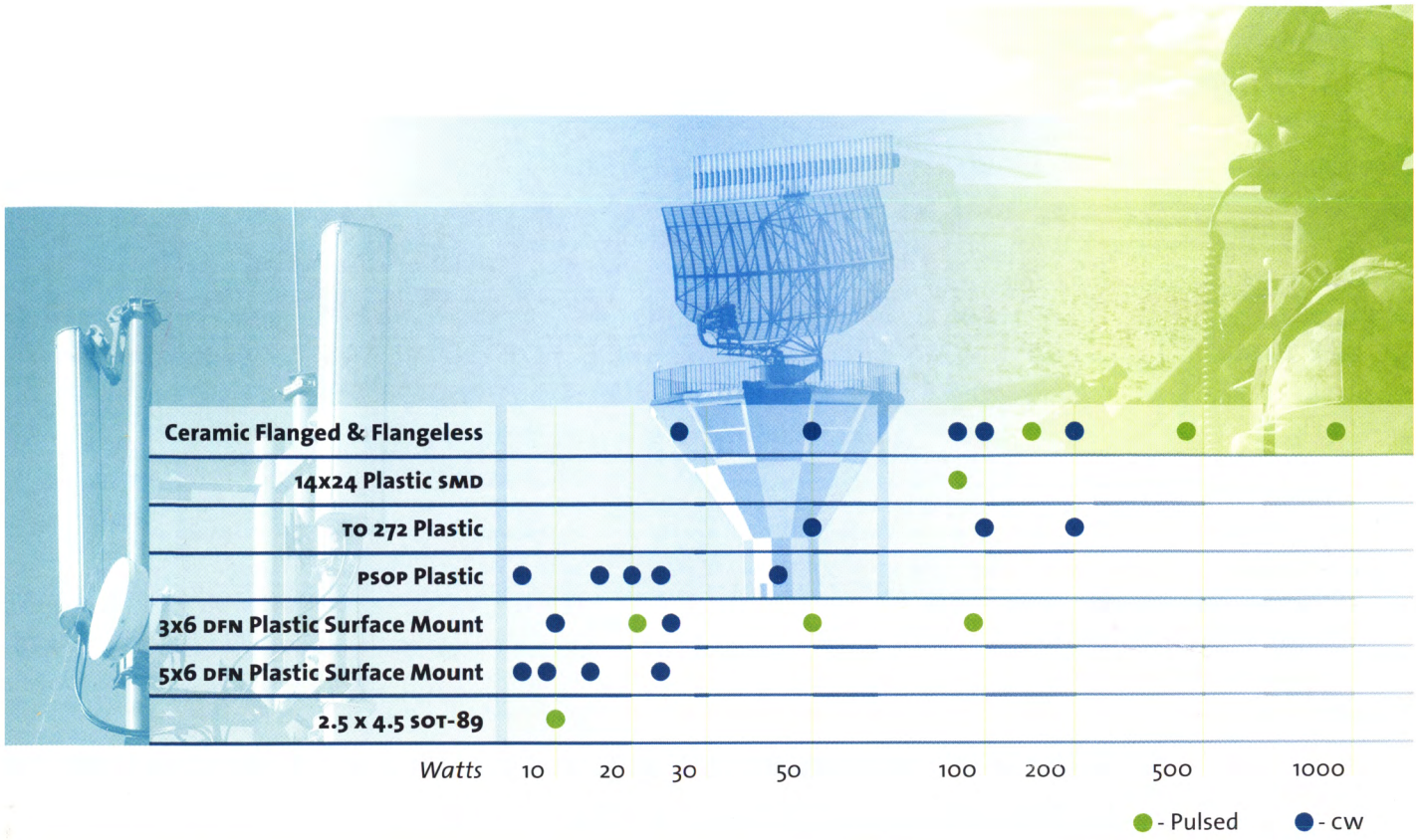

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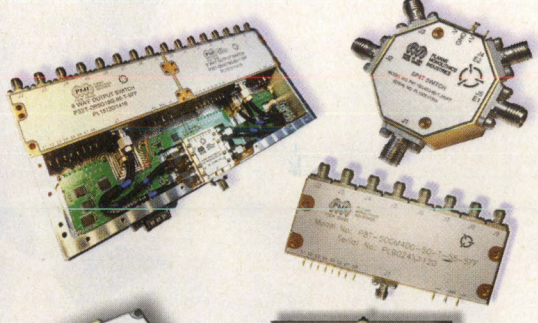
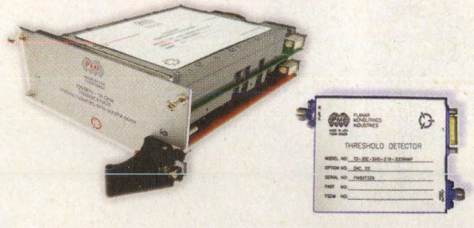
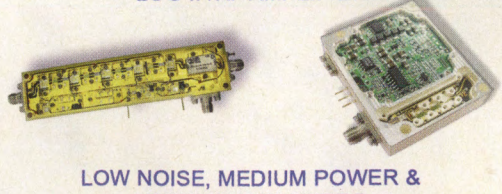


RECEIVER FRONT ENDS, TRANSCIEVERS SYNTHESIZERS, DTOs, DROs, IFMs & THRESHOLD DETECTORS



SDLVAS, DLVAS, ERDLVAS & LOG IF/RF AMPLIFIERS



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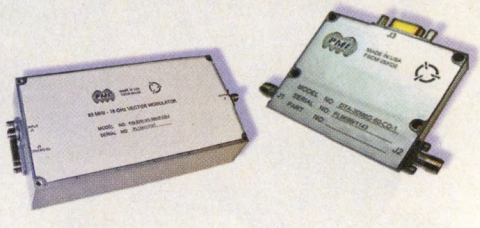
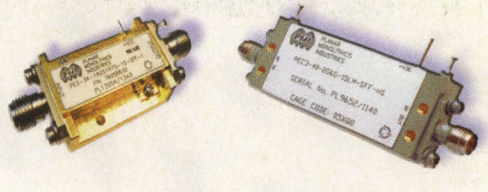


LOW NOISE, MEDIUM POWER & LIMITING AMPLIFIERS



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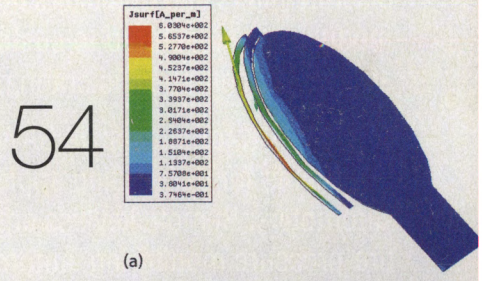

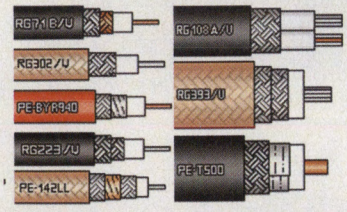

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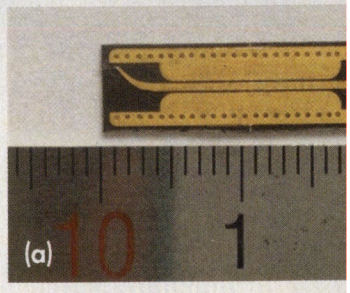

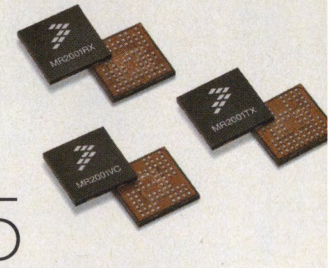

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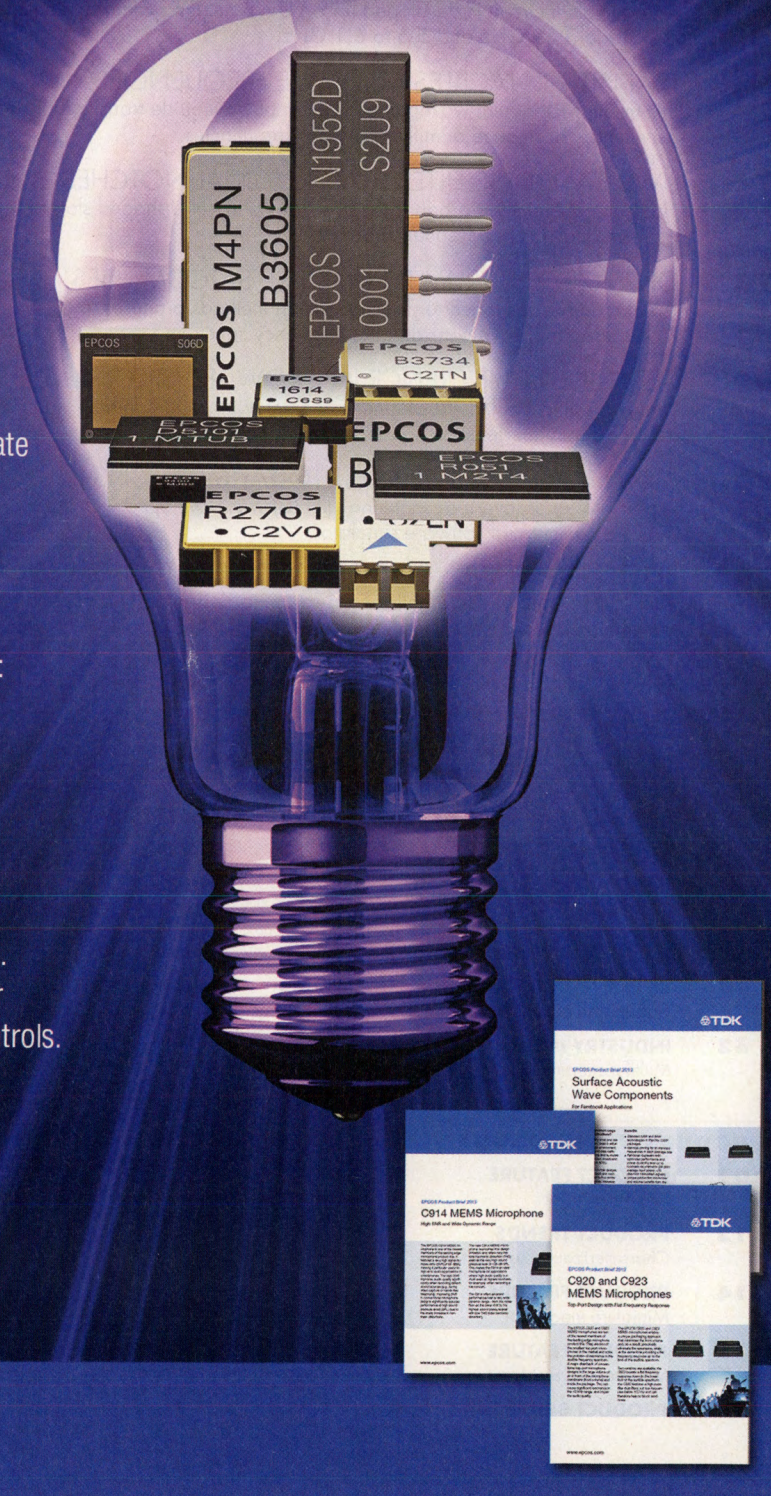

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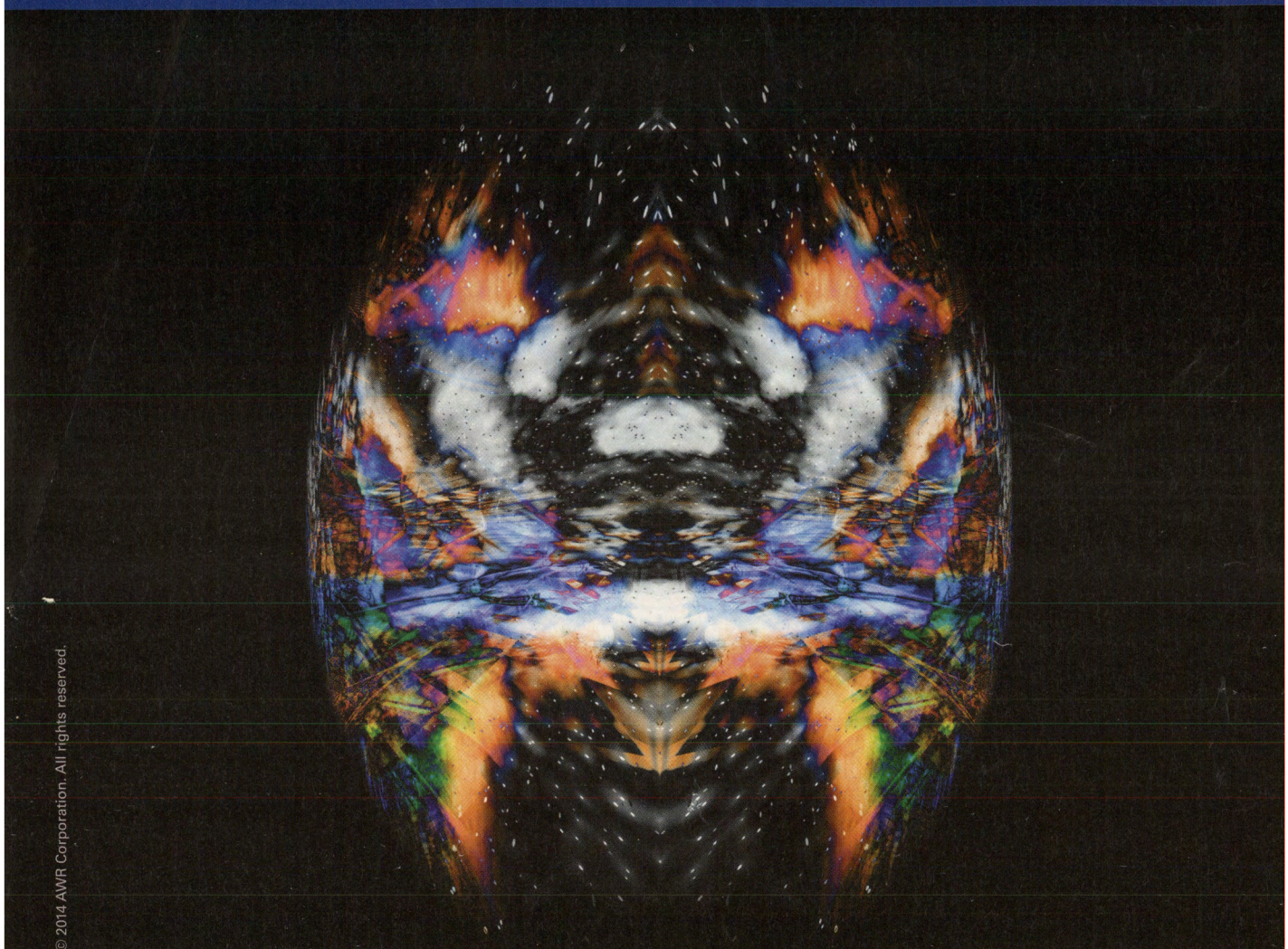

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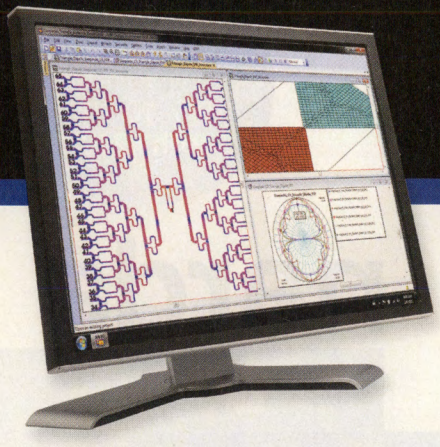

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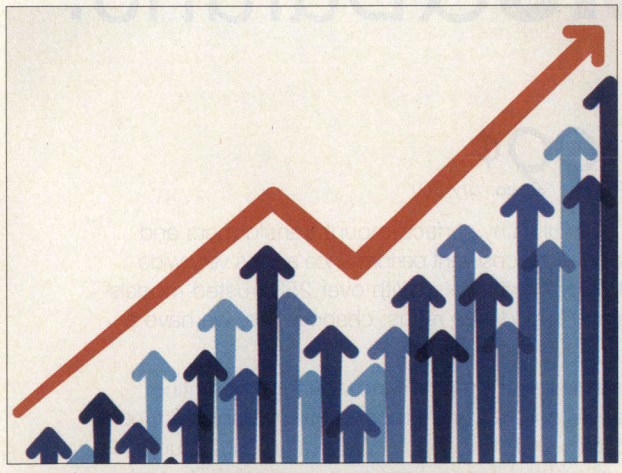
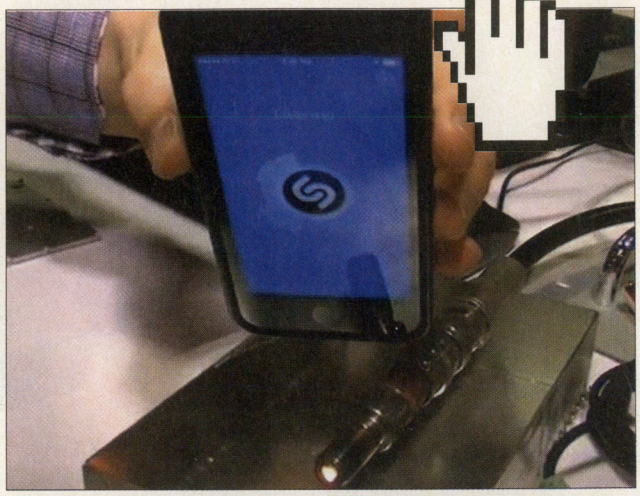
WILL SMART WEARABLES SURVIVE?

The acquisition rate of wearable devices continues to rise—but one-third of these new owners abandon their devices within six months of purchase, according to a new study. It's a struggle for companies to deliver products that provide a sustained benefit to the mass market, and today's devices are generally considered just convenient rather than being genuinely useful.



SMALL-CELL MARKET, BIG GROWTH

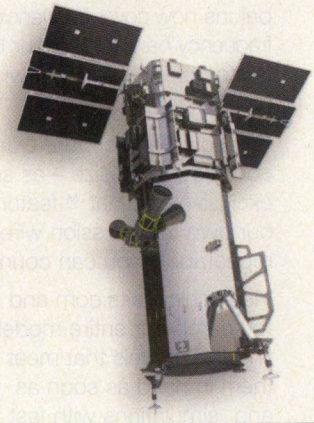
The small-cell and low-power base-station market is enjoying a surge of growth, as exemplified by the deployment of 200,000 small cells in Asia last year alone. Currently, the total revenue for small base stations is $1.1 billion. According to Mobile Experts' market study, Small Cells and Low Power Base Stations, the market will be worth $10 billion by 2018, which translates into a compound annual growth rate (CAGR) of 36%.



VIDEO: PLAY MUSIC ON AN RF PLASMA SPARK PLUG

This automotive RF plasma spark plug from NXP was set up to play music by modulating the output power with the audio signal—Technical Engineering Editor Jean-Jacques DeLisle played "Pompeii" by Bastille as a demonstration, and put the audio to the test using the Shazam music recognition app.

WORLDVIEW-3 TAKES OFF



The WorldView-3 satellite successfully launched aboard an Atlas V 401 on Aug. 13, 2014. It marked the 118th consecutive successful Atlas launch to date. The next satellite in the system, WorldView-4, is expected to launch in 2016.

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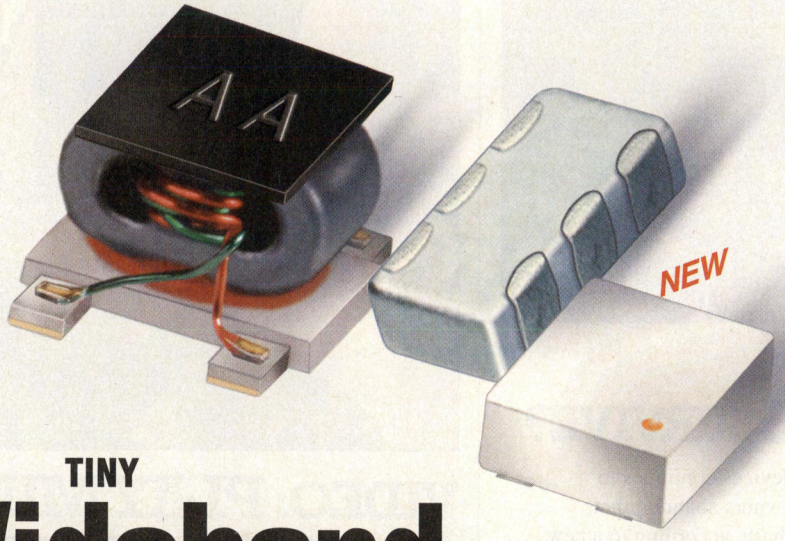

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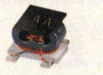

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Editorial

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Content Director
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Technology Gives Back

Last month marked the 100th anniversary of the outbreak of World War I. Thanks to advances in surgery, that war saw more injured soldiers return home than any previous conflict. To help these men regain their mobility and potentially return to work in some capacity, research and development was quickly devoted to prosthetics. According to Thomas Schlich, author of "The 'bionic men' of World War I" (www.cnn.com), "Virtually every device produced today to replace lost body function of soldiers returning from our modern wars—as well as accident victims, or victims of criminal acts, such as the Boston Marathon bombings—has its roots in the technological advances that emerged from World War I."

Given the advances in computing, manufacturing, materials, networking, and more since World War I, such a statement is very surprising. Yet it makes sense in that the goal of prosthetics has always been to replace a body part with one that at least partially restores function and/or appearance. With today's technical advances, of course, prosthetic development is moving toward serving as a complete replacement or even an improved enhancement. It is this rapid evolution—combined with the need to help so many returning soldiers—that inspired us to delve into the engineering achievements behind today's cutting-edge prosthetics.

As Penton's Design Engineering & Sourcing Group, our staff of technical experts has researched and covered this topic from a variety of specialized engineering disciplines. The results can be seen in articles, interviews, image galleries, and other multimedia efforts on the *Microwaves & RF*, *Machine Design*, *Hydraulics & Pneumatics*, and *Electronic Design* sites. In each special section, the editors pinpointed and detailed the leading edge in prosthetics development—whether that edge was in wireless networking, sensors, multiprocessing, motors and motor control, or fluid power and hydraulics.

As exciting as these developments are technically, we were especially proud to cover them because you, our engineering audience, have had so much impact on the lives of our returning soldiers. With two wars abroad, many of our men and women are coming home physically injured and with intense mental trauma. If technology can help them restore some of their physical capabilities, the hope is that they may be put on a road to greater healing.

The Design Engineering & Sourcing Group would like to thank all of the researchers, designers, investors, and others that make these latest prosthetic advances possible. In addition to healing our heroes, you are heroes yourselves, given the recovery that you're enabling. Please join me also in thanking our team for their work on this very special project: Bill Wong and Don Tuite, Ken Korane, Stephen Mraz, and Jean-Jacques DeLisle. Don't forget to visit our "Healing Heroes" hub on our websites to see the cross-brand and multimedia coverage of this topic. MW

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0.5 - 12 GHz
New
25 WATT CW





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Typical Performance @ + 25 Deg. C

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LS0520P25A	0.5 – 2.0	0.6	1.4:1	+20
LS0540P25A	0.5 – 4.0	0.7	1.4:1	+20
LS0560P25A	0.5 – 6.0	1.3	1.5:1	+20
LS05012P25A	0.5 – 12.0	1.7	1.6:1	+20
LS1020P25A	1.0 – 2.0	0.6	1.4:1	+20
LS1060P25A	1.0 – 6.0	1.2	1.5:1	+20
LS1012P25A	1.0 – 12.0	1.6	1.6:1	+20
LS2040P25A	2.0 – 4.0	0.7	1.4:1	+20
LS2060P25A	2.0 – 6.0	1.2	1.5:1	+20
LS2080P25A	2.0 – 8.0	1.3	1.6:1	+20
LS4080P25A	4.0 – 8.0	1.3	1.5:1	+18
LS7012P25A	7.0 – 12.0	1.6	1.6:1	+18

Note: 1. Insertion Loss and VSWR tested at -10 dBm.
Note: 2. Typical limiting threshold: +6 dBm.
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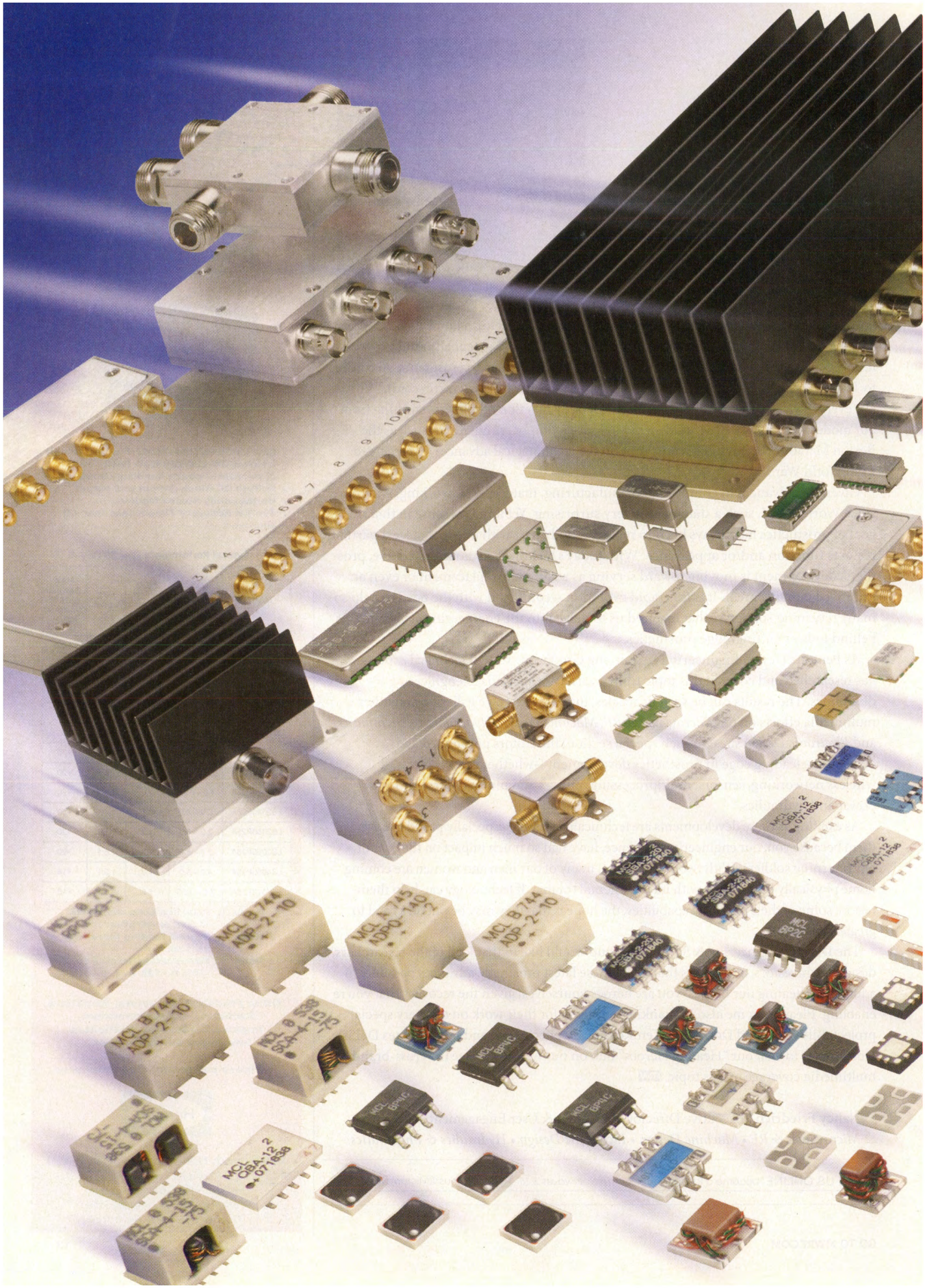

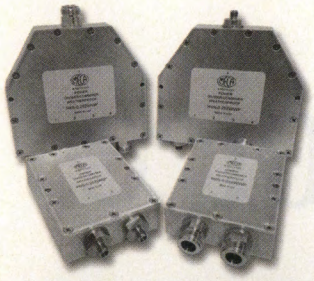

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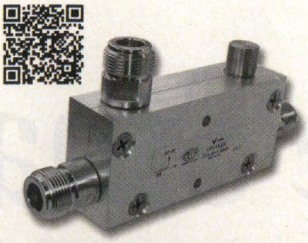
Low PIM Loads
MECA's Low PIM (-165 dBc Typ) loads for DAS Applications feature industry leading PIM performance of -160 dBc Min all while handling full rated power to 85°C. All terminations cover the 0.698 – 2.700 GHz frequency bands in 7/16 DIN or Type N connectors as 30, 50, 100 & 150 watt rated. Ideal for IDAS / ODAS, In-Building, base station, wireless infrastructure, 4G and AWS applications.





Low PIM Couplers
MECA's Low PIM (-160 dBc Typ) Directional Couplers for DAS Applications feature unique air-line construction that provides for the lowest possible insertion loss, high directivity and VSWR across the 0.698-2.700 GHz bands. Rated for 500 watts average power. Nominal coupling values of 15, 20, 30 & 40 dB.

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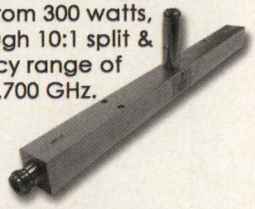

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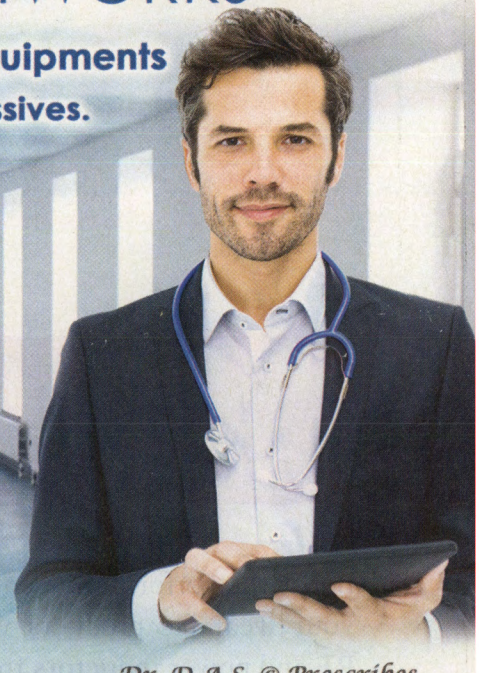

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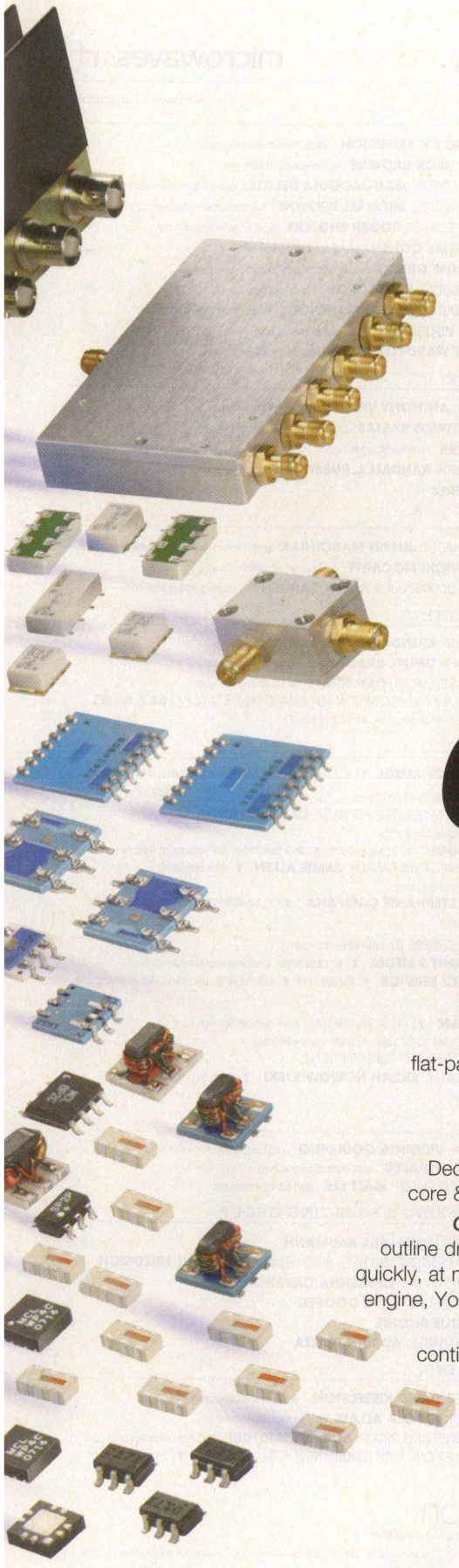

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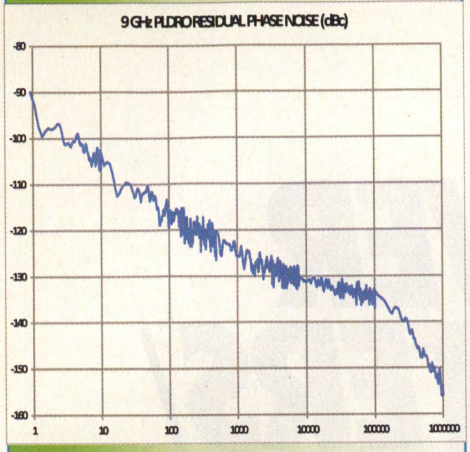

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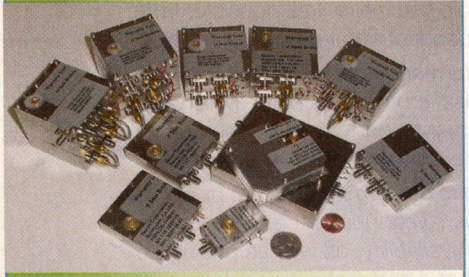

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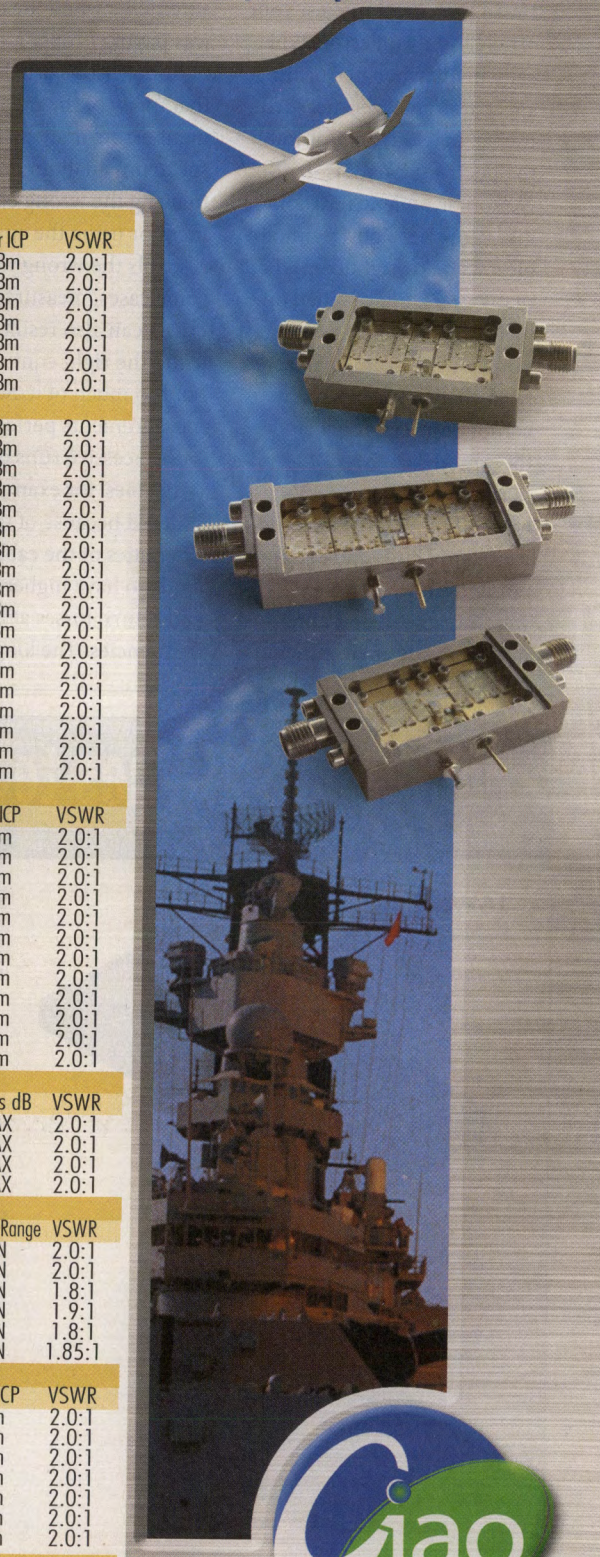

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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KEEPING COUNT OF ANALYZER ERRORS

I read with great interest your article in July on errors typically made when performing spectrum-analyzer measurements, in "8 Errors Common to Spectrum Analysis" by Bob Nelson of Agilent Technologies (now Keysight Technologies; www.keysight.com). For many years, I have relied on measurements made with portable spectrum analyzers from that company's main competitor, Tektronix, and their models 492 and 494 portable spectrum analyzers. Although these analyzers were fairly large and certainly not light in weight, they were capable of operating in almost any environment. They provided reliable and accurate RF/microwave measurements when the operator was paying proper attention.

Bob Nelson's article notes that many of the measurement errors made with a spectrum analyzer are due to using the wrong equipment or using the analyzer's controls the wrong way. In some cases, measurement errors can also result from using the right equipment, but too much of it. Some measurements performed with excessive runs of coaxial test cables, for example, have suffered because of the characteristics of the cable, which tends to have higher insertion and return losses at higher frequencies. The long run of cable (which was about 3× the length required for the measurements being made) exhibited excessive loss for the measurements being made, especially at the higher frequencies within a 2-to-18-GHz range.

The article offered a concise summary of some common problems, such as too much input power and the effects of signal distortion products. But sometimes it is just simple reasons, such as long runs of cable or improperly torqued test cables, which can also throw off the accuracy of a spectrum-analyzer measurement. Much of the accuracy and repeatability will come from common sense and experience, and even spending time with the owner's manual, most of which do an excellent job of guiding both inexperienced and experienced users to achieving optimum test results with their spectrum analyzers.

LARRY COLEMAN

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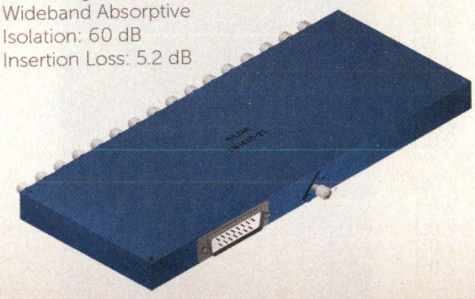

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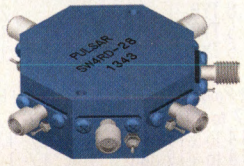
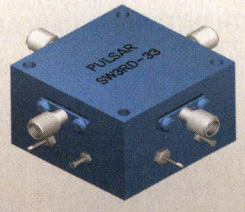
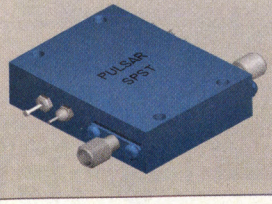


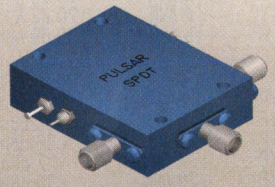
SP3T Broadband, 0.3-18 GHz
Reflective
Isolation: 60 dB
Insertion Loss: 3 dB

SPDT 0.3-18 GHz Switch
Absorptive
Isolation: 50 dB
Insertion Loss: 3.5 dB



SPST 0.3-18 GHz Switch
Absorptive
Isolation: 60 dB
Insertion Loss: 2.5 dB





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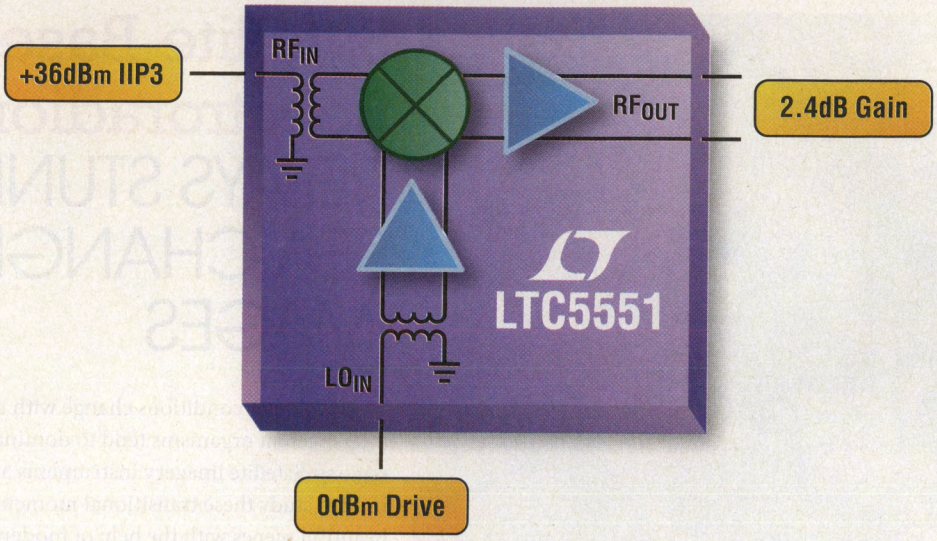

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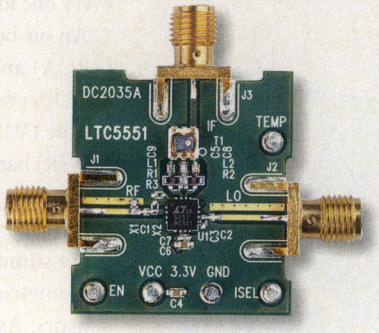
Product Features

- 300MHz to 3.5GHz Frequency Range
- +36dBm IIP3
- 2.4dB Conversion Gain
- 9.7dB NF
- 0dBm LO Drive
- Low Power: 670mW

LTC5551 Demo Board



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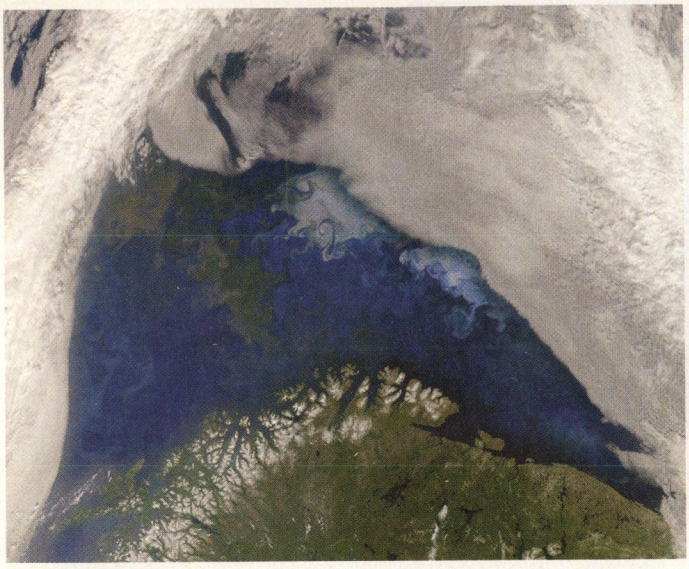
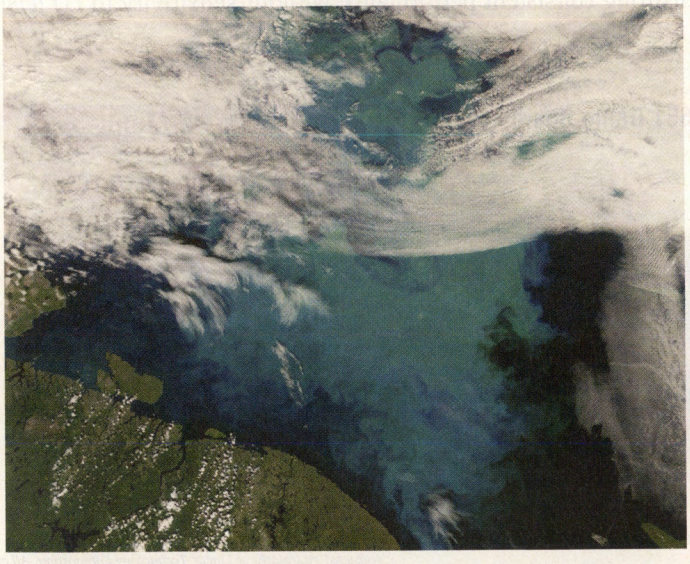
LINEAR TECHNOLOGY

News



On July 10, 2014, a MODIS aboard the Aqua satellite captured the first natural-color image of phytoplankton blooming in the water. Although it is impossible to know the specific type of phytoplankton (note the green and blue-white swirls in the water) without sampling the water, analysis of previous images suggest that they are diatoms (green) and coccolithophores (blue-white). (Images courtesy of NASA)



Three weeks later, on August 3, 2014, Terra satellite's MODIS acquired this image above the Barents Sea. It appears that the coccolithophores have "taken over" the surface waters.

Satellite-Based Spectroradiometer RELAYS STUNNING SEA-CHANGING IMAGES

As water conditions change with the seasons, different organisms tend to dominate particular regions. Satellite imagery instruments are now being used to study these transitional moments, capturing the beautiful scenes with the help of moderate resolution imaging spectroradiometers (MODIS). The instruments, built into NASA's Aqua and Terra satellites, recently captured microscopic, plant-like organisms, known as phytoplankton, blooming in the waters off of Norway and Russia.

MODIS captures images using the 1000-m, 500-m, and 250-m resolution spectral bands with 12-bit radiometric sensitivity. Spectral bands ranging from 0.4 to 14.4 μm are custom-tailored to handle low out-of-band responses. Each scan undergoes infrared (IR) calibration to reduce 1/f noise and boost accuracy. A ±55-degree scanning pattern achieves a 2330-km swatch, providing global coverage every one to two days.

An on-board spectroradiometric calibration assembly (SRCA) and full-aperture blackbody (BB) help foster MODIS precision functionality. The SRCA monitors the visible (VIS), near IR (NIR), and short-wave infrared (SWIR) bands on the MODIS. It can also generate band-to-band registration information while in orbit for all 36 spectral bands. Using a variety of optics and mechanisms, input stimuli can be modified in three modes—spectral, radiometric, and spatial—without interfering with other sensors. As a result, the SRCA can generate calibration information while the MODIS simultaneously collects and records spectral data, allowing for longer stretches of continual data.

Continued on p. 26

EXPANDED COVERAGE WILL DRIVE CONNECTED-CAR MARKET



WITH 48% OF passenger cars worldwide expected to have embedded connectivity by 2024, it seems the connected-car industry is about to take off. Statistics compiled by Analysys Mason for its new "Connected cars: worldwide trends, forecasts and strategies 2014-2024" report, help support this claim. However, mobile network operators (MNOs), a main focus of the report, must seamlessly deliver connectivity, value-added services, and dependable road coverage in order to advance the market.

Today's nearly all-electronic cars come fitted with various computer components and LTE connectivity for navigation, multimedia, and diagnostics. An embedded, networked connection, though, would foster compliance with emerging entertainment apps, such as Apple CarPlay. Such a network must support machine-to-machine (M2M) communications and all multimedia forms, all the while providing uninterrupted service. To that end, deals between vehicle manufacturers (VMs) and MNOs reportedly will bring connected-car models to market by 2015.

The report advises MNOs eyeing the connected-car market to broaden their "connected lifestyle" credentials. Beyond offering additional services, MNOs must strengthen automotive connectivity support—namely, avoid interference and bad coverage along roads. Mobile data growth is in the cards, though, if MNOs can provide, say, cloud-based services and automotive multi-device shared-data plans.

By the end of 2014, approximately 20 million cars will feature embedded connections. Forecasts show that number will balloon to 654 million (a compound annual growth rate, CAGR, of 36%) by 2024—with 89% of new cars sold integrating embedded connectivity. Mobile tethered devices, which enable drivers to access smartphone applications, should also see a major market upswing. Devices with tethering-enabled cards are expected to rise from 4 million to 654 million between 2014 and 2024, a CAGR of 65%.

Analysys Mason's report also homes in on the aftermarket, specifically the manufacturing, distribution, retailing, and installation of vehicle parts post-sale from original equipment manufacturer (OEM) to consumer. Usage-based insurance (UBI) and commercial vehicle fleet tracking will account for 191 million connections worldwide by 2024, opening up a good opportunity for MNOs to serve the aftermarket. However, the opportunity is limited—the market will likely flatten in and around 2018 and come to a halt in 2021, being replaced by embedded-connectivity solutions.

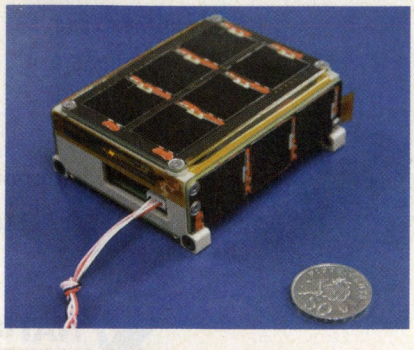
So what's the plan of attack for MNOs? Foremost, mobile-network planning must evolve to deliver a more enriched, seamless experience. Value-added services (e.g., cloud-based media content) will help operators move up the value chain. Also, regardless of whether or not MNOs have partnered with VMs, integrating smartphones into vehicles will increase the volume of mobile data traffic. Embedded connectivity's success will ultimately be driven by new-car sales, buttressed by strong M2M module form factors and progress in SIM-card technology.

What isn't clear right now concerns the price consumers will pay for connected-car services. When surveyed, only 22% of consumers said they would pay extra for connected-car services. This could create added issues in terms of demand, considering semi-autonomous vehicles will be rather commonplace by 2024. ■

ZIGBEE CONQUERS SPACE-BASED Satcom Tests

AS RESEARCHERS WORK to build lighter, more powerful satellites, communications payloads must adapt to the new surroundings, which means finding a compliant infrastructure. Engineers at the Satellite Research Centre of Nanyang Technological University in Singapore recently turned to ZigBee, typically only used for land-based wireless systems, as an alternative for satellite communications (satcom). In an experiment, the team recently launched VELOX-I, which consisted of a nanosatellite and piggyback picosatellite. Both satellites were configured with a ZigBee wireless sensor network (WSN).

Onboard sensor-node functionality, including local sensing, distributed computing, and data-gathering, support intra-satcom. The miniature satellites—weighing 3.5 kg (nanosatellite) and 1.5 kg (picosatellite)—were able



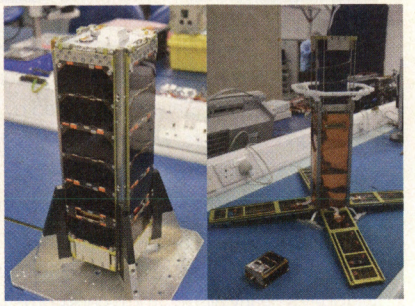
The picosatellite aboard VELOX-I only weighs 1.5 kg. (All images courtesy of World Scientific: Unmanned Systems)

to maintain inter-SATCOM with each other over long distances.

Having previously tested the satellites' range in the laboratory, the team this time applied a link budget analysis based on the Friis transmission equation, to test the range in free space. An average theoretical distance of 4.186 km and a maximum of 15.552 km were derived.

WSNs also proved proficient for intra-satellite communications. The team found that replacing internally wired connections with wireless links could reduce a satellite's mass by up to 10%. Overall, by essentially eliminating the communications cabling in typical satellites and minimizing development costs and risks, WSNs could lead to a new platform for formation-flying satellite missions.

All findings were published in a special issue of *World Scientific's Unmanned Systems*. ■



VELOX-I before (left) and after (right) launch.

SINGLE LASER SOURCE
Transmits Data at 43 Tbits/s Via Multicore Fiber

THE LATEST INTERNET technologies require ever-more bandwidth at the highest speeds, but it shouldn't come at the expense of greater power consumption. According to DTU Fotonik, the Technical University of Denmark, emissions linked to the total energy consumption of the Internet corresponds to more than 2% of global man-made carbon emissions—putting it on a par with the transport industry.

To that end, the High-Speed Optical Communications (HSOC) team at DTU tested a new fiber-optic technology that meets those bandwidth and power-consumption goals. By transmitting at 43 Tbits/s using a single laser source, the team broke the 26-Tbit/s record set by researchers at Karlsruhe Institut für Technologie.

The new optical fiber, borrowed from NTT, expands from the typical one core (glass thread) to seven cores. A central core transmitted a synchronization signal

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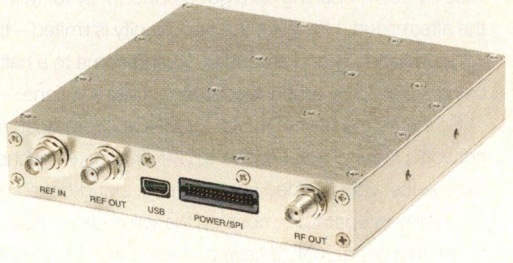

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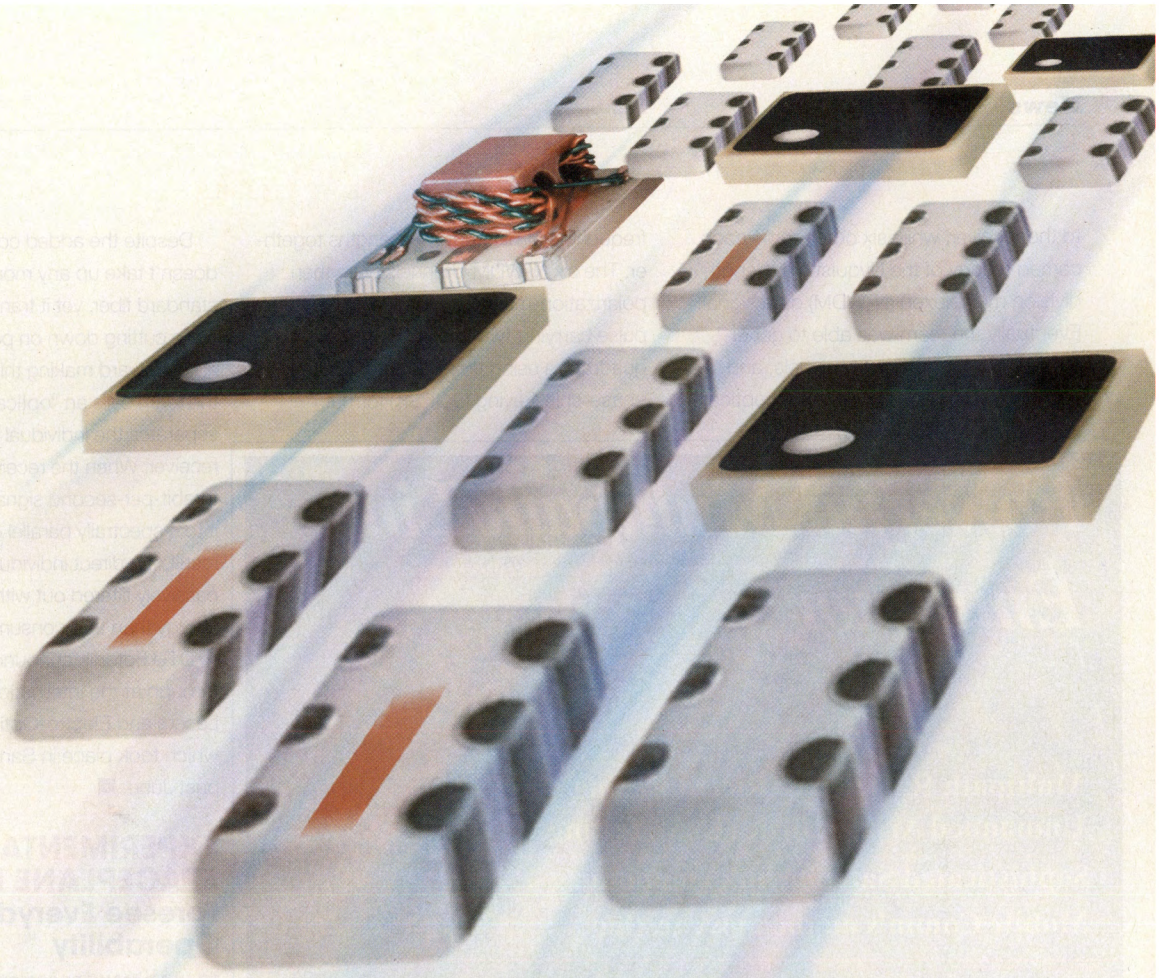

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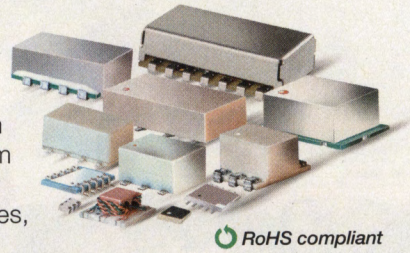

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to the receiver, while six outer cores each carried a copy of the Nyquist wavelength division multiplexed (N-WDM) data signal. Eventually the team was able to generate 320-Gbaud Nyquist channels, and multiplexed six of the channels (in optical frequency) at different wavelengths together. The six N-WDM channels were then polarization-multiplexed, with each optical pulse carrying two bits of information in quadrature using the differential quaternary phase-shift-keying (DQPSK) format.

Despite the added cores, the new fiber doesn't take up any more space than a standard fiber, yet it transfers more data while cutting down on power consumption. A key toward making this possible is what the team calls an "optical time lens," which separates the individual data channels in the receiver. When the receiver gets the Nyquist terabit-per-second signal, the lens converts it to a spectrally parallel data signal. As a result, the direct individual channels can be passively filtered out without using more energy than that consumed by the lens.

DTU Fotonik announced the breakthrough at the international Conference on Lasers and Electro-Optics (CLEO 2014), which took place in San Jose, Calif., this past June. ■



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TO HELP MAKE space operations more routine, responsive, and affordable, the U.S. Defense Advanced Research Projects Agency (DARPA) created the Experimental Spaceplane (XS-1) program. The program serves to develop a fully reusable unmanned vehicle that would bring aircraft-like access to space. When completed, the plane would deploy small satellites into orbit via expendable upper stages. DARPA recently awarded prime contracts for phase one of the program to Boeing (working with Blue Origin), Masten Space Systems (working with XCOR Aerospace), and Northrop Grumman (working with Virgin Galactic).

Phase one includes development of the XS-1 demonstration vehicle; identification and conducting of critical risk reduction of core component technologies and processes; and development of a technology maturation plan for the system's fabrication and flight test capabilities. The plan seeks a reusable first stage that would fly to hypersonic speeds at a suborbital altitude. Then, one of the expendable upper stages would separate and deploy a satellite into Low Earth Orbit (LEO).

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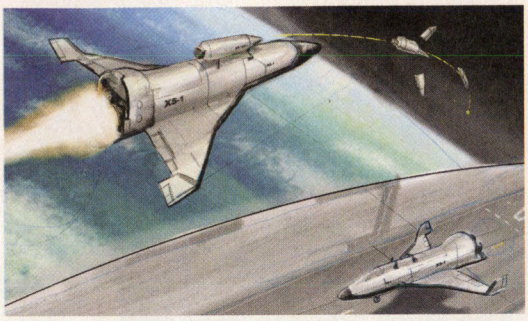
The reusable first stage would subsequently return to earth and be prepared for its next flight. Reuse of the modular components and durable thermal-protection systems, along with automatic launch, flight, and recovery systems, would help reduce logistical needs and enable more rapid turnaround between flights. This would also help reduce the cost of access to space for 3000- to 5000-lb. payloads to less than $5 million per flight.

The XS-1 program includes other technical goals, such as the ability to fly 10 times in 10 days, flying Mach 10+ at least once, and launching a representative small payload to orbit. ■



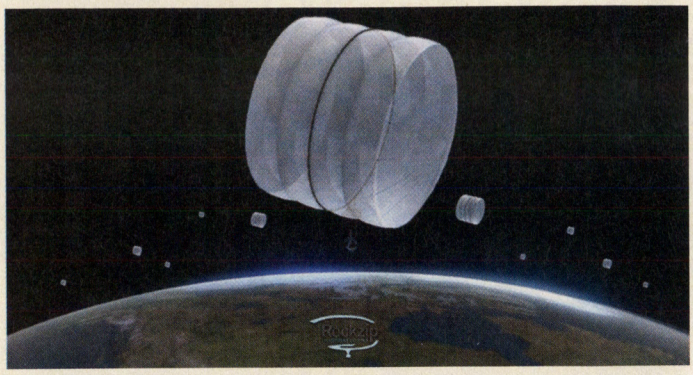
One of the goals of the XS-1 program is the ability to fly 10 times in 10 days. (Artist's concept courtesy of DARPA)

Satellite-Based Spectroradiometer

Continued from Page 20

The BB, tasked with thermal-band calibration, makes it possible to determine photon temperature simply by viewing them in the far IR, or mid- and long-wave IR bands. On top of that, the BB's assembly provides a full-aperture radiometric calibration source for the mid-wave IR (MWIR) and long-wave infrared (LWIR) bands to within 1% accuracy. A proprietary process used to create the device's nonreflective, black surface minimizes scatter and ensures effective cavity emissivity. Twelve sensors below that surface monitor temperature in order to retain precise measurements.

In addition to the MODIS, the Aqua and Terra satellites both house a CERES instrument that's similar to the one used in the JPSS-1 weather satellite (see "UPDATE: JPSS-1 Weather Satellite Boosts Forecasting Accuracy" at www.mwrf.com). The satellites are part of the international, NASA-centered Earth Observing System (EOS). EOS is a coordinated series of polar-orbiting and low inclination satellites that gather data from long-term, global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. ■



Rockzip breaks "highballooning" down to five easy steps: build your payload; fill it up; launch it; track it; and go pick it up wherever it lands.

HIGH-ALTITUDE BALLOONS FLOAT TOWARD MULTIPLE APPLICATION POSSIBILITIES

SOMETIMES REFERRED TO as a "poor man's satellite," high-altitude balloons can serve as an inexpensive, practical invitation into a variety of near-space applications. This includes everything from bringing Internet access to remote areas, to testing potential rocket components. A new aerospace startup, Rockzip Highballoons, recently started a Kickstarter crowdsourcing campaign to commercialize its first model of "highballoons" as floating space satellites.

Standard highballoons filled with helium can reach altitudes of around 120,000 ft., floating for months at a time. Rockzip's current Pro Highballoon model has a float time of five-plus hours at a maximum altitude of 30,000 ft., is tetroon (tetrahedral) shaped, and measures 7 ft. wide edge to edge. Current applications include Internet coverage in remote areas (for example, Google's Project Loon), space testbeds such as CubeSats, and hurricane-tracking bots. Rockzip hopes that by commercializing the technology, highballoons could be used for things like crop inventory and yield production; sending cargo into space; and deforestation tracking in places like the Amazon rainforest.

Rockzip breaks "highballooning" down to five easy steps: build your payload (cameras, GPS, radio transmitters, etc.); fill it up; launch it; track it; and go pick it up wherever it lands. This makes them ideal for students, much like NASA's CubeSat program, serving as inspiration to them regarding science, technology, engineering, and mathematics (STEM) applications and giving them an affordable venue to foster ideas. Rockzip's Kickstarter campaign is also promoting a full-size beta prototype of its highballoon. The team hopes to raise $15,000 by mid-September in efforts to bring the Pro model into production. ■

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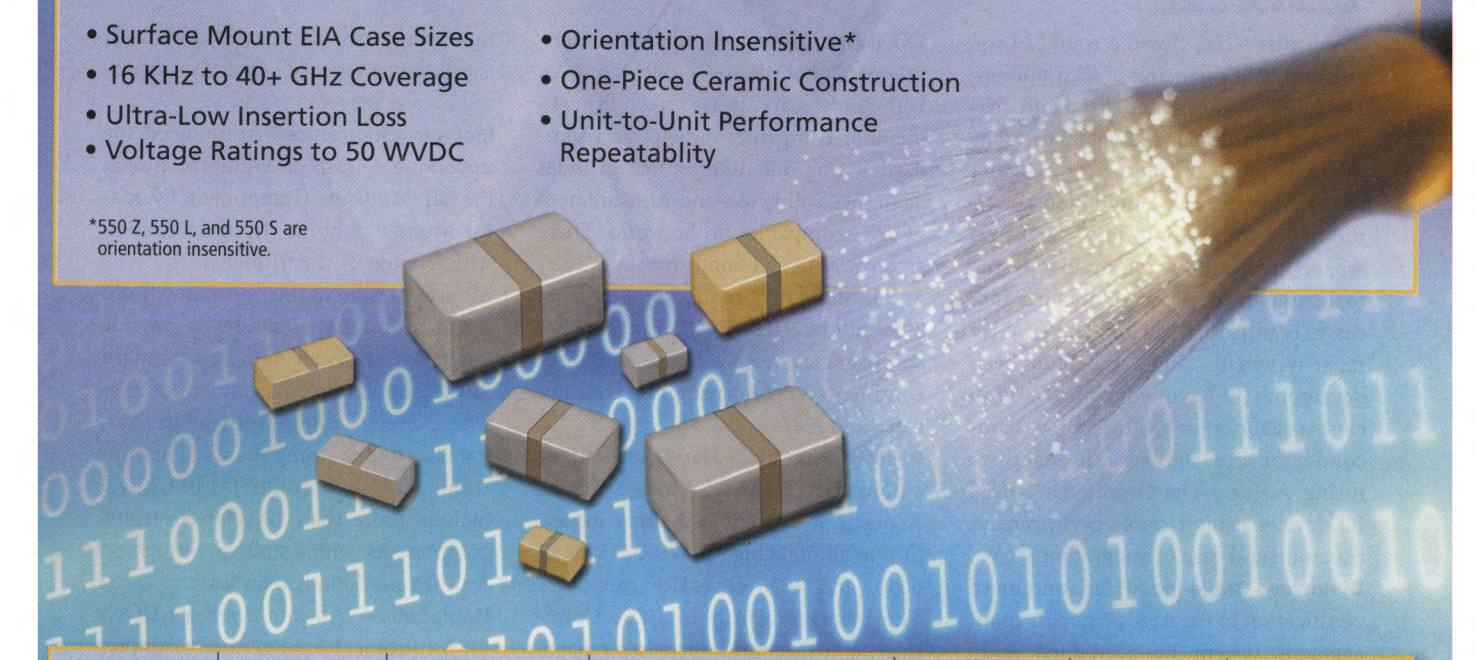

ATC Series	EIA Size	Capacitance	Frequency Range	Insertion Loss	Voltage Rating	Orientation Insensitive
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550 U	0301	100 nF	16 KHz to 40+ GHz	<0.4 dB typ.	6.3 WVDC	No
550 L	0402	100 nF	16 KHz to 40+ GHz	<0.5 dB typ.	16 WVDC	Yes
550 S	0603	100 nF	16 KHz to 40+ GHz	<1 dB typ.	50 WVDC	Yes

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CONTRACTS

Mercury Systems Inc.—Received $4.4 million in orders from a leading defense prime contractor for advanced radio-frequency (RF) microwave tuner and intermediate-frequency (IF) products for a naval signals intelligence (SIGINT) application. The orders were booked in Mercury's fiscal 2014 fourth quarter and are expected to be shipped by its fiscal 2015 second quarter. The company provides affordable, commercially developed, open-sensor processing systems and services for critical commercial, defense, and intelligence applications.

MERCURY Scores SIGINT App

U.S. ARMY Calls on Sonim

Sonim Technologies Inc.—Was selected as the preferred device manufacturer for testing to provide next-generation LTE smartphone capabilities for combat trainers at the U.S. Army's National Training Center and Joint Readiness Training Center. After an extensive review of consumer off-the-shelf cellphone technologies, the Army chose Sonim devices based on their rugged features, such as 20-plus hours of LTE-based talk time; extreme durability in heat, dust, and wet environments; visibility in direct sunlight; and support for a wide range of Android applications and accessories.

FRESH STARTS

Omniradar—Has closed a round of equity and debt financing of €2.6 million. The funds will be used to bring into production Omniradar's single-chip radar as a new precision sensor for personal security, industrial automation, environmental monitoring, and other novel sensor applications. Omniradar is the first company in the world that has successfully integrated a complete 60-GHz radar system in a single chip. It has been developing the technology since 2011 in close collaboration with leading semiconductor supplier NXP as its manufacturing partner. The Omniradar RIC60 IC devices exhibit stable performance, precision and ease of integration.

Dynawave Cable Inc.—Has announced certification to the AS9100 quality management system by accredited audit firm UL DQS Inc. AS9100 Certification is a prestigious status requiring companies to demonstrate practices and capabilities that meet the demanding, complex, and unique requirements of the defense and commercial aerospace industry. This status is only available to companies that pass strict audit requirements and rigorous evaluations of their contract review, training, manufacturing, design, and engineering processes for conformance with the high standard of quality required in the aerospace industry. AS9100 Certification consists of a host of additional requirements over ISO 9001, a status earned by Dynawave back in 1997.

LXI (LAN eXtensions for Instrumentation) Consortium—Is celebrating its 10th anniversary. It has grown from 13 member companies in 2004 to a standard-setting organization that includes 52 of the leading test-and-measurement (T&M) companies in the world. There are now 2614 LXI-conformant products in 262 different product families from 39 vendors. The LXI Consortium has conformance testing houses on three continents, encompassing the U.S., Europe, and Asia.

Passive Plus Inc.—Has added a 100% automated CSAM (C Mode Scanning Acoustic Microscopy) internal inspection to all of its high-power 2225, 3838, 6040, and 7676 series RF capacitors. The primary benefit of 100% CSAM internal inspection is increased reliability by screening out electrically undetectable internal defects such as voids, cracks, de-laminations, or electrode discontinuities that can lead to short-term or latent catastrophic failures. Typical MLCC electrical tests may not reveal these internal defects.

Infineon Technologies AG—Agreed to buy International Rectifier Corp. for about $3 billion, a deal uniting mature semiconductor makers that points to quickening consolidation in the sector. Infineon's move is the latest in a wave of combined efforts between makers of chips and related products, a large market with more than 300 specialized suppliers. Though sales are growing in most segments, companies with cash are finding a series of benefits in acquiring smaller players.

Mouser Electronics—Announced the upcoming release of MultiSIM BLUE, the NI Multisim Component Evaluator-Mouser Edition. In collaboration with National Instruments, the new Mouser version of the free tool will add features and functionality to provide engineers with an industry-standard SPICE simulation environment of electronic circuits using Mouser Electronics' distributed components. This upcoming release of MultiSIM BLUE will include more than 100,000 electronic components with intuitive simulation features and SPICE analyses.

CableLabs—Will join Averna's DOCSIS 3.1 Protocol Analyzer Early Adopter Program. According to Averna, a developer of test solutions and services for communications and electronics device-makers worldwide, CableLabs will add its voice and experience to the development and review process for Averna's next-gen DOCSIS 3.1 Protocol Analyzer. The DOCSIS Protocol Analyzer is the industry standard for functional DOCSIS and EuroDOCSIS network analysis, providing visibility into all layers of the network. Multiple system operators (MSOs), chipset manufacturers, product developers and certification bodies use Averna's DOCSIS Protocol Analyzer to quickly find and correct troublespots.

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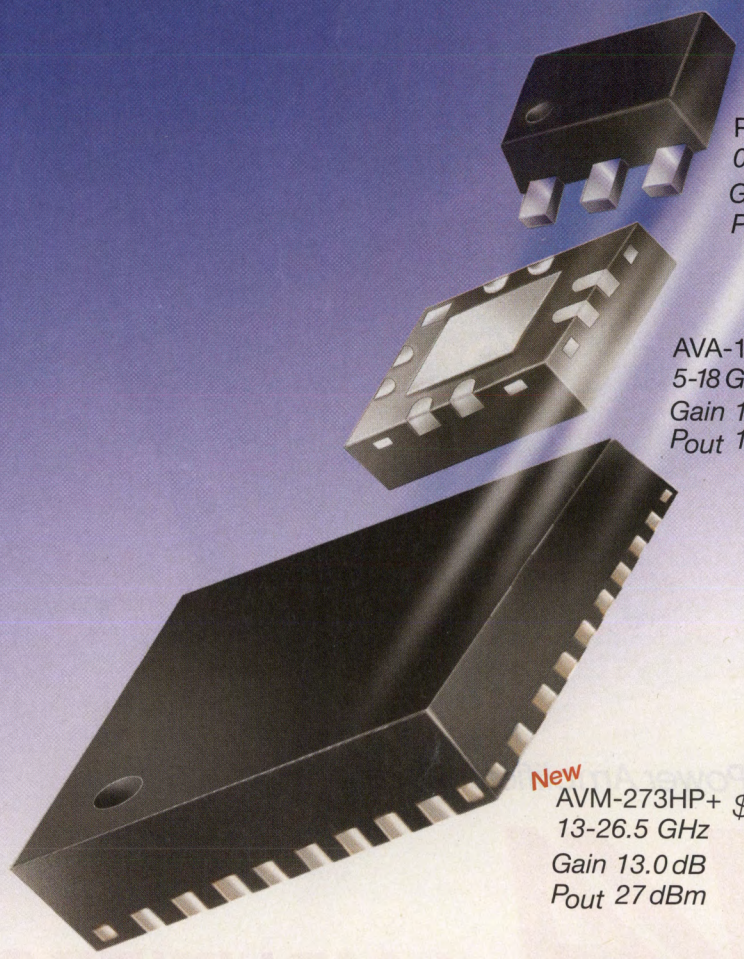

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P_{out} 22 dBm

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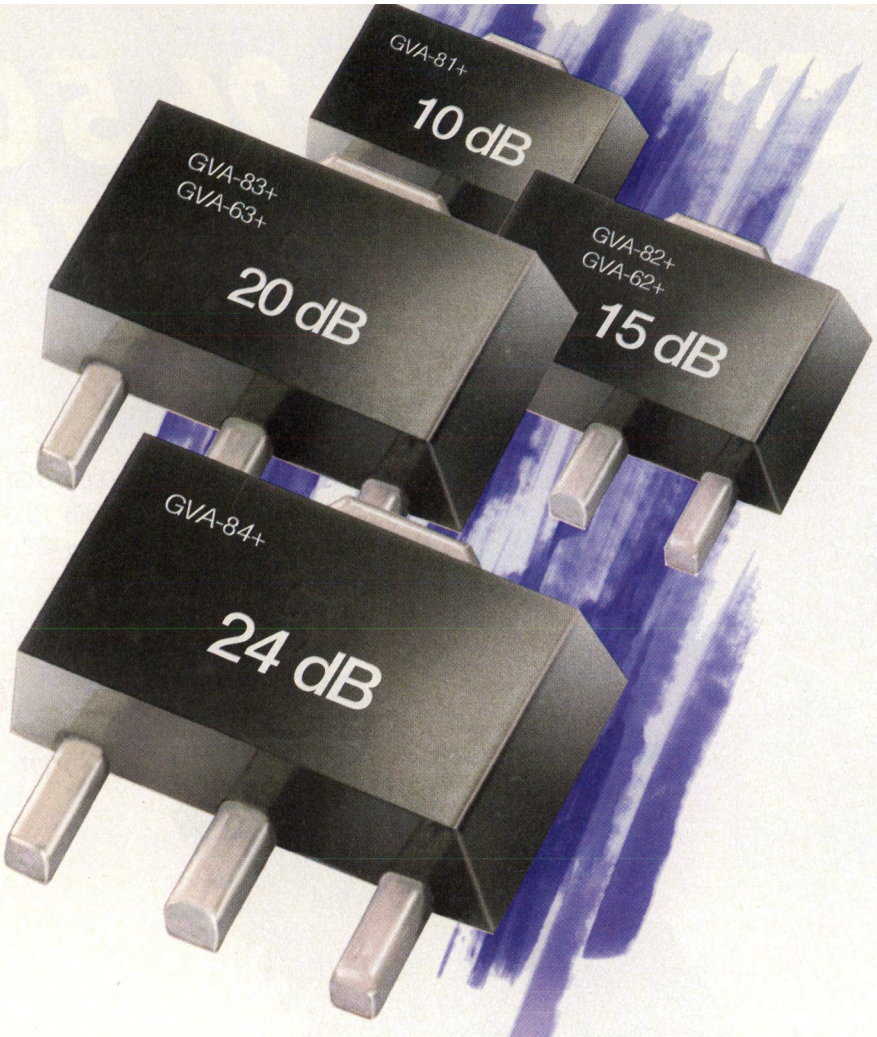

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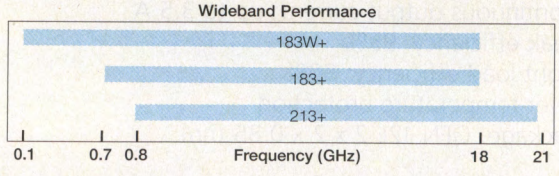

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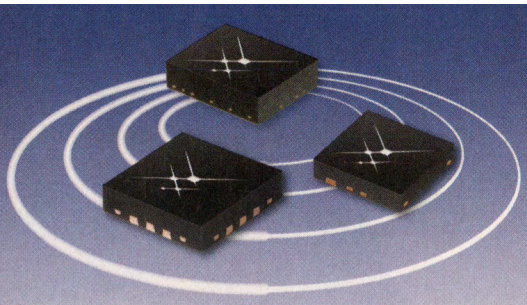

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Inside TRACK with Duncan Pilgrim,

VP of Marketing for Peregrine Semiconductor

Interview by JEAN-JACQUES DELISLE



JJD: What are the main benefits of RF silicon-on-insulator (SOI) technology?

DP: RF SOI technology has a multitude of benefits over traditional RF processes, including RF performance, manufacturability, and integration. Basically, RF SOI technology combines the economic benefit of a complementary-metal-oxide-semiconductor (CMOS) process with the performance levels traditionally seen with gallium arsenide (GaAs). In regard to RF performance, RF SOI technology delivers what we like to call the three key advantages—low insertion loss, high isolation, and high linearity.

Low insertion loss enables lower power-amplifier (PA) drive and, thus, lower energy consumption and higher output efficiency. High isolation prevents signal contamination between different RF signal paths. Additionally, high linearity lends itself to support higher-order modulation schemes without signal degradation.

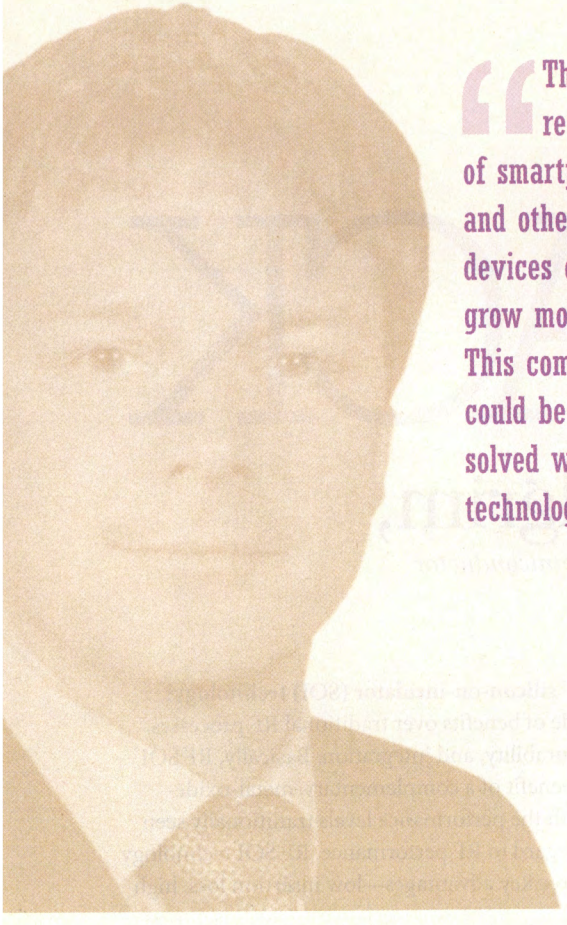
> "If an RF SOI technology utilizes a mainstream CMOS process flow, it offers the bonus of leveraging a standard CMOS process. In doing so, it can add high scalability and fabrication capability factors."

If an RF SOI technology utilizes a mainstream CMOS process flow, it offers the bonus of leveraging a standard CMOS process. In doing so, it can add high scalability and fabrication capability factors, which are not otherwise accessible with RF integrated-circuit (IC) technology. CMOS also is recognized for its manufacturing repeatability, which reduces end-product performance variability.

Unlike other technologies, RF SOI enables these unique RF properties to be integrated along with analog, digital, and mixed-signal capabilities. The unique benefit of RF SOI is that it can accommodate multi-domain capabilities all in one chip. This superior level of integration delivers a smaller form factor, higher flexibility/configurability, higher reliability, and better performance.

JJD: What limitations does SOI technology have, and what applications would you expect not to see in SOI technology?

DP: RF SOI is not ideally suited for very high-power applications, such as wireless-infrastructure or PA applications. There, RF SOI technology is complementary to high-power technologies like gallium nitride (GaN) and laterally diffused metal-oxide semiconductor (LDMOS). However, the RF SOI technologies that use a sapphire substrate have excellent high-frequency capabilities.



> "The radio requirements of smartphones and other wireless devices continue to grow more complex. This complexity could be best solved with silicon technology."

Sapphire is an almost perfect insulator. As such, it allows the use of monolithic-microwave-IC (MMIC) design techniques, which have traditionally been used on GaAs technologies. The same benefits of SOI at lower frequencies can now be realized at these high frequencies. Simple capabilities, such as high electrostatic-discharge (ESD) performance and integrated control interfaces, also can be featured in products at millimeter-wave frequencies. As we see the key requirements for fifth-generation (5G) rollout, I think this capability will become increasingly important.

JJD: How has RF SOI been transformed over the course of the past few decades?

DP: RF SOI was once considered an exotic niche technology, which couldn't achieve the performance or cost structure required to compete with technologies like GaAs and silicon germanium (SiGe). Yet innovation in the three key areas of process, substrate, and design/IP have enabled it to achieve the RF performance required to compete with the incumbent technologies. As with all CMOS-based processes, RF SOI's cost structure improved as volumes increased.

In 2009, for example, we hit a major milestone for our handset switch products when the UltraCMOS 5 technology beat the incumbent GaAs technology on all performance metrics. At that point, RF SOI quickly became a widely accepted RF technology. It is now uncommon to find an antenna switch that utilizes GaAs. RF SOI enables many new products for which other technologies are not suited.

JJD: What applications does RF SOI technology best fit, and how are those applications adopting the technology?

DP: SOI is the best fit for RF applications that need high-end RF performance, configurability, high reliability, and a future need for integration. Cost can never be ignored and, fundamentally, RF SOI is a CMOS technology. It therefore benefits from the enormous manufacturing scale brought by CMOS. The additional advantage is that it doesn't utilize the most advanced technology node. As the complexity of end applications increases, the benefits of using an RF SOI process also rises. We expect this to continue as the world becomes a more connected place.

JJD: Where do you see RF SOI fitting in with the explosion of wireless devices and the Internet of Things?

DP: Assuming that all things are connected via the Internet, the critical requirements become size and power. The integration and scaling capability derived from SOI technology enables product and solution design at a performance level that would be very difficult to reach with any other technology. For example, our all-CMOS RF front-end product, UltraCMOS Global 1, boasts a level of integration and RF performance that is not feasible with other technologies. The core capability of the latest RF SOI technology for the handset market has very broad applicability across other applications.

In addition to Wi-Fi and small cells, it can be leveraged into adjacent markets like infotainment and connectivity systems for the automotive market. Currently, the primary industry focus for RF SOI is on the mobile market. However, RF SOI technology supports many other end markets, such as wireless infrastructure, test and measurement, and automotive. These markets are also pushing for higher levels of performance and integration, and RF SOI is ideally suited to drive these demands.

JJD: We saw the recent news regarding Murata's acquisition of Peregrine Semiconductor. What were the key factors in Murata's interest in Peregrine?

DP: This acquisition will combine Murata's mobile RF-module capabilities with Peregrine's RF-front-end products. Peregrine invented RF SOI, has led its development for 20-plus years, and accomplished a large number of industry firsts. As a result, I would say that the acquisition will deliver advanced RF-front-end capabilities and the world's best SOI process technology to Murata. RF SOI is a key enabler for the growing integration of mobile technologies. The radio requirements of smartphones and other wireless devices continue to grow more complex.

This complexity could be best solved with silicon technology. Peregrine supplies devices to many wireless markets, including smartphones, test and measurement, automotive, public-safety radio, and wireless infrastructure. Peregrine will also give Murata a strong portfolio of Intellectual Property Rights (IPR), covering a wide range of proprietary RF SOI front-end solutions and techniques. MW

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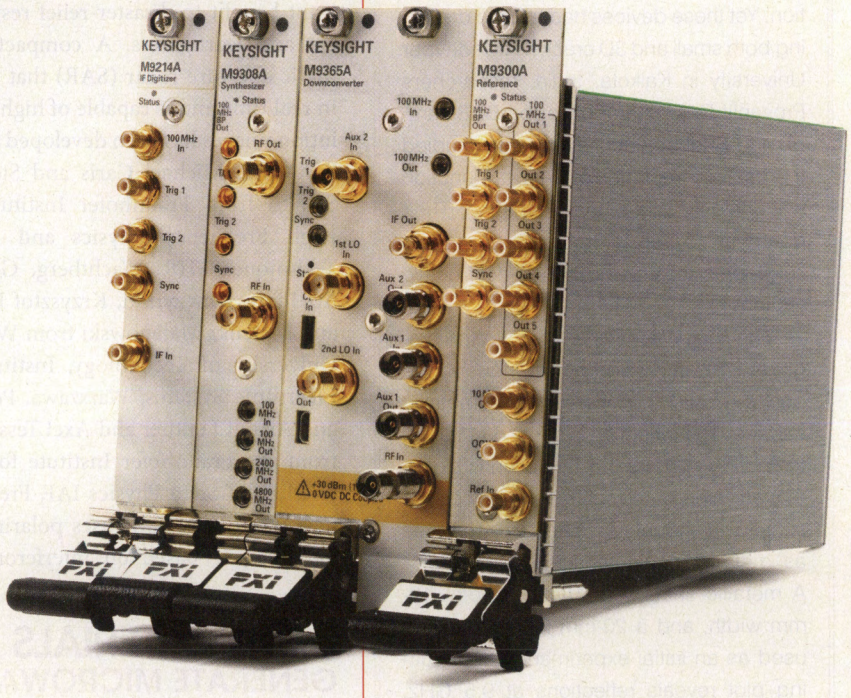

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MILLIMETER WAVES DETECT CRACKS IN COMPONENTS

SINCE THE 1970s, researchers have been using microwaves to detect surface cracks in metallic components. Generally, open-ended rectangular waveguides were used for low-resolution crack detection. Yet these devices had trouble detecting both small and 3D cracks. At Jadavpur University in Kalkota, India, researchers Prosenjit Das, Sharanbasappa B. Belamgi, and Sudhabindu Ray recently studied the use of a rectangular e-type T-junction waveguides with X-band radiation. Their goal was to detect 3D cracks in metallic objects for enhanced non-destructive testing.

The study uses the T-junction waveguide with an X-band power input on the port opposite the one facing a metallic surface. The reflection is sensed at the intersecting port. As the T-junction is slowly moved along, the difference in power sensed at the intersecting port changes as a function of the surface continuity. A metallic sheet with 10-mm depth, 10-mm width, and a 20-mm length crack is used as an initial experiment. The resulting plot reveals reflections at 9.5 GHz, which are approximately the dimensions of the cracks.

Next, a parametric study is used to determine the measurement techniques' ability to gauge the depth and width of 1-to-10-mm cracks at 1-mm increments. The subsequent plots indicate a consistent decrease in the reflections at the intersecting port, which is consistent with the depth increase. In the parametric study of crack width (again, from 1 to 10 mm at 1-mm increments), there also is a direct correlation between the position of the dips in the power plots of the intersecting port, which corresponds to the edges of the crack. See "Non Destructive Crack Detection At X-Band," *2014 International Conference on Electronics, Communication, and Instrumentation (ICECI)*, Jan. 2014, p. 1-2.

MICROWAVE IMAGING SOARS HIGH WITH UAVS

USING SMALL UNMANNED aerial vehicles (UAVs) to survey ground conditions with conventional cameras isn't new. Thanks to new millimeter-wave imaging techniques, however, high-quality, all-weather, and day/night surveillance may bring significant benefit to disaster-relief responders and warfighters. A compact synthetic aperture radar (SAR) that works in real time and is capable of high-resolution images has been developed by the following: Michael Caris and Stephan Stanko from Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Wachtberg, Germany; Piotr Samczynski, Krzysztof Kulpa, and Mateusz Malanowski from Warsaw University of Technology, Institute of Electronic Systems, Warszawa, Poland; and Arnulf Leuther and Axel Tessmann from the Fraunhofer Institute for Applied Solid State Physics IAF, Freiburg, Germany. Their SAR uses polarimetry, 3D imaging based on interferometry, and moving target indication (GMTI) based on along-track interferometry.

This radar was developed for the all-weather-penetrating UAV applications (SARape) project using a real-time, miniaturized, 94-GHz SAR system. That system is designed for use with manned and unmanned airborne applications. To create a significantly long synthetic antenna—ranging from hundreds of meters to several kilometers—GPS-based methods are coupled with an inertial navigation platform and autofocusing procedures using the received radar signal. The paper discusses the benefits of new techniques that are enabled by frequency-modulated continuous-wave (FMCW) generators with bandwidths of 1 GHz. The use of small antennas enables the SARape system to capture resolutions to 15 cm in range and cross-range directions. See "mm-Wave SAR Demonstrator as a Test Bed for Advanced Solutions in Microwave Imaging," *IEEE A&E Systems Magazine*, July 2014. p. 8-15.

METAMATERIALS AND ELECTRON BEAMS GENERATE MICROWAVES

WITH METAMATERIALS, SIMULTANEOUS negative permittivity and permeability can be achieved. As a result, metamaterials have been explored for lens design, cloaking, antenna design, accelerator applications, and coherent microwave generation. The generation of microwave energy using an easily and cost effectively fabricated metamaterial structure could be promising. After all, the manufacturing of vacuum electronic devices, such as traveling-wave tubes (TWTs) and backward-wave oscillators, poses intrinsic difficulties. At the Plasma Science and Fusion Center at MIT, Jason Jummelt, Samantha Lewis, Michael Shapiro, and Richard Temkin have explored the use of a metamaterial array in a negative index waveguide.

By relying on an array of split-ring resonators alongside an array of metallic posts, the researchers achieve both negative permittivity and the permeability-induced negative index modes. The metamaterial arrays are placed within a transverse-magnetic-mode waveguide, which has a cutoff frequency above 2.6 GHz. Particle-in-cell simulations using CST Particle Studio are then used to evaluate the efficiency of a 500-keV S-band-based device. According to the simulation, 5.75 MW of output power was delivered with 14% efficiency. The experimental excitation of the negative index transverse-magnetic mode near 2.6 GHz corresponds to the results. See "Design of a Metamaterial-Based Backward-Wave Oscillator," *IEEE Transactions on Plasma Science*, Apr. 2014, p. 930-936.

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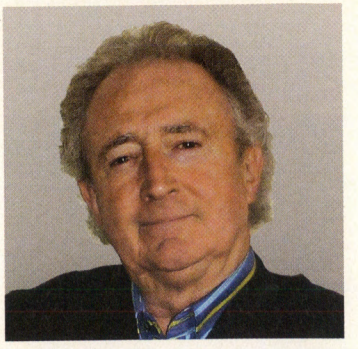

PAUL WHYTOCK

Standards Battle Heats Up as Wireless Charging Market Booms

INDUSTRY ANALYSTS' predictions on the value of the wireless charging market are becoming increasingly bullish, with estimates claiming the global market to be worth €5.3 billion in 2017—a substantial rise from 2011's €337 million.

Today, wireless chargers come in a variety of guises but are still based on electromagnetic (EM) coupling, whereby charging is enabled via EM fields. Currently, there are five wireless technologies: inductive coupling technology, RF technology, magnetic resonance technology, microwave technology, and optical beam technology.

But as is so often the case with burgeoning technologies, commercial progress of the wireless charging market is hindered by the absence of standards necessary to ensure compatibility between different providers' technologies.

However, on a more positive note, it is certainly true that the wireless charging industry has numerous consumer-related application opportunities that it can exploit. These include charging of mobile phones *(see the figure)* at wireless charging facilities in restaurants, cinemas, railway stations, airports, and many public areas. Not surprisingly, it is expected the increased use of wireless charging technologies by consumers during the next three years will create a global user-base of approximately 140 million units.

So a speedy and pragmatic finalization of industry standards that will allay consumers compatibility fears is an indisputable imperative.

There are, in fact, three standardization bodies jostling for a leading position in the wireless charging market. The Wireless Power Consortium (WPC), which established the Qi standard, has 180 industry members. It is a globally recognized standard, and there are approximately 380 products certified as conforming to Qi.

Formed in 2012, the Power Matters Alliance (PMA) has about 100 members and is currently working on the formalization of its industry standard.

Finally, the Alliance for Wireless Power (A4WP), founded in 2012, has 60 members; the first products that meet the requirements of this standard are expected to be launched in 2014.



The increased use of wireless charging technologies by consumers during the next three years could result in a globally installed user-base of approximately 140 million units.

The standards from WPC and PMA are based on inductive charging; thus they are defined as tightly coupled systems. Each is recognized as being more efficient than the alternative loosely coupled approach that employs resonant charging. However, as the name suggests, tightly coupled charging relies on the receiver and transmitter physically being within a few millimeters of each other.

The A4WP is an advocate for resonance charging, a technology with a distinct advantage in that it allows greater freedom of how units have to be positioned against the charging transmitter unit. It allows more spatial flexibility and could offer the advantage of being able to place numerous devices on a charging pad simultaneously. However, spatial freedom can hinder efficiency.

Reduced efficiency is a particularly important issue when it comes to wireless charging. Low efficiency would mean longer charging times and could exacerbate heat-dissipation problems. It is generally accepted that tightly coupled wireless charging provides efficiencies higher than 70%, whereas loosely coupled wireless charging performs at 60%.

System safety is another significant concern. All wireless charging systems must have the capability to recognize foreign objects in order to avoid potentially hazardous heating of metal-based objects that are inadvertently positioned on the power transmitter. As a result, foreign object detection (FOD) becomes an essential design element.

Therefore, emerging standards from the various industry bodies not only need to define the myriad of electrical and electronic specifications required for wireless charging compatibility. They must also formalize and implement precise and sustainable communication and safety criterion.

As in any sphere of electronics, there is inevitably a standards battle when it comes to emerging technologies, as demonstrated by the Betamax versus VHS and the Blu-Ray versus HD-DVD skirmishes in commercial television markets. Predicting the wireless charging standard that will emerge as all-conquering at this stage of development is tricky, because each standard organization is concentrating on different technological approaches. mw

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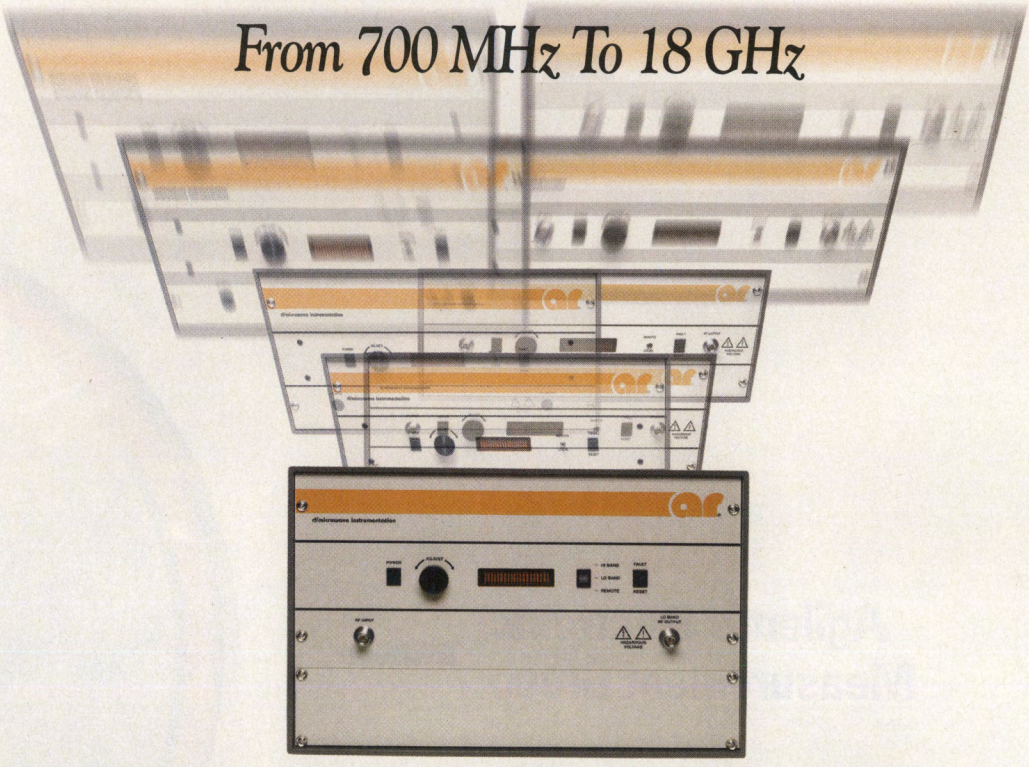

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HEALING HEROES

SPECIAL REPORT

JEAN-JACQUES DELISLE | Technical Engineering Editor

HEALING HEROES
ONE WIRELESS



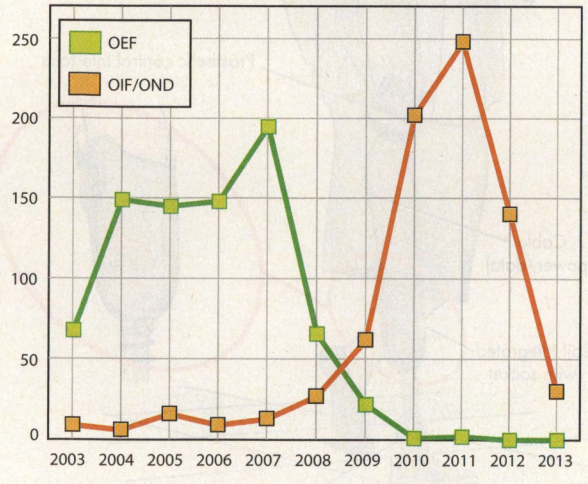
Using Bluetooth, magnetic resonance, and near-field communications, prosthetics developers are creating cutting-edge and waterproof options for warriors so they can get back into action.

LIMB AT A TIME

At the end of 2013, the number of U.S. soldiers who suffered crippling battle-related amputations in the wars overseas exceeded 1500 *(Fig. 1)*.[1] Many of these soldiers suffered multiple limb amputations. Given the limitations of most current prosthetics, they were looking to a future that was bereft of most of the activities that formerly defined their lives.

To both preserve the assets of injured career soldiers and improve their quality of life, organizations began investing in prosthetic technology development. From the Alfred E. Mann Foundation (AEMF) to DARPA, NIH, TATRC, the Walter Reed National Medical Center, Advanced Arm Dynamics, and Ottobock, these organizations strived to help a soldier live a healthy and active life post-injury—and potentially even continue to serve. As part of this effort, RF/microwave technology is being analyzed, reviewed, and even adopted to aid in next-generation prosthetics, which will soon function in ways indistinguishable from natural limbs.

Number of individuals with battle-injury major limb amputations from OEF and OIF/OND for the years 2003 to 2013.



1. The number of major battle-related injuries from Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND) by the end of 2013 totaled 1558. (Source: CRS communication with Dr. Michael Carino, Army Office of the Surgeon General, January 10, 2014)

Before the invention and availability of the microprocessor-controlled prosthetic, there were very limited options for prosthetics that could be used throughout an active daily routine. This led to mostly application-specific prosthetics—for example, for running, walking, water use, or sports. Yet the microprocessor-controlled prosthesis allowed an adjustable interface to control the mechanical movers within the limb.

Such enhanced limb rotation and control, which can be customized for the individual patient, enables much more lifelike and natural motion. By including joint programmability, developers added an extra layer of programming and patient training. Additionally, a power source and a controller for switching between different use modes were required. As a result, the patient now had to charge the prosthetic and adjust the programming of its microprocessor on a regular basis.

To ease this process, companies like Ottobock embraced wireless technology while adding usability and convenience features that would otherwise be prohibitive to implement. The firm's two main innovations were the wireless charging of the prosthetic battery and the wireless programming and mode switching of the microprocessor-controlled prosthesis rule-settings. Both of these clever uses of wireless technology remove the need for physical connectors in a prosthesis.

External connectors are common points of failure and environmental ingress. For its part, Ottobock developed the C-Leg, which employs inductive charging of the lower-limb prosthesis with a magnetic attachment at a point behind the knee. This attachment point functions as a wireless power receiver. The inductive resonant coil behind the knee couples with a specialized charger, which is equipped with another resonant inductive coil. Charging lights and other indicators help to update the patient on the prosthesis' battery condition.

Electronics within the C-Leg convert the low-megahertz wireless energy into direct current (DC) while a charging controller recharges the internal battery.

Because the charging system used with the C-Leg is inductive and resonant in nature, the prosthesis' charging adapter can transfer power through clothing and even cosmesis. These cosmetic additions improve the aesthetics of the prosthesis.When converting the interconnect technology of a microprocessor-controlled prosthesis to wireless, the next step is to enable wireless programming and patient control of the various modes.

Originally, Ottobock used a USB Bluetooth transmitter connected to a PC. It communicated with a Bluetooth receiver wired to the prosthesis, also through a USB port. According to Philipp Kampas, program manager of lower extremity prosthetics for Ottobock, "The idea originated when patients ended up entangled in the cables during the setup process of the prosthesis. During initial configuration of the microprocessor knee, the patient had to walk around while connected by many wires to the prosthetist's PC.

"We first used Bluetooth as an add-on device that replaced a serial communication cable for programming the microprocessor knee," he continues. "As soon as this was established, it was obvious that an embedded Bluetooth receiver could also be used for the interface of the remote control."

This solution solved many of the challenges stemming from the programming and mode setting of the microprocessor-controlled prosthesis. But the Bluetooth receiver also added an external component, which had its own set of failure modes and power requirements.

The next stage of advancement was to incorporate wireless connectivity into the leg design. This revision of the wireless prosthesis omitted wired connections altogether. The redesign enabled a waterproof prosthetic leg that is essentially impervious to environmental ingress during regular activity.

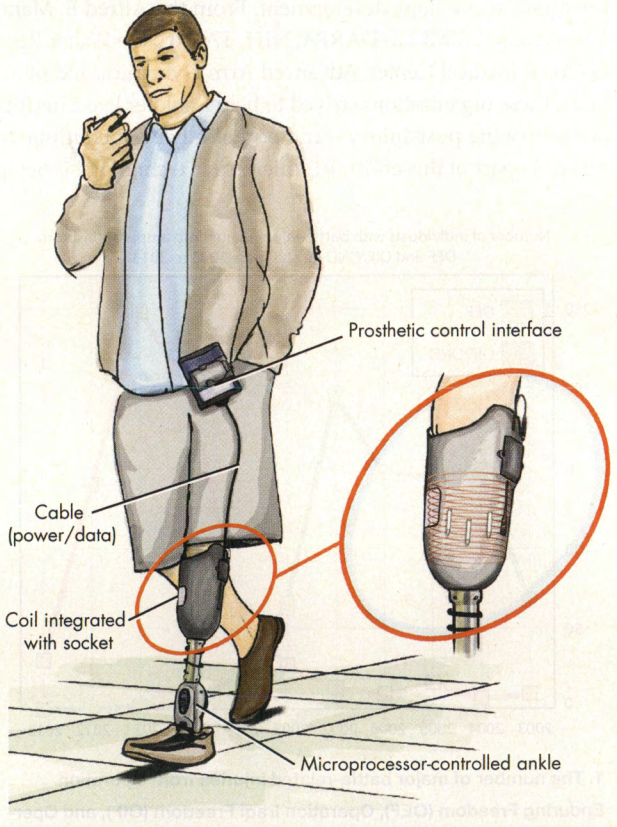
The Genium and X3 lower-limb prosthesis are the result of this development. They use a Bluetooth communications link between a PC and the prosthesis. "We sell our products globally, and our patients travel around the world," states Robert Hoffmann, head of Electronic Research & Development/ Lower Extremities for Ottobock. "We needed a technology that could be used globally. Eleven years ago, there were not many options. This led to the use of the 2.45-GHz ISM band. The standard approach at the time was to use a proprietary amplitude-shift-keying (ASK) or frequency-shift-keying (FSK) single-frequency solution.

The key advantages of Bluetooth are the robust frequency-hopping scheme, the low-power consumption, and the support of the PC world. Hoffmann adds, "The Bluetooth and inductive-charging technology are integral parts of the waterproof feature, since there are no more user-accessible connectors that are a potential weak spot for corrosion."

Even with the complications and failure modes associated with the physical connections removed, integrating wireless technologies in a rugged and mobile platform made from moving conductive parts posed many challenges. Typically, prosthesis materials consist of aluminum, titanium, steel, or carbon-fiber composites, which are also conductive. Because an external antenna would reduce the rugged capabilities of the prosthesis, sophisticated designs and high-quality components were required.

To maintain high security with the wireless prosthesis' connection, a custom-designed USB Bluetooth module for a PC is used to program the prosthesis. Specialized software adds another level of safety features, thereby ensuring correctly transmitted parameters.

A large number of soldiers have left the battlefield with amputations, leaving a palpable demand for prosthetics to become more lifelike and to integrate with technology that is familiar to the wearers. Hoffmann comments, "The next challenges are interfacing with mobile devices like Android and iOS smartphones. Also, reducing power consumption and optimizing RF and mechanical integration to get maximum transmission range are still issues." Although wireless charging and programmability have enhanced many features of prosthesis technology, using sophisticated sensors with wireless capability promises to bring space-aged—and much hoped for—control of robotic limbs as prosthesis *(Fig. 2)*.



2. To enhance the use of microprocessor-controlled joints, myoelectric implantable sensors are being investigated to enable electromyography control for prosthesis. (Courtesy of the Alfred E. Mann Foundation)

WIRELESS SENSORS TAP MUSCLE NERVES

Together with DARPA and other research-to-market organizations, the Alfred Mann Foundation (AEMF)—a transitional research engine that aids in bringing medical-device technology from research labs to commercial markets—is developing technology to enable sensors that will be implanted within muscle tissue. Such sensors will be able to wirelessly communicate with a robotic prosthesis worn by an amputee. The implantable myoelectric sensor (IMES) system uses sensors embedded in residual muscle tissue in an amputated limb.

These sensors rely on the same control nerves as a natural limb for directing the analogous prosthesis. What enables this technology to work is the remote powering and communication performed by an in-sensor wireless module and a power-transmitting/receiving antenna within the prosthesis socket. Using embedded sensors improves the signal integrity and isolation significantly over current technology. Because other approaches use electromyographical (EMG) patches, which rest on the surface of the skin, they result in imprecise nerve signals.

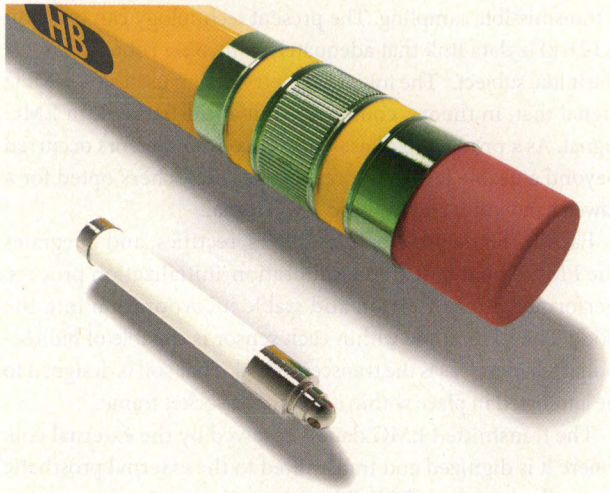
The myoelectric sensor module is composed of a ceramic cylinder with biocompatible metallic end-caps. The end-caps contain the custom electronics for both the EMG signal sensing and module, as well as house the RF functions *(Fig. 3)*. A custom application-specific integrated circuit (ASIC) within the sensor module is used to convert the analog EMG signals into a transmissible sampling. The present technology can transmit a 121-kHz data link that adequately controls a robotic arm for the initial subject.[2] The initial telemetry design used a 6.78-MHz signal that, in theory, could transmit a full-bandwidth EMG signal. As a product of phase-coherence issues, errors occurred beyond a usable level. As a result, the researchers opted for a lower-bandwidth and sampled EMG signal.

Each IMES device amplifies, filters, rectifies, and integrates the EMG signal based on a calibration-initialization process, performed after insertion and stable incorporation into the body. The RF module within each sensor is capable of bidirectional telemetry, as is the transceiver coil. That coil is designed to be laminated in place within a prosthetic socket frame.

The transmitted EMG data is received by the external coil, where it is digitized and transmitted to the external prosthetic controller interface (PCI). The system is capable of processing multiple EMG signal channels and retransmitting those to the PCI. The multiple EMG signals can be used to reconstruct different motor-control signals.

The PCI is capable of splitting the multiple EMG digital data streams from the external coil and reconstructing the digitally converted data back into analog data. The data then goes through another round of filtering. Next, the reconstructed





3. Given the size constraints of an implantable sensor, this unique tubular housing made of biocompatible materials is necessary to enable a myoelectric sensor. It measures just 16.0 by 2.5 mm. (Courtesy of the Alfred E. Mann Foundation)

and filtered analog signal is sent to the motor controller for the specific nerve tapped by the IMES. In this approach, multiple motor actions can occur simultaneously, which enables complex motor-control motions like pick-and-place and wrist pivoting while extending or contracting multiple fingers. The first IMES system implemented by the group offered three simultaneous degrees of freedom using six separate sensors for a transradial amputation of a patient's arm. The Touch Bionics i-limb ultra-hand enabled the patient to control wrist pronation/supination, hand open/close, and thumb abduct/adduct.

To extend the technology's usefulness, plans are in place to use an IMES system with patients that have undergone targeted muscle reinnervation (TMR) surgery. TMR surgery remaps the nerves that are used for more external limb-control functions to less external limb nerve sites. Using an IMES on this remapped nerve site would enable amputees with little limb remaining to use a bionic prosthesis. The AEMF is working with the Ottobock DynamicArm for TMR control in conjunction with the IMES. This solution is currently under regulatory review for a clinical feasibility study in the EU.

Future enhancements include the addition of a sensor on a leaded IMES (LIMES), which can be used to target nerve-control centers beyond a feasible distance from a prosthesis socket. This method would enable an IMES to target nerve sites up to 12 inches away from the power transfer and telemetry zone of the external coil. The LIMES may also simplify the design of the external coil, allowing a standard coil design while preventing the need for custom coils.

As the commercial-wireless and defense markets continue to invest in advancing wireless technology, more options will emerge to overcome control, sensing, and communications challenges in many industries. With the benefits of access to sensor data closer to the source of the information—and without degradation from physical cables—the market for more low-cost and small-form-factor wireless sensor nodes will increase.

Many expect the Internet of Things (IoT) to be used mainly for convenience technologies like smart homes and fitness tracking. But there are many more uses of the base technologies enabling the IoT, such as prosthetic limb control, remote machine control in biohazard/harsh environments, and exploring the world around us in ever-increasing detail. MW

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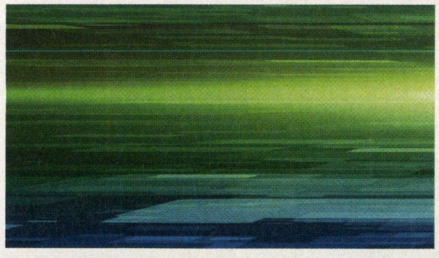



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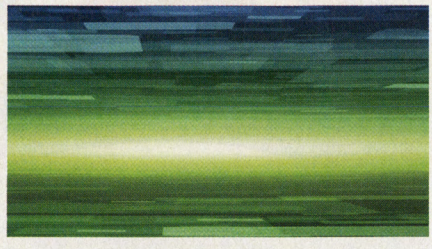

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JEAN-JACQUES DELISLE | Technical Engineering Editor

What's in Your Coaxial Cable?

Coaxial cables are a standby of the RF/microwave industries, as they connect vital components ranging from smartphones and laptops for everyday life to radar and GPS for military and aerospace.

FOR ALMOST EVERY application, it is challenging to transfer signals from one component to another while maintaining adequate signal integrity. Adding complex and dynamic signal paths requires a flexible platform for adapting to many environments and applications. One solution was proposed by the renowned engineer and mathematician Oliver Heaviside. He patented a design for a shielded telegraph transmission line in 1880.

In 1929, to overcome the limitations in Heaviside's design, Bell Labs' Lloyd Espenschied and Herman Affel developed the broadband coaxial cable with an air-like dielectric spacer. Since this invention, coaxial-cable technologies have advanced in both materials and performance, providing solutions for a wide range of RF/microwave/millimeter-wave interconnection problems.

The most basic version of a coaxial cable is composed of a center conductor, which is mechanically separated from a cylindrically symmetric conducting shield by an air-like dielectric. This cylinder-within-a-cylinder conductor geometry allows electromagnetic (EM) signals below a maximum cutoff frequency to create a transverse-electromagnetic (TEM) wave within the separation space between the conductors.

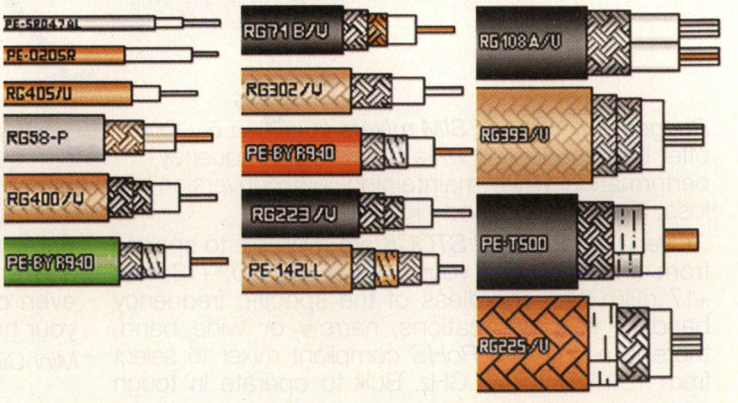
For signals beyond the cutoff frequency, the size of the wavelengths are small enough to generate non-perpendicular transverse-electric (TE) and transverse-magnetic (TM) waveguide modes. These additional modes reduce signal integrity and performance. Generally, the larger the diameter of the coaxial cable, the lower the cutoff frequency will be. Power-handling capability also increases with size.

Due to the sensitivity of the TEM mode wave within the coaxial cable, all of the cable's geometric components must be consistent throughout the transmission line. Otherwise, the signal will suffer from a variety of degrading reflections and phase variations. "An engineer has to think about a cabling assembly as if it's just another microwave component. Designs often require engineers to spend hundreds and thousands of dollars to get a precision amplifier, filter, or other components with major impact on system performance," states Steve Ellis, interconnect product manager for Pasternack.

The materials used to construct coaxial cable may vary, electrically, as a function of vibration, temperature, moisture, current, flexure, and strain. Such variations affect the cable's performance. Additionally, there is the skin effect—a physical phenomenon that describes the increased distribution of electrons traveling near the surface of a conductor as the frequency of the signal is increased. The skin effect makes the signal traveling along a coaxial cable susceptible to imperfections in conductor surface finish.

As a product of these sensitivities, coaxial-cable designers have developed advanced practices and materials to ensure the highest possible performance while meeting cost, weight, flexibility, loss, and ruggedness needs.

The dielectric spacer within a coaxial cable is critical, as it maintains the coaxial geometries of the two conductors with the added challenge of behaving as much like air as possible. Being air-like involves having close to the same magnetic permeability μ/μ_0 and electric permittivity $\varepsilon/\varepsilon_0$ of air (or an ε and μ of approximately 1, which are both components of the loss



1. The many varieties of coaxial cables meet different electrical and mechanical performance criteria. The frequency and power requirements dictate the physical dimensions of a coaxial cable. (Courtesy of Pasternack)

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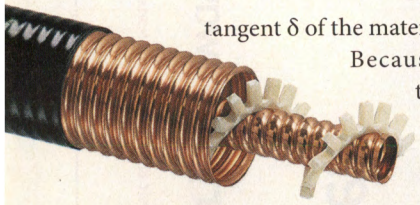


2. Cable weight and material use can be reduced with the placement of a dielectric spacer, which grips the groves in a corrugated center and outer conductor. In doing so, it maintains the coaxial nature of the cables. (Courtesy of CableWave)

tangent δ of the material).

Because very few materials have the same electric and magnetic properties as air, techniques that reduce the amount of disturbing dielectric material employed are common. Such techniques include the use of the following: expanded plastic foams with high air content; spiraled dielectric spacers; and materials designed to be more like air.

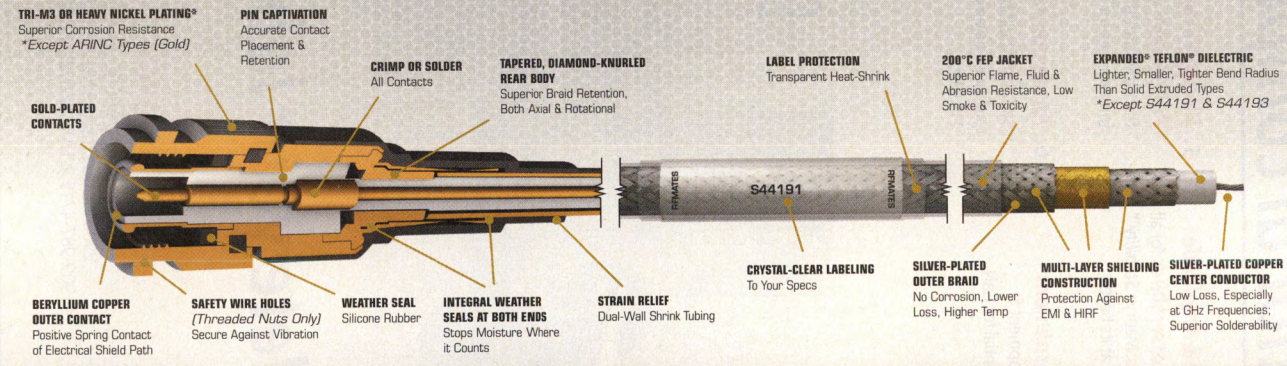
To maintain the air-like mechanical and thermal properties of a dielectric, much investment has focused on the chemical material development of plastics. Originally, solid tubes of Teflon were used for the coaxial dielectric, as Teflon is highly electrically stable. It also has high chemical and thermal resistance at low cost. Unfortunately, however, Teflon flows at room temperature. As a result, it has been mostly replaced in low-cost applications by polytetrafluoroethylene (PTFE) foams or nylon materials.

Other materials, such as extruded fluoropolymer resin, offer enhanced performance over PTFE in terms of phase stability and velocity of propagation (VOP). Teflon and nylon dielectrics typically have a phase velocity in the 70% range. In contrast, PTFE-expanded air dielectrics can reach the low-to-mid-80% range.

The center conductors of a coaxial cable can be made from many conducting materials in various styles, depending on the application. The traditional center conductor is a simple solid copper wire that extends throughout the coaxial cable. To increase the flexibility of the cable by trading off high-frequency performance, a braided or stranded center conductor can be utilized. This approach also ensures that good electrical performance is maintained at higher frequencies.

Techniques that are similar to those used on the center conductor are applied to the outer conductor to reduce weight and cost. Designers also strive to improve flexibility and reduce environmental strain. Because the outer conductor serves as the return path for the electrical signal, sufficient thickness must be maintained to prevent leakage/interference of the signal path in most applications. However, maintaining adequate thickness for a solid outer conductor increases weight while reducing flexibility. As a result, methods of braiding, stranding, and winding have been developed to offer adequate protection and performance.

For low-cost applications, minimal braiding is used to reduce cost, weight, and size. According to Paul Pino, principal electrical engineer for Gore Microwave Cable Products, "Cable



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manufacturers use a variety of material types, depending upon performance, cost, and manufacturability targets. Center conductors are generally silver-plated copper, though tin-plated copper is also used. Silver-plated, copper-clad aluminum is used in lightweight applications."

Lighter weight and smaller size may be desirable for higher-performing cables. This trend has led to the development of methods that add shielding layers, which are either woven, wound, or wrapped.

Such techniques produce disadvantages when it comes to the flexure and mechanical motion performance of the cable. As a result, additional techniques are required to maintain electrical performance under stress. Using a mechanically insulating dielectric layer between the multi-layered shields helps to prevent shielding deformation and wear over time with motion.

Additionally, a crush layer—typically comprising wound cylindrical steel—can be used to surround the high-performance cable. It will prevent damage from high pressures and torqueing. "Increasing the density of the dielectric increases its crush resistance," says Paul Warren, principal design sngineer for Gore Microwave Cable Products. "But the performance of the coaxial cable suffers. So the most common practice is to use a stiffer jacket. For example, adding stainless-steel braid over the coaxial shield improves crush resistance while sacrificing weight and flexibility. Armored cable jackets are the most effective, but they are also very heavy and expensive."

Depending on the cable's environment, several methods of jacketing a coaxial cable can also protect its performance. The standard coating, polyvinyl chloride (PVC), can be made in a variety of thicknesses and colors. Although PVC is relatively chemical and temperature resistant, it cannot withstand mechanical stressors. A woven outer jacket using high-tensile synthetic materials is sometimes used to increase the mechanical performance of a coaxial cable. Such a jacket provides snug pressure in addition to a coating that is resistant to cuts, slices, and abrasions.

"The other thing that can really affect cable assemblies—and the reason that there are so many varieties—is mechanical performance," notes Ellis. "Performance may have to do with the environment in which the cable will operate."

To account for such stresses, some companies have developed a number of proprietary materials and cable layers that help to enhance the performance of the cable under various conditions. mw

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BCF020T	0.3 x 200	DC - 26.5	60	13.5	20.0	31
BCF030T	0.3 x 300	DC - 26.5	90	13.5	21.5	30
BCF040T	0.3 x 400	DC - 26.5	120	13.0	23.0	32
BCF060T	0.3 x 600	DC - 26.5	170	12.5	25.0	32
BCF080T	0.3 x 800	DC - 26.5	240	11.2	26.0	27
BCF120T	0.3 x 1200	DC - 26.5	340	11.2	28.0	31
BCF240T	0.3 x 2400	DC - 26.5	720	9.8	30.4	26.7

Power pHEMT	Gate Size (μm)	FREQ. (GHz)	I_{dss} (mA)	GAIN (dB)	P_{1dB} (dBm)	PAE (%)
BCP020T*	0.25x200	DC - 26.5	65	17.7	24	60
BCP030T*	0.25x300	DC - 26.5	95	15.6	25.5	65
BCP040T	0.25x400	DC - 26.5	120	14.0	26.0	65
BCP060T*	0.25x600	DC - 26.5	180	12.0	28.0	60
BCP060T2	0.25x600	DC - 26.5	180	12.5	29.0	65
BCP080T*	0.25x800	DC - 26.5	240	10.5	30.0	60
BCP080T2	0.25x800	DC - 26.5	240	11.5	30.0	65
BCP120T	0.25x1200	DC - 26.5	350	11.0	32.0	60
BCP160T	0.25x1600	DC - 26.5	500	10.5	33.0	60
BCP240T	0.25x2400	DC - 26.5	700	10.0	34.5	55

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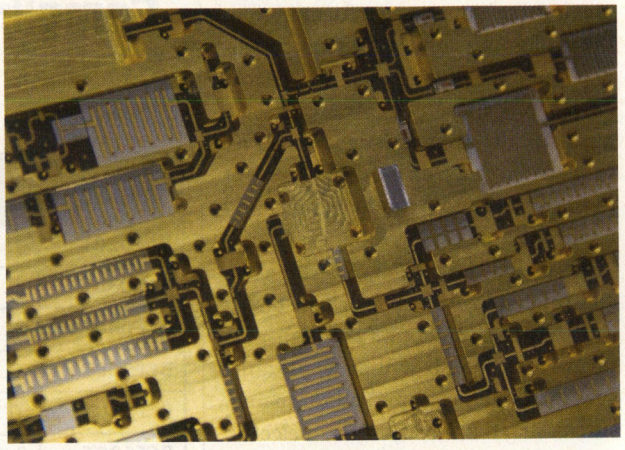
JEAN-JACQUES DELISLE | Technical Engineering Editor

Is Going Soft a Good Thing? How about Full-Auto?

Compressed design cycles and more complex devices are making software and automation techniques an integral part of an engineer's toolkit.



1. Gold plating thin-film filter components and the use of metallic materials, such as brass, increase the performance and reliability of RF/microwave components, which are susceptible to corrosion conditions and thermal stress. (Courtesy of Mercury Systems)

A COMMON THEME in every sector of the RF industry is the rapid acceleration of product cycles and technological advances. This trend could stem from the inclusion of RF technology in many widely adopted consumer products. Or it could result from a few technology breakthroughs that have expedited the manufacturing process. Either way, design cycles for custom devices are forced to match this velocity and deliver increasingly complex and multi-domain designs. Fortunately, software tools and automation techniques are helping engineers keep up with these rapid and highly integrated deliverables *(Fig. 1)*.

In past years, the interaction between custom RF/microwave multi-function device manufacturers and their customers involved a predefined specification and an outline drawing. The specifications were relatively straightforward, and they had several months to several years to deliver a final product. These custom multifunction modules (CMMs) lacked the digital, analog, and power components present in modern-day electronics.

With the increased focus on high levels of integration and multi-domain functionality, a more hands-on approach was needed. According to Anthony Pospishil, general manager for Mercury Systems' West Caldwell Advanced Micro Center, "When we work with a customer to develop their architecture, we break down their requirements into block diagrams and then into components and elements. Next, the system is simulated from end to end according to the performance necessary to meet their requirements. We develop a specification using statistical models to see what is really producible and feed that back to the customer. The specification doesn't always match their needs. And sometimes, requirements and performance criteria shift and there is a back and forth with the specifications. "

A much more detailed approach to the early design stage has been enabled by software that can model high-level to low-level capability. Previous spreadsheet-based methods functioned on cascade analysis, which was done with simple mathematical equations and the generic simulation of component operations. Yet this approach failed to account for many linear and nonlinear design aspects, as complex mathematical models would be needed to predict the performance of a more complex system. "Software is essential to the development of custom integrated assemblies," states Douglas Okamoto, senior electrical engineer for Microsemi. "It is important to understand the interactions and bottlenecks within the integrated assembly to optimize performance parameters."

Today's system-design tools can now include advanced behavioral models, which target portions of the device that are not yet fully defined, as well as inter-stage interactions. These aspects are mixed with more detailed parametric models of previous designs. Statistical models that more accurately resemble real systems can also be integrated into this early process.

Today's advanced software design suites are taking a large leap by including linear and nonlinear modeling and simulation. "Designers must understand the capabilities and limitations of software CAD tools," notes Okamoto. "High accuracy is often at odds with development time, so it is imperative to know how large of a problem the software can handle to yield results in an

acceptable amount of time. Although CAD tools and computing power have both improved over the years, designers must still verify the accuracy of simulations."

Electromagnetic (EM) simulators are often used to delve into the interactions among the various components in a CMM. These solvers can be used to predict coupling, interference, and even electro-thermal effects for a complete CMM, including the enclosures. Certain components of a CMM—mainly filters, mixers, and oscillators—are heavily influenced by parasitics and enclosure electrodynamics.

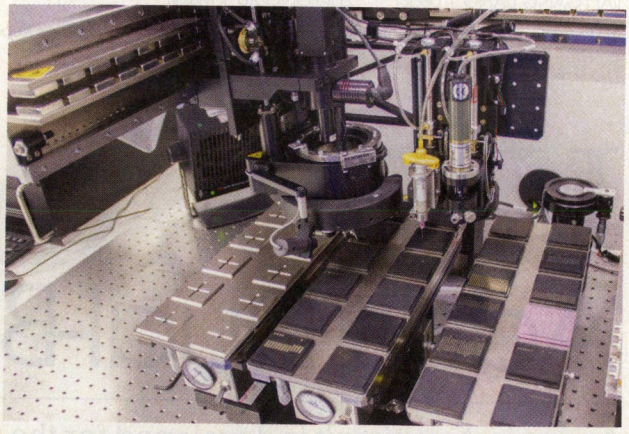
Many simulation tools can be used to create parasitic extractions and coupling models, which enable the appropriate shielding, filtering, or isolation to be applied. Some simulation suites are even capable of including EM, thermal, and structural analysis in one package.

For complex CMM designs, another innovation has quickly become common practice: Use of a controlled design process involving representatives of each design aspect as the project progresses. These design reviews often involve parties from RF, analog, digital, power, test, manufacturing, and quality control. This approach ensures that each discipline's needs are met early in the process. As design cycles have shrunk, such a capability has of course become more critical.

Design for automated manufacturing is another critical time-reducing step in today's design process. It also requires additional considerations in the early design stages. Thankfully, automated manufacturing steps, such as wire bonding and quality-control testing, are growing increasingly reliable. They are helping to produce small to high volumes of CMMs that can consistently meet high-end standards with less wastage *(Fig. 2)*.

As the machine manufacture and assembly of the latest electronics becomes more common and electronics grow more complex, automated manufacturing processes will be able to exceed the handmade manufacturing of even the most refined technicians. This has not been the case yet with many sensitive components, such as filters. After all, many of the components that traditionally compose these devices require custom and hands-on manipulation for tuning. Yet future components, which are designed specifically for automation, may soon replace the older hand-style components for the benefits of cost, reliability, repeatability, and quality control.

Design for test is a significant consideration in this process, as the models' precision can be refined to avoid costly troubleshooting. If test points aren't specifically designed for in advance, there may not be adequate access to the necessary signals in a component or integrated circuit (IC).



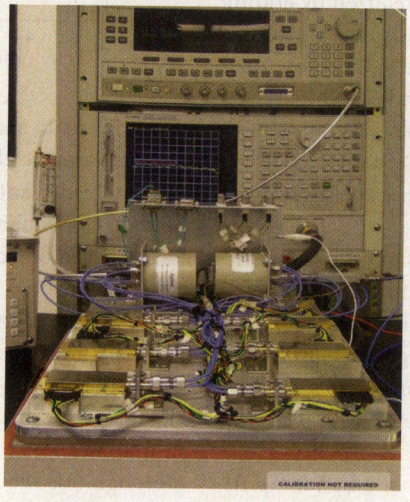
2. Automated pick-and-place machines help to ensure consistent and reliable assembly modules in a fast and cost-efficient assembly process. (Courtesy of Mercury Systems)

Additionally, designing for test can mitigate interference from the test setup and probes in advance.

"We can get a lot more electrical testing done now with automated testing," states Pospishil. "For example, we have complex modules with 10 inputs and outputs. To test a module like that, we will use automated testing with a controller and thermal platform with software written around the test requirements."

Automated testing can provide tremendous amounts of data, which can later be used to fuel future models, validate current ones, or test extremely complex multiple-input multiple-output (MIMO) components/devices. Those latter devices would otherwise be inaccessible or require shortcuts *(Fig. 3)*.

New software tools, design-process techniques, testing techniques, and process automation are enabling the rapidly shrinking design cycles of the most advanced multi-function devices. These new approaches deliver significant cost and time savings. At the same time, however, they may create distance between a design engineer and the circuits/components with which they are working. Considering that these software tools and models are relied upon more extensively, they're now replacing the physical testing and validation that was once the precedent.



3. Testing automation can enable characterization and analysis of complex module performance in ways that may be too costly or time intensive otherwise.

Changes like these raise the question of how far these simulation tools and models can be trusted. Yet another argument is that the new wealth of data enabled by these methods is providing skilled designers with even greater understanding of the underlying mechanics of today's devices. These technologies and tools can more readily transform that understanding to actionable designs. MW

Design Feature

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UWB Antenna Adds Dual-Band Notches

An equivalent circuit is developed for the fabrication of an UWB antenna with band notches at 3.30 to 3.89 GHz and 5.6 to 6.1 GHz.

The number of applications utilizing ultrawideband (UWB) electronic systems has increased, and all of them rely upon effective antenna designs. For practical use, UWB antennas should also coexist with narrowband applications within the UWB frequency range, which can be done via the inclusion of band notches within the antenna's UWB frequency coverage range.

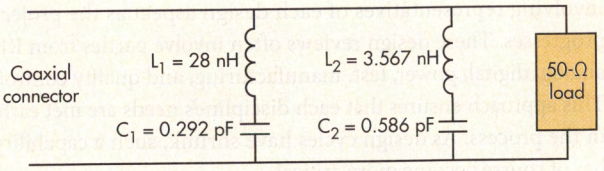
Fortunately, an equivalent circuit has been developed for an UWB antenna with a pair of frequency notches to minimize interference from narrowband applications. The equivalent circuit was used to produce a printed-ellipse-slot (PES) UWB antenna with a frequency range of 3.0 to 10.8 GHz, in addition to band-notched functions at 3.30 to 3.89 GHz and 5.6 to 6.1 GHz.

These band-notched functions can be realized by adding two "braids" to the antenna design—braids that are equivalent to two series inductance-capacitive (LC) resonances in the antenna circuitry. The notched bands can be used to cover working bandwidths of 5.725 to 5.850 GHz for wireless local-area networks (WLANs) and 3.30 to 3.70 GHz for WiMAX, minimizing interference from those applications for UWB systems.

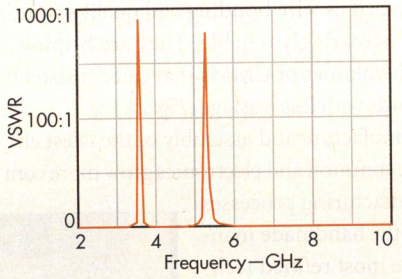
UWB systems are gaining attention for their capabilities to support high transmission rates at low power levels and small-sized circuits.[1,2] Because of existing applications operating within the UWB frequency range, such as WLAN and WiMAX systems, the interference from these more narrowband applications must be resolved before UWB circuits can be used.

One possible solution is the addition of a bandstop filter to the UWB system, although the filter adds complexity. A more practical approach is the use of an antenna with band-notched functions.

Various methods can be employed to realize band-notched functions in an antenna with UWB coverage. These include adding parasitic elements,[3-5] using matching units,[6] working with a slot antenna,[7-11], and using a fractal antenna.[12] Methods for achieving band-notched functions in an antenna are based on adding a parallel or series LC resonator to the antenna.



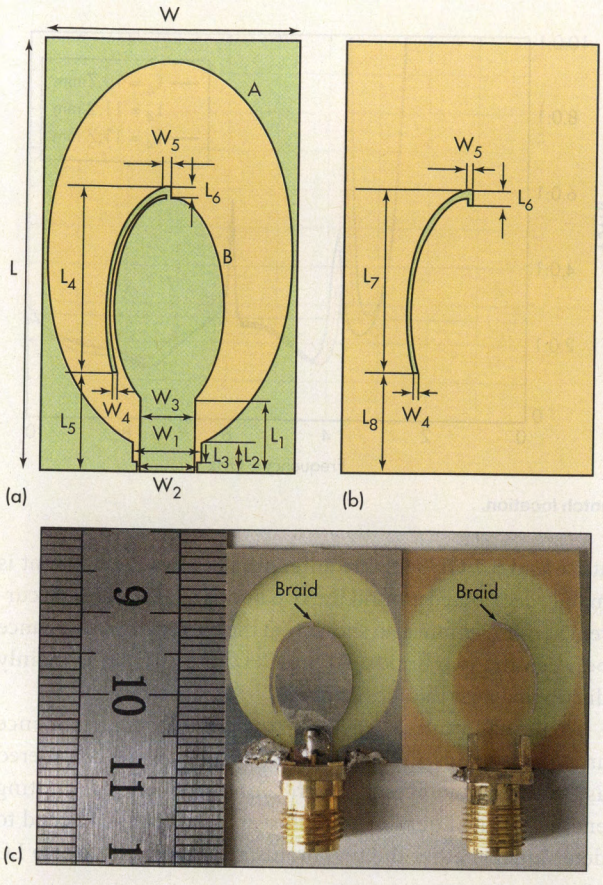
1. This equivalent circuit was used to represent the antenna with the inductor and capacitor values shown.



2. This plot shows the VSWR characteristics of the equivalent circuit as simulated by ADS software.

For a slot antenna with band-notched functions, the slot in the radiating unit serves as a parallel or series LC resonator.[13] Adjusting the spectral position of the band notch involves changing the size of the slot. Also, the band-notched antenna function can be realized by means of split-ring resonators, although this requires a typically artificial electromagnetic (EM) structure.

As a practical solution, a wideband planar monopole antenna was developed with two braids to achieve the two band notches. The approach yields effective results without adding



3. These images show the proposed antenna: (a) front view, (b) rear view), and (c) a photograph of the fabricated antenna.

undue complexity to the antenna. To reinforce the validity of the approach, simulation results based on the High Frequency Structure Simulator (HFSS) electromagnetic (EM) simulation software from Keysight Technologies (formerly Agilent Technologies; www.keysight.com) will be presented along with experimental results.

The basic principle of a dual-band notched antenna is somewhat equivalent to adding two bandstop filters to an antenna. In the process of designing such an antenna, the bandstop filters can be alternated by using special structures, much like the braids described in this report. The braids within the antenna play a role much like filters to reject two target frequency bands.

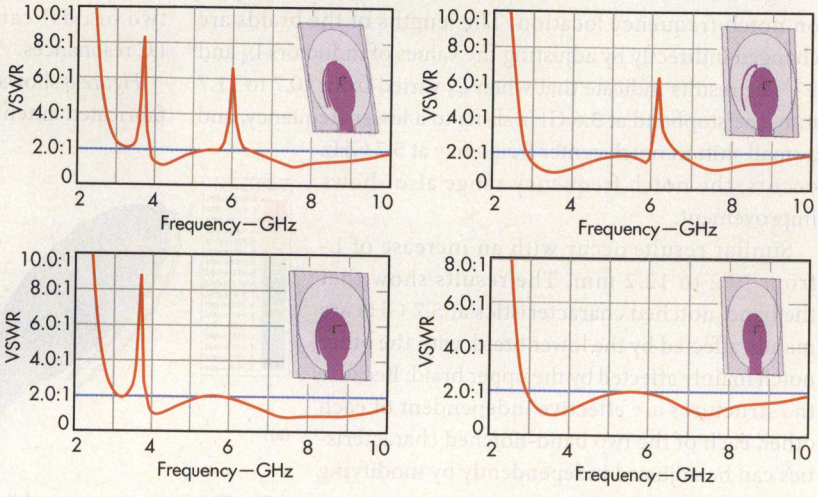
The antenna operates in a transmission-line-like mode. The UWB antenna and feeder are equivalent to a 50-Ω load in the equivalent circuit, with two simple series LC branches added to the circuit *(Fig. 1)*. Using the Advanced Design System (ADS) simulation software from Keysight to obtain simulation data *(Fig. 2)* for use as a reference, the results shows that two obvious band-notched functions are realized at 3.6 and 5.7 GHz, when L_1 = 28 nH, C_1 = 0.292 pF, L_2 = 3.567 nH, and C_2 = 0.586 pF.

The simulation results confirmed that adding two series LC resonances to the antenna circuit is a feasible way to obtain the dual-band-notched characteristics. The LC resonances can be realized by means of special structures, but a number of steps should be taken beforehand. First, to confirm whether a special structure will provide the desired resonance, the input impedance of the proposed antenna should be well known. According to resonance theory, the imaginary part of the input impedance should have two downward trends at the notch frequency points.

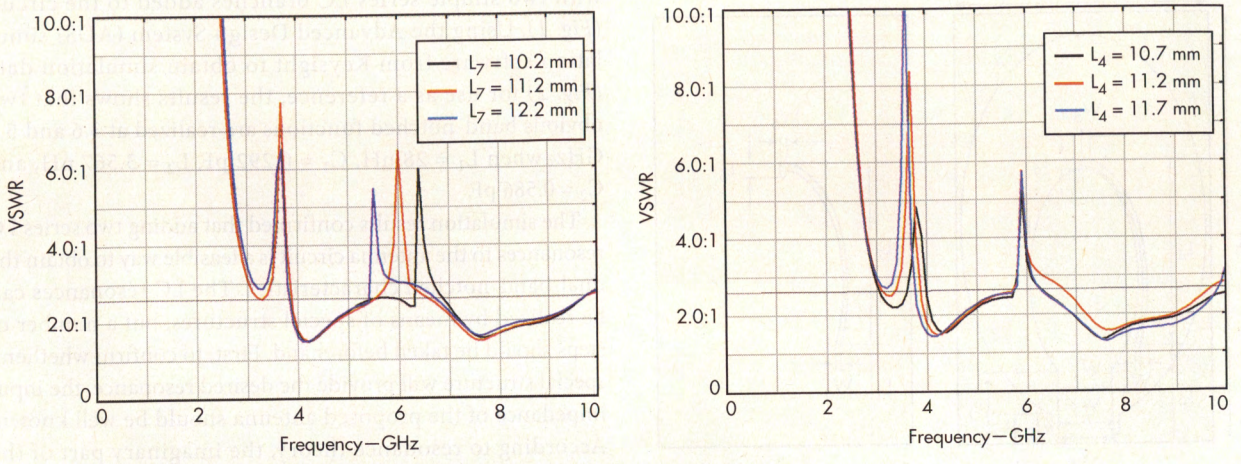
Second, the notch frequency spectral responses should be somewhat adjustable, which requires that the structures used for the resonances be isolated and adjustable independently. Finally, any added structures should not impact the directional and/or impedance-matching characteristics of the original UWB antenna design.

Based on this analysis, an UWB antenna with standard band-notched functions at 3.3 to 3.89 GHz and 5.6 to 6.1 GHz was developed *(Fig. 3)*. It was fabricated on high-frequency substrate material with dielectric constant of 4.5, loss tangent of 0.0035, and thickness (h) of 1 mm. The antenna features an elliptically shaped radiating patch.

To further improve the antenna's impedance, a rectangular slot measuring $L_2 \times 3 \times W_1$ was etched from the antenna's coplanar-waveguide (CPW) ground plane. The axis of ellipse A measures 11.7 mm, with an axial ratio of 0.747. The axis of ellipse B is 6.5 mm, with an axial ratio of 0.6. The braids



4. These plots show the VSWR characteristics of the different proposed antennas.



5. The plots responses show the influence of different braid lengths on notch location.

are obtained by employing a larger ellipse with an axis that measures 7.5 mm and an axial ratio of 0.6 inserted by a smaller ellipse that features an axis measuring 7.1 mm and an axial ratio registering 0.6.

The quality of the band-notched antenna's response is mainly determined by the location of the stopbands and the frequency ranges of the notches. Theoretical analysis shows that band-notch location is mainly related to the length of the braid. To better understand this, the effects of different lengths of inductors L_4 and L_7 and different structures with one or two braids were examined.

Figure 4 shows the antenna's reflection coefficients when loaded with different structures. The results show that the original UWB antenna (without braids) offers good impedance response from 3.0 to 10.8 GHz, with each of the braids helping to remove interference at the band-notched frequencies.

Figure 5 shows the influence of different braid lengths on notch frequency location. The lengths of the braids are changed indirectly by adjusting the values of inductors L_4 and L_7. The results indicate that when L_4 varied from 10.7 to 11.7 mm, the stopband at 3.6 GHz shifts to a lower frequency, and a small shift in notch center frequency at 5.7 GHz occurs; the notch frequency range also shows improvement.

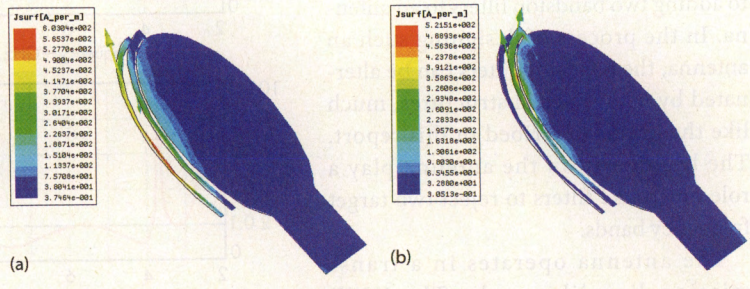
Similar results occur with an increase of L_7 from 10.2 to 12.2 mm. The results show that the band-notched characteristics at 5.7 GHz are mainly affected by the lower braid, with the other notch mainly affected by the upper braid. Because the structures are effective independent of each other, each of the two band-notched characteristics can be adjusted independently by modifying the parameters of each structure.

Figure 6 presents surface current distributions at 3.6 and 5.7 GHz for the antenna. It shows that current is mainly distributed around the two braids at 5.7 GHz. The current vector diagram also shows that the current is in resonance between the two braids. At 3.6 GHz, the current is mainly distributed near the above braids.

Analyzed intuitively, because the current is in resonance around the braids, the additional structures can be considered as two LC resonances at notch center frequencies, limiting energy radiated outward. Further analysis will be needed to determine whether the two braids are equivalent to two LC series resonances.

Figure 7 shows the input impedance for the proposed antenna. Two sudden drop points can be seen from the imaginary part of impedance (the blue line), corresponding to two notch-frequency-point positions. The impedance plot shows that the imaginary part of impedance is small enough at the notch center frequency. Analyzed from the theory of resonance, the two LC resonances (corresponding to the two braids) can be considered equivalent to two series LC resonances.

Figure 8 shows the E- and H-plane radiation patterns of the fabricated antenna at 3 and 7 GHz. The simulated and mea-



6. The EM diagrams represent the antenna's surface current distributions at (a) the first notch frequency, 5.7 GHz, and at (b) the second notch frequency, 3.5 GHz.



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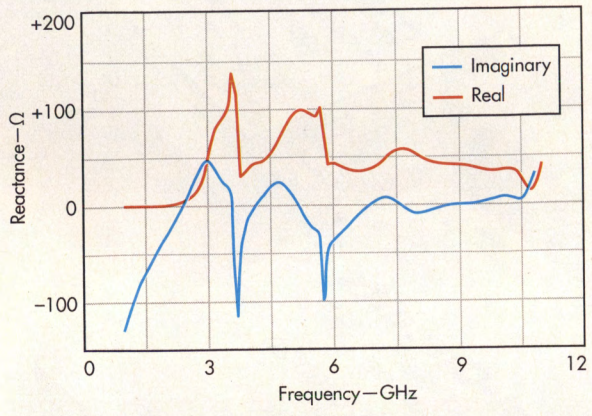
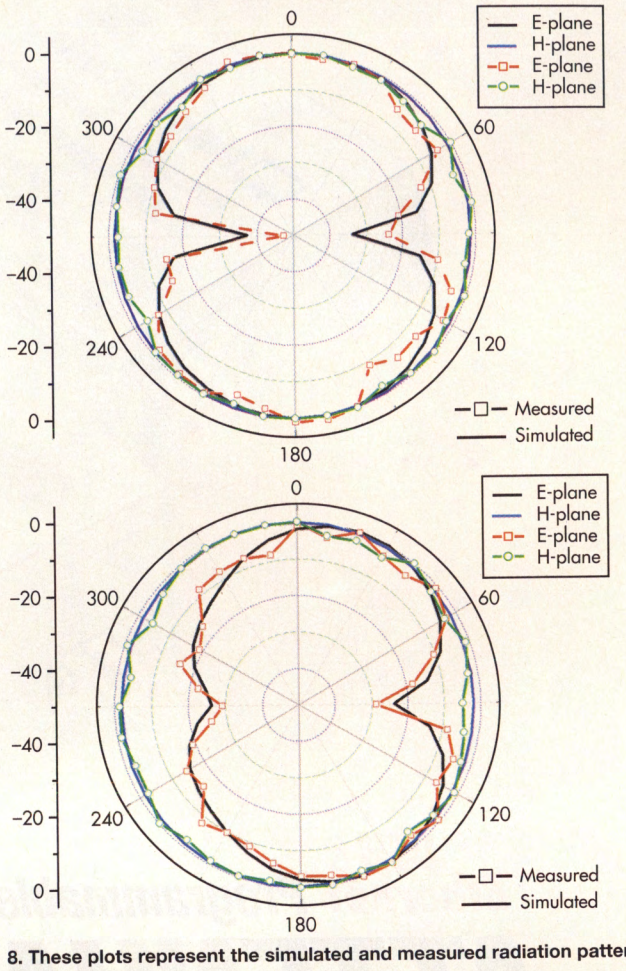


7. These curves show the simulated input impendence of the proposed antenna.

sured results both exhibit relatively omnidirectional radiation patterns. The radiation patterns actually resemble those of a vertical dipole antenna. They also show that the added structures have little effect on the radiation patterns of the modified antenna compared to the original antenna design.

Figure 9 shows the simulated and measured VSWR results for the proposed antenna. The simulated and measured results show good performance and consistency, with clear band-notched characteristics at 3.5 and 5.7 GHz.

These results point to this antenna design, with its dual-band-notched characteristics, as a viable candidate for UWB applications where interference from other wireless applications (such as WLAN and WiMAX systems) may be a concern. mw



8. These plots represent the simulated and measured radiation patterns of the antenna.

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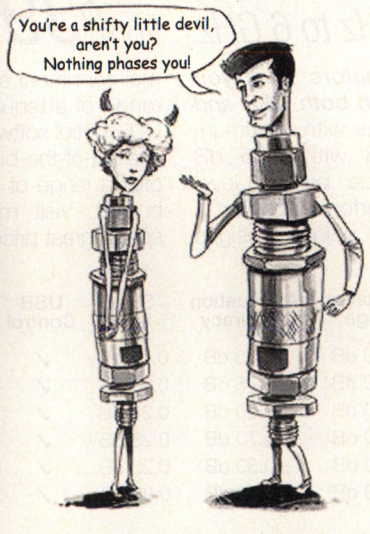

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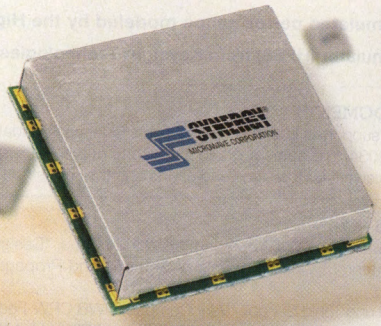

Model	Frequency (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Max.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
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HFSO745R84-5	745.84	0.5 - 12	+5 @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 @ 30 mA	-146
HFSO914R8-5	914.8	0.5 - 12	+5 @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 @ 35 mA	-141
HFSO1600-5 *	1600	0.5 - 12	+5 @ 100 mA	-137
HFSO2000-5 *	2000	0.5 - 12	+5 @ 100 mA	-137

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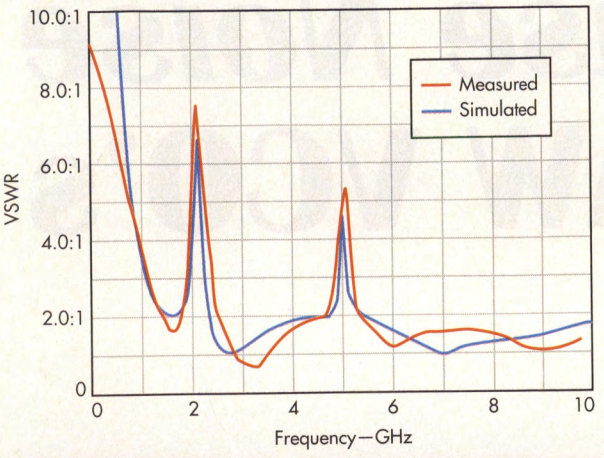

9. These plots show the simulated and measured VSWR behavior of the UWB antenna. The responses show a range of impedance mismatches equivalent to a VSWR as high as 10.0:1 for a frequency range from DC through 10 GHz, comparing actual measurements with computer-simulated performance modeled by the High Frequency Structure Simulator (HFSS) from Keysight Technologies.

SUMMARIZING THE DIMENSIONS OF THE PROPOSED ANTENNA (ALL DIMENSIONS IN mm)

W 18	W_1 4.8	W_2 4.3	W_3 3.78	W_4 0.35	W_5 0.3
L 26	L_1 4.3	L_2 1.75	L_3 0.5	L_4 11.2	L_5 5.9
L_6 1	L_7 11.2	L_8 6.0	H 1		

ACKNOWLEDGMENTS

This work was supported in part by the National Science Foundation China under grant No. 6132034. The authors would also like to deliver sincere gratitude to the anonymous reviewers for their time and efforts and their constructive comments.

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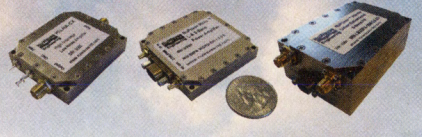

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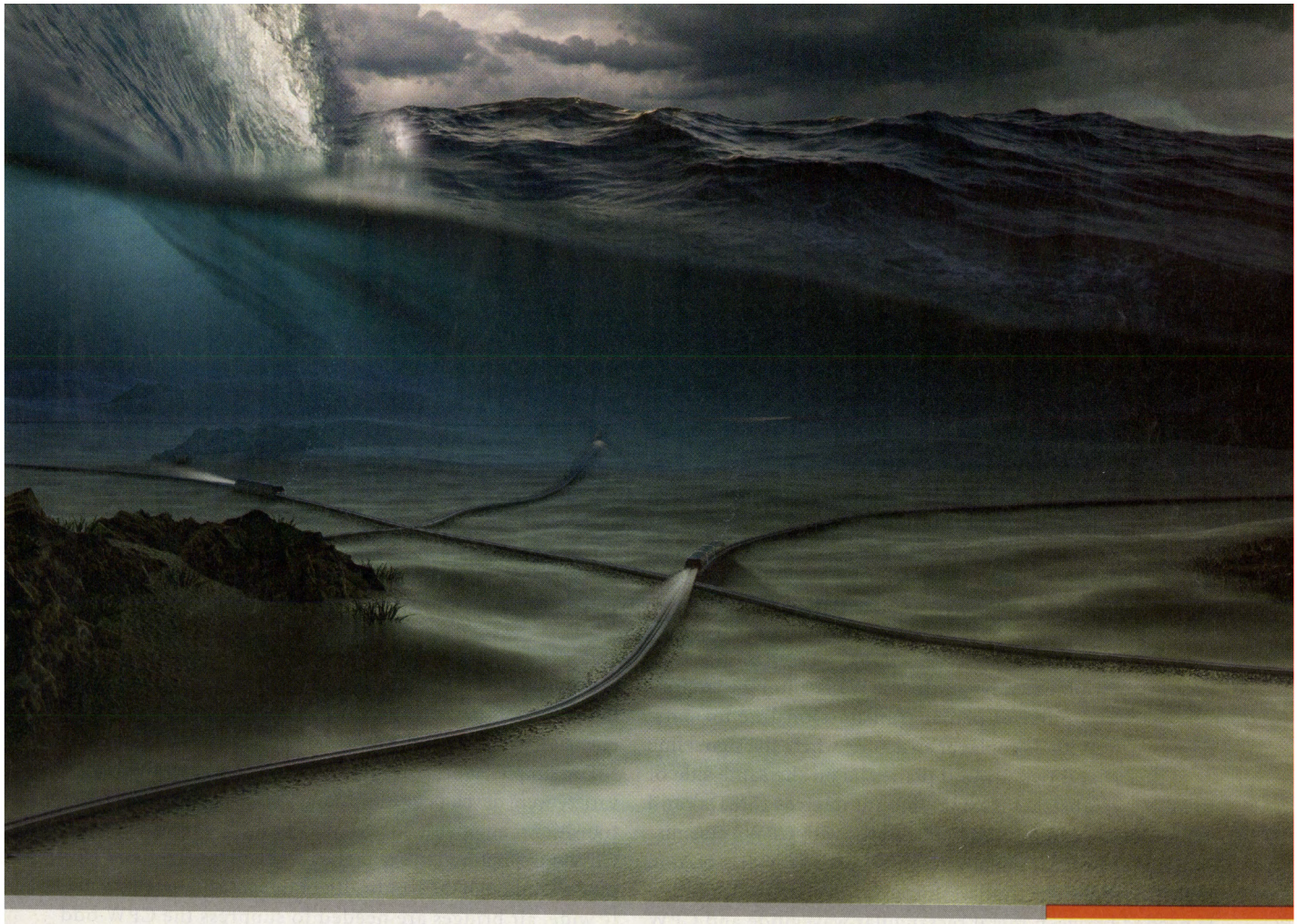

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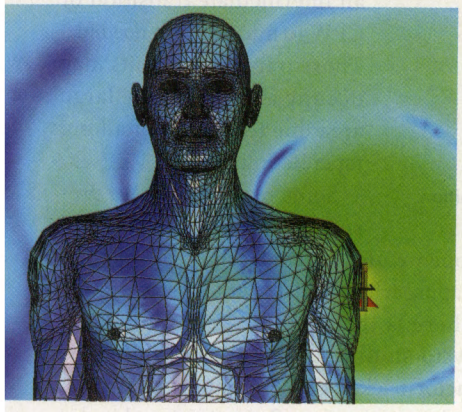

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Transition Tackles MM-Wave Frequencies

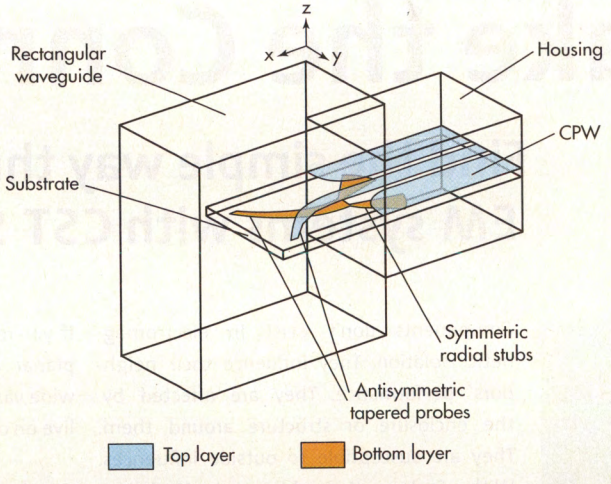
This in-line rectangular-waveguide-to-coplanar-waveguide transition provides excellent performance at millimeter-wave frequencies.

Coplanar waveguide (CPW) is among the more popular of planar transmission-line formats. With its coplanar structure, where the signal line and two ground planes lie on the same side of the circuit substrate, surface-mount devices (SMDs) and active devices can be readily integrated with CPW transmission lines.[1] Because metal waveguides are still widely used in high-frequency electronics,[2] however, an effective transition is needed between metal rectangular waveguide and CPW transmission lines.

Several waveguide-to-CPW transitions have been presented in the open literature[3-16] and some good performance levels have been observed. These transitions are mainly either along the propagation direction of the waveguide[3-15] or transverse to the propagation direction.[16] By way of one possible solution, a simple structure has been developed to serve as an effective in-line waveguide-to-CPW transition.

Some complex approaches have been developed in pursuit of waveguide-to-CPW transitions.[3,4] In a continuous transformer, the waveguide ridge acts as the center conductor of the CPW, and such a configuration can gradually transform the CPW's electric fields into the transverse electromagnetic (TE_{10}) electric fields of a rectangular waveguide. A waveguide-to-CPW transition with enhanced performance at X-band employed a discrete three-step Chebyshev transformer.[5] No bond wires are needed to suppress the CPW odd mode in those transitions; however, their assembly becomes very difficult at millimeter-wave frequencies, incurring high fabrication costs.

For simpler fabrication, transition circuits of the planar variety were developed.[6-16] Among these waveguide-to-CPW transitions, an open-ended planar probe fed by asymmetric CPW was employed to excite the rectangular-waveguide TE_{10} mode.[6] Although the bandwidth of this transition is extremely wide, air bridges are needed to suppress the CPW odd mode resulting from the asymmetric discontinuity.



1. This is the basic structure of the waveguide-to-CPW transition.

Some broadband transitions have been achieved by using a tapered finline.[7-10] In ref. 7, the air bridge is eliminated by means of a special CPW housing design. In ref. 10, there is likewise no need for an air bridge, but the bandwidth is limited by the design's phase shifter, and an intermediate transition of CPW to microstrip is needed.[9] Those transition circuits may occupy an electrically large area due to the use of a long tapered finline.[7-10]

Some researchers have presented waveguide-to-CPW transitions using an open-ended tapered strip.[11,12] Although the circuit size for this approach is typically smaller than finline-based transitions, there is the need for an intermediate transition from CPW-to-slotline as well as air bridges. The transition with conductor-backed CPW[12] features a narrower bandwidth than the other types of configurations, and it also requires viaholes.



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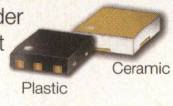

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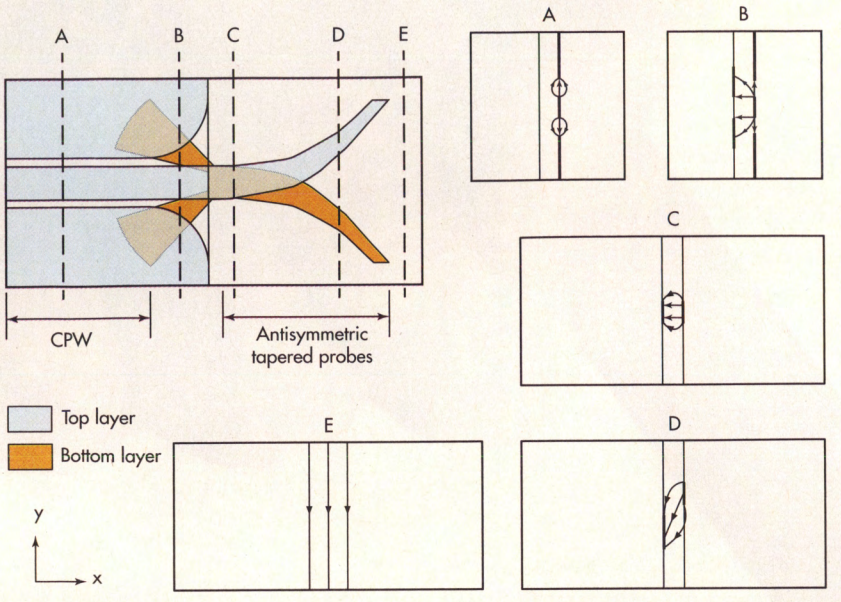


2. The diagrams show the cross-sectional E-field distribution of the transition.

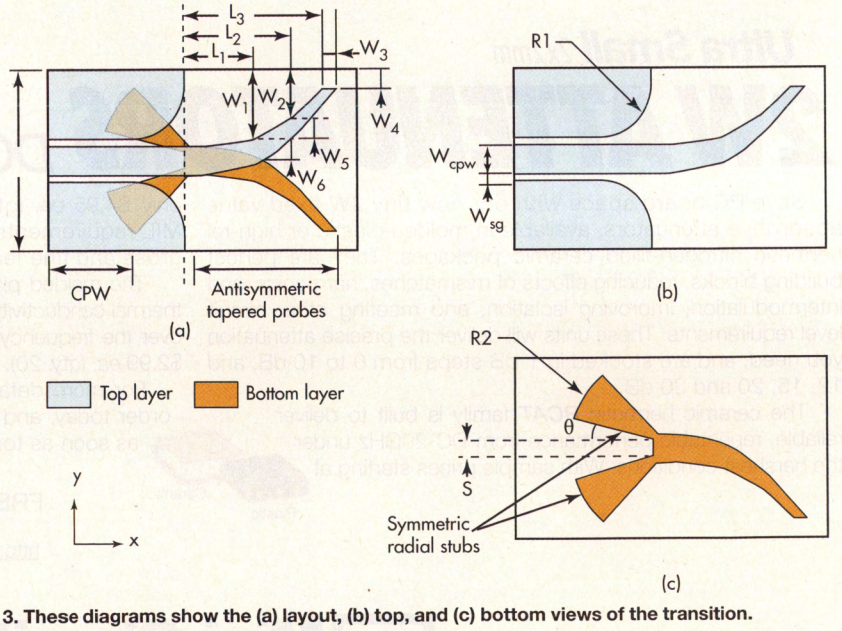
Figure 1 shows the configuration for the proposed transition between rectangular waveguide and CPW. The transition consists of rectangular waveguide, antisymmetric tapered probes, symmetric radial stubs, and CPW. The rectangular waveguide is standard WR-28 with dimensions of 7.112 × 3.556 mm, which will ensure single-mode TE_{10} propagation at Ka-band frequencies. RT/Duroid 5880 PCB material was used as the circuit substrate material for the transition; the PCB material has relative permittivity of 2.22, loss tangent of 0.009, and thickness of 0.254 mm. The waveguide-to-CPW transition is a planar, double-sided circuit. CPW is fabricated on the top of the substrate, symmetric radial stubs are fabricated on the bottom of the substrate, and antisymmetric tapered probes are fabricated on both sides of the substrate.

In ref. 13, an end-fire antenna was applied in the design of a waveguide-to-CPW transition. A truncated bow-tie antenna was used for broadband performance,[14] but it still requires an intermediate transition and air bridges.[13,14] In one design, a right-angle transition between waveguide and CPW was achieved by using slot antennas.[16] The approach doesn't require an air bridge, but it is narrowband. More recently, a miniaturized waveguide-to-CPW transition was realized by using inductance-compensated slotline technology, which involves multiple-section slotline.[15] But this multiple-section design has some problems at millimeter-wave frequencies, and also requires an air bridge.

The antisymmetric tapered probe was introduced in the design of a waveguide-to-microstrip transition.[17] In this earlier design, the microstrip is a double-layer transmission line while the CPW is a uniplanar transmission line, where the signal line and the two ground planes are on the same side of the substrate. As shown in *Fig. 1*, the antisymmetric tapered probe is inserted into the center of a standard waveguide E-plane. The CPW is within a metal housing with dimensions of 3.556 × 3.556 mm, which ensures only CPW-mode propagation at Ka-band frequencies.

NOVEL TRANSITION

In pursuit of simplicity, a new type of waveguide-to-CPW transition was developed based on coupling probes; it requires neither air bridges nor an intermediate transition. An experimental version was fabricated using WR-28 rectangular waveguide and RT/Duroid 5880 printed-circuit-board (PCB) material from Rogers Corp. (www.rogerscorp.com). A back-to-back transition prototype was fabricated; the scattering parameters were measured to verify the performance of the design. The transition, with good performance at Ka-band frequencies, offers advantages of ease of fabrication, broad bandwidth, and low loss.



3. These diagrams show the (a) layout, (b) top, and (c) bottom views of the transition.

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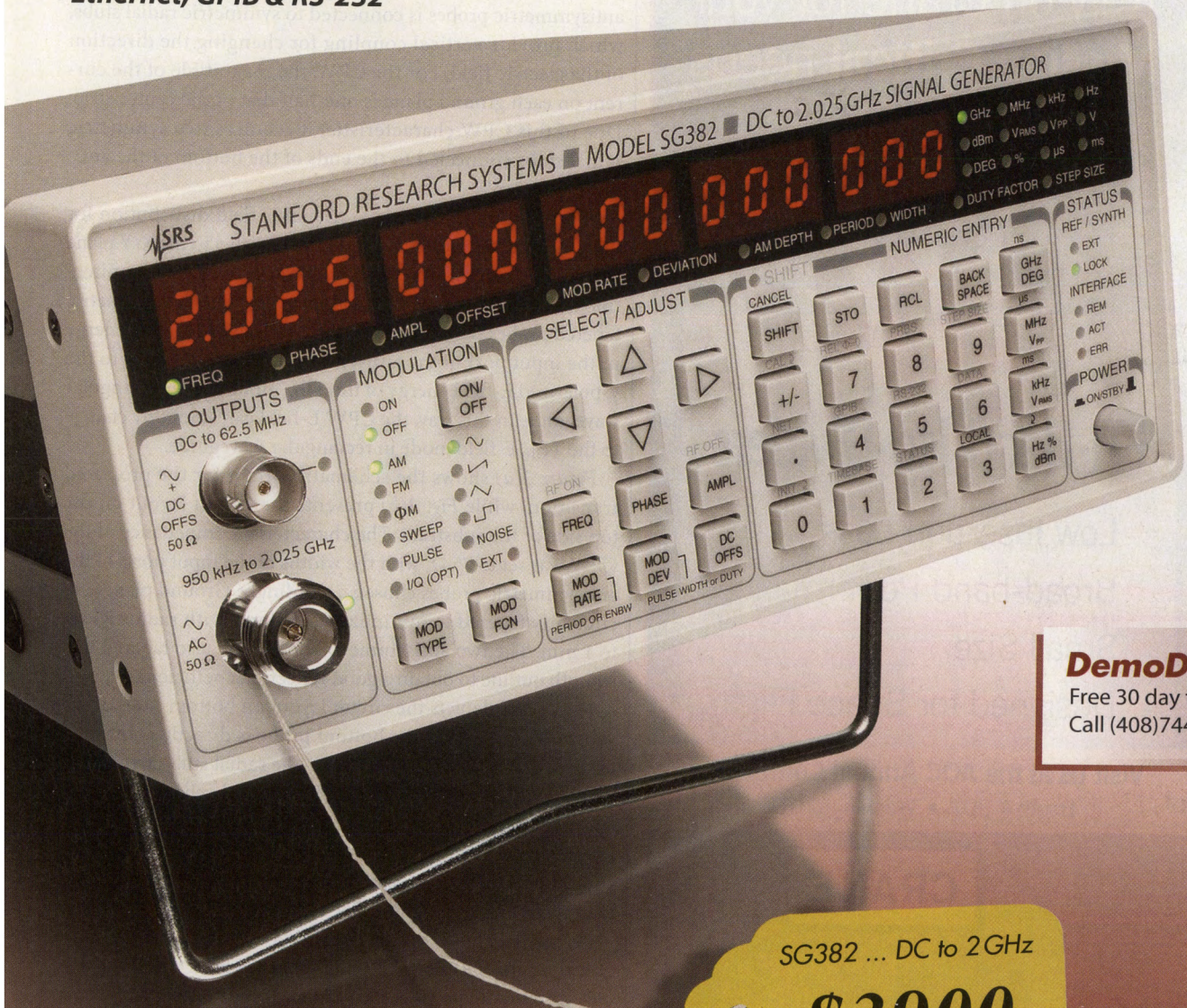

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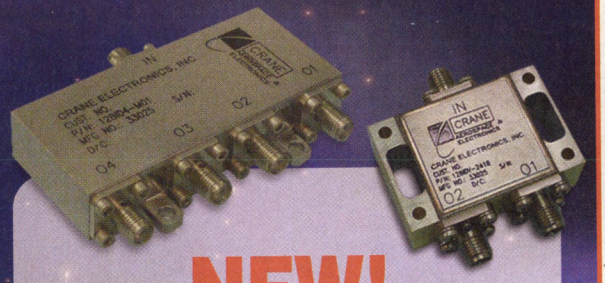

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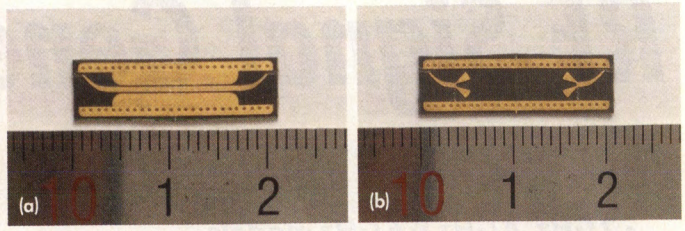

4. The photographs show the (a) top and (b) bottom views of the substrate fabricated for the back-to-back transition.

The center strip of the CPW is directly connected to the top probe of the antisymmetric probes. The bottom probe of the antisymmetric probes is connected to symmetric radial stubs, which provide vertical coupling for changing the direction of the electric field. For the CPW, the magnitude of the current on each ground plane is one-half that of the center strip. Due to this CPW characteristic, it requires two symmetric radial stubs connected to the ends of the bottom of the antisymmetric probes.

Figure 2 shows the cross-sectional E-field distribution for the proposed transition. The E-field is parallel to the X/Y plane in the CPW section. The radial stubs serve to change the direction of the E-field from parallel to vertical. The antisymmetric tapered probes then transform the z-polarized E-field's energy in the input port of the antisymmetric tapered probes to the y-polarized E-field energy of the TE_{10} mode in the rectangular waveguide. In this way, the CPW E-field can smoothly change to the TE_{10} E-field mode in rectangular waveguide.

Figure 3(a) shows the schematic circuit for the proposed transition, while *Fig. 3(b)* presents the circuit layout on the top side of the substrate. The characteristic impedance of the CPW was set to 75 Ω, with the widths of the input ports of the antisymmetric probes chosen accordingly. Ground planes are circularly tapered to minimize reflections, with radius R_1 set to 1 mm. The two antisymmetric probes are also tapered in a smooth outline to obtain a good reflection coefficient.

Figure 3(c) depicts the circuit layout on bottom sides of the substrate. The end of the bottom probe is directly connected to the two symmetric radial stubs. The radial stubs are rotated with an optimal angle of 16 deg. to smoothly change the electric field from a y-axis direction to a z-axis direction. The overlap area between the radial stubs and the CPW ground planes should be optimized to provide sufficient electromagnetic (EM) coupling and to minimize reflections.

The radial stub is optimized with a radius, R_2, of 1.85 mm and an angle of 31 deg. The length of the entire transition circuit is approximately 4.6 mm. No air bridge is needed for this transition due to the symmetric structure of the radial stubs. *Figure 4* shows the fabricated substrate of the transition circuit.

The proposed transition was simulated and optimized using the High-Frequency Structure Simulator (HFSS) EM simulation soft-

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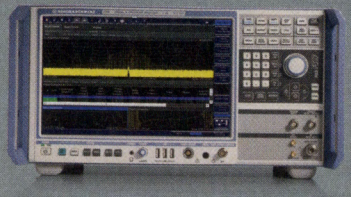

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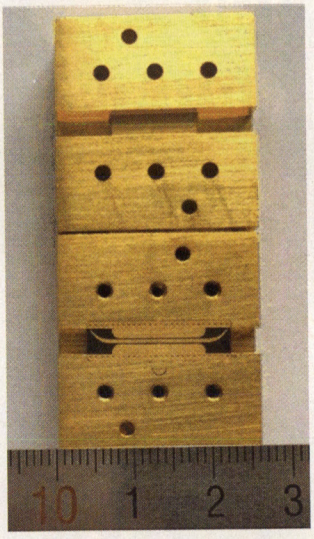
ware from Ansoft Corp. (www.ansoft.com). The dimensions of the transition circuit are shown in *Fig. 3*. The final value of the parameters are W_{cpw} = 0.55 mm, W_{sg} = 0.15 mm, W_1 = 1.4 mm, W_2 = 1 mm, W_3 = 0.26 mm, W_4 = 0.4 mm, W_5 = 0.38 mm, W_6 = 0.5 mm, L_1 = 1.38 mm, L_2 = 2.13 mm, and L_3 = 2.74 mm. To experimentally evaluate the performance of the proposed transition, two identical transitions were cascaded back to back.

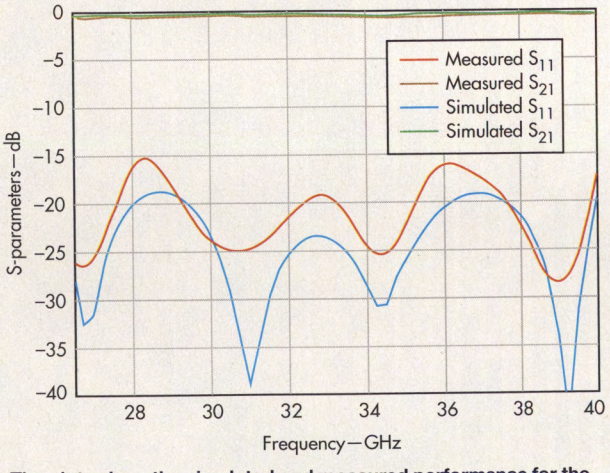
Figure 5 shows the fabricated back-to-back transitions. Measurements were made with a commercial vector network analyzer (VNA) and a pair of coaxial-line-to-waveguide adapters. A thru-reflect-line (TRL) calibration was performed at the WR28 access points. *Figure 6* shows the simulated and measured results of the back-to-back transitions, which are in close agreement. The measured results show that the insertion loss of back-to-back transition is less than 0.7 dB, with better than 15-dB return loss from 26.5 to 40 GHz. This implies that the insertion loss of a single transition is less than 0.35 dB across Ka-band frequencies.



5. The photograph shows the fabricated back-to-back transition.

In short, a broadband waveguide-to-CPW transition has been proposed based on tapered probes and symmetric radial stubs. Neither an air bridge nor an intermediate transition is needed for this transition, making it relatively easy to fabricate. To demonstrate the effectiveness of the design approach, a Ka-band back-to-back transition was fabricated and measured, with close agreement between simulated and measured results. Given its advantages of ease of fabrication, compact size, and low loss, such a broadband transition should be attractive for many millimeter-wave applications.

The use of the HFSS EM simulation software enabled measured results in *Fig. 6* that are quite close at different frequencies across the broadband range of study. As noted, the structure with its back-to-back transitions was calibrated with the aid of a commercial VNA and the resulting test results reveal quite low forward and return loss characteristics. The waveguide-to-CPW transition is fairly straightforward in design and fabrication, with low loss levels and minimal effects of reflections from the various circuit junctions even at millimeter-wave frequencies extending to 40 GHz. mw



6. The plots show the simulated and measured performance for the back-to-back transition through 40 GHz.

ACKNOWLEDGMENT

This work was supported by the Fundamental Research Funds for the Central Universities of China under Grant ZYGX2012J030.

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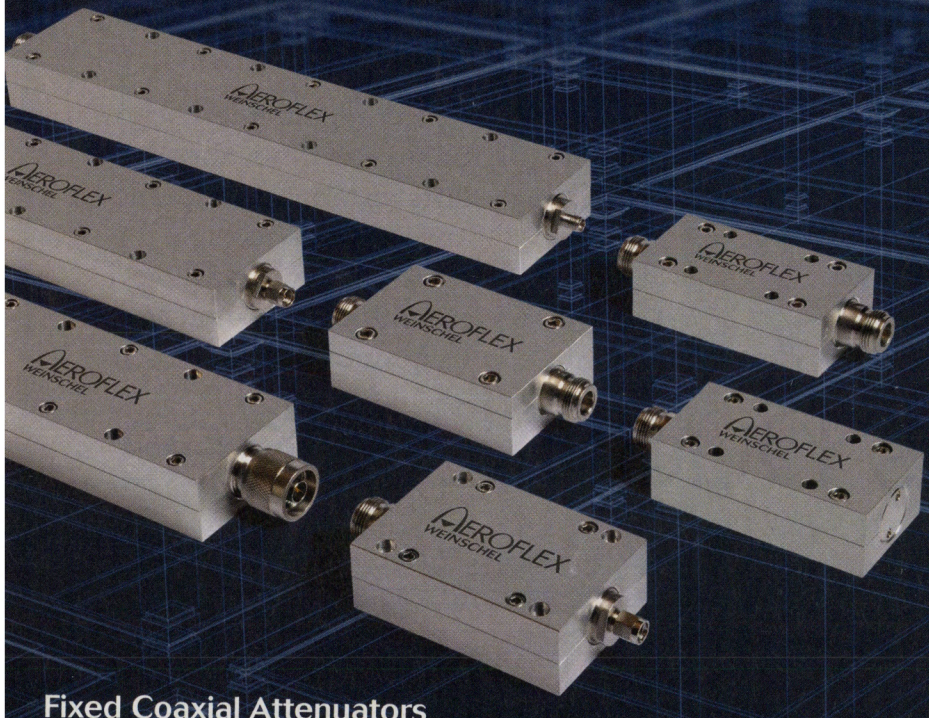

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253	DC to 6.0	550	10	10, 20, 30, 40	1.10 to 1.20*	SMK (2.92mm) or N
257	DC to 6.0	250	10	10, 20, 30, 40	1.10	SMK (2.92mm) or N
258	DC to 6.0	400	10	10, 20, 30, 40	1.10 to 1.25*	SMK (2.92mm) or N
268	DC to 6.0	100	10	6, 10, 20, 30, 40	1.10 to 1.15*	SMK (2.92mm) or N
284	DC to 10.0	50	5	3, 6, 10, 20, 30, 40	1.10 to 1.30*	SMK (2.92mm) or N

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1470	DC to 6.0	100	10	1.20	SMK (2.92mm) or N
1471	DC to 6.0	250	10	1.20	SMK (2.92mm) or N
1472	DC to 6.0	400	10	1.20	SMK (2.92mm) or N
1473	DC to 6.0	400	10	1.20	SMK (2.92mm) or N
1476	DC to 10.0	50	5	1.25 to 1.40*	SMK (2.92mm) or N

* Varies with frequency.

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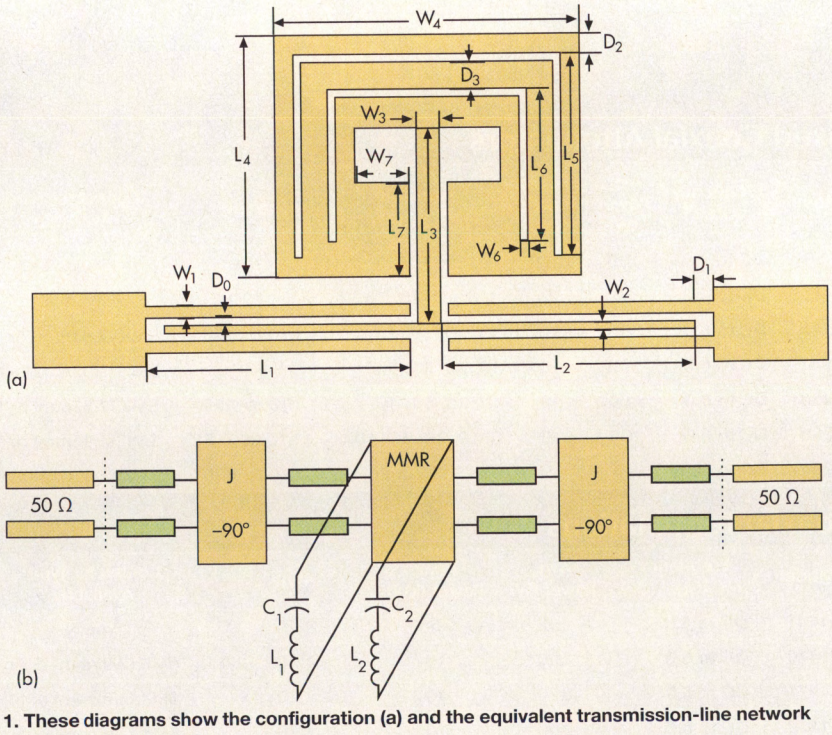
However, UWB systems cover very broad bandwidths, subjecting them to interference from many exist-



1. These diagrams show the configuration (a) and the equivalent transmission-line network (b) for the UWB BPF.

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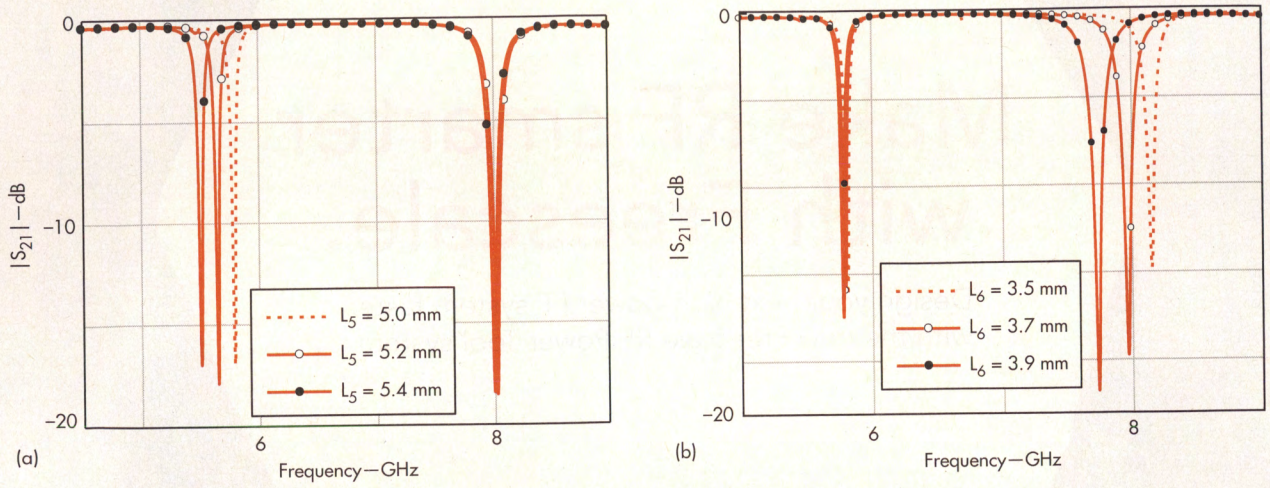


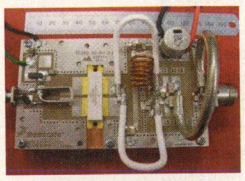
2. The simulated S-parameters for U-shaped slots have different values of filter parameter L_5 (a) and L_6 (b).

ing wireless networks, including 5.8-GHz wireless-local-area-network (WLAN) systems and some 8-GHz satellite-communications (satcom) systems. To minimize the effects of interference, UWB BPFs with multiple notched bands are needed to reject the unwanted signals.[10-17] One step toward achieving desired band-notched performance levels in UWB systems involved evaluation of stepped-impedance resonators.[10-13] Unfortunately, these designs came up with only one notched band. As a possible solution, double open-circuit stubs were embedded into the middle layer of broadside-coupled, stepped-impedance resonators,[14] with folded stepped-impedance resonators vertically coupled to the second layer of the multiple-layer circuit design.[15]

This approach produced two notched bands in a UWB BPF circuit. However, using such a multiple-layer circuit structure would ultimately lead to increased fabrication costs and incompatibility with typical existing microwave integrated circuits (MICs). Some work yielded BPFs with dual notched bands,[16,17] but these filters offered relatively low selectivity and less-than-ideal rejection levels for the notched filter bands.

Seeking improvements, engineers designed and developed a new compact UWB BPF with dual notched bands and good selectivity. An initial E-shaped multiple-mode resonator (EMMR) was used to create a basic UWB BPF with a pair of transmission zeros appearing in the lower and upper stopbands to improve skirt selectivity. Then, two parallel U-shaped slots (USSs) were etched into the initial EMMR to obtain the dual notched bands with a high degree of adjustment freedom, but without increasing filter size. The UWB BPF features notched bands centered at 5.8 and 8.0 GHz. To verify the validity of the design approach, measurements and computer-simulated results are presented for comparison.

Figures 1(a) and (b) illustrate the configuration of the proposed UWB BPF with dual notched bands and its equivalent circuit network, respectively. *Figure 1(a)* shows two microstrip interdigital coupled lines and an initial EMMR with two



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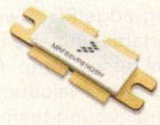

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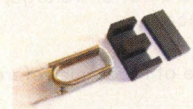

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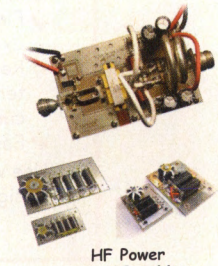

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embedded parallel U-shaped slots (USSs). The microstrip interdigital coupled lines provide sufficiently strong coupling in the desired UWB band.

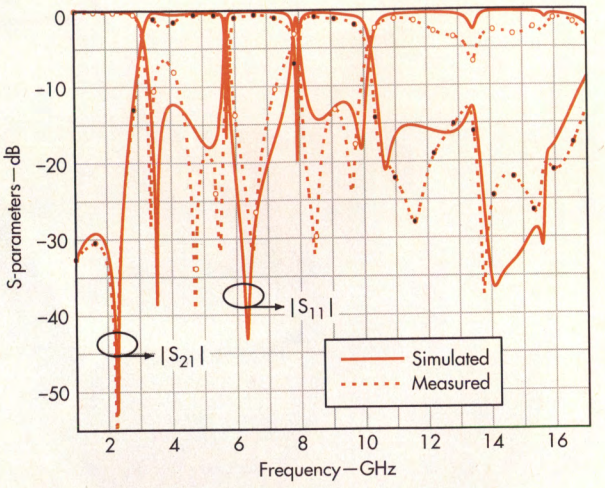
As seen in the equivalent-circuit network for the proposed UWB filter *(Fig.1(b))*, it's possible to model the microstrip interdigital coupled lines as two single transmission lines at two sides and a J-inverter susceptance in the middle. The two parallel USSs etched into the initial EMMR can be considered as two shunt-series resonant branches.

Adjusting the length of each USS, which is about one-half the wavelength of the desired frequency, tunes the center frequency of a notched band. Essentially, each USS is a half-wavelength resonator. To postulate the resonant frequency, refer to Eqs. 1 and 2:

$$f_{notch\text{-}lower} = c/[\lambda_{notch\text{-}even}(\varepsilon_{eff})^{0.5}] = c/[(2W_5 + 4L_5)(\varepsilon_{eff})^{0.5}] \quad (1)$$

$$f_{notch\text{-}upper} = c/[\lambda_{notch\text{-}even}(\varepsilon_{eff})^{0.5}] = c/[(2W_6 + 4L_6)(\varepsilon_{eff})^{0.5}] \quad (2)$$

where:



3. The plot compares measured and simulated S_{21} and S_{11} parameters for the fabricated UWB filter.

f_{notch} is the center frequency of the notched band;
λ_{notch} is the corresponding wavelength;
ε_{eff} is the effective dielectric constant;
and c is the speed of light in free space.

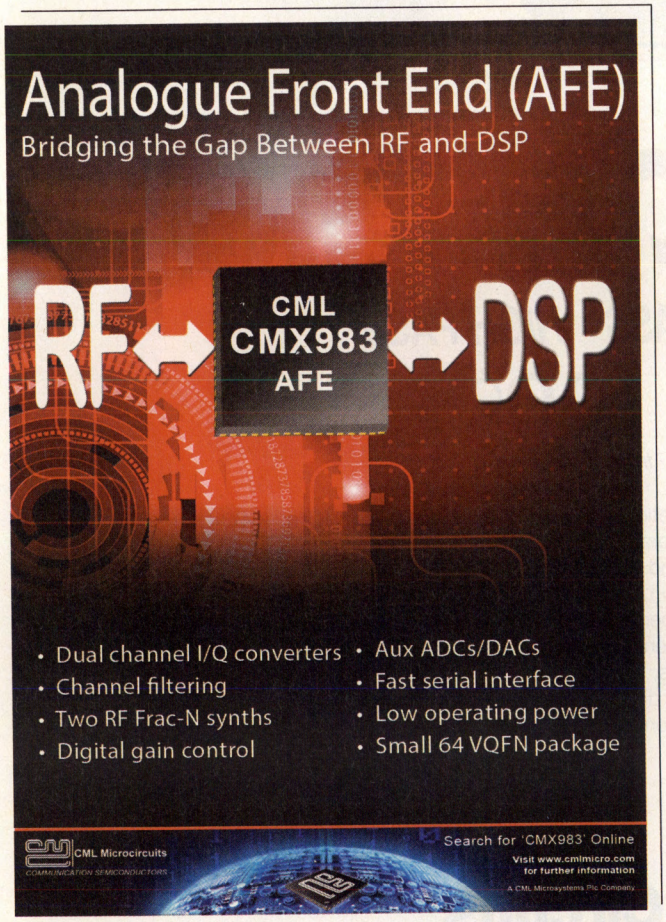
To validate the resonant properties, the frequency characteristics of USSs with various dimensions were simulated with Version 11.0 of the High Frequency Structure Simulator (HSFF) electromagnetic (EM) simulation software from Ansoft/ANSYS (www.ansys.com; *Fig. 2*). The frequency locations of the lower notched bands move downward in frequency with increases in the dimensions of L_5.

However, with decreases in the dimensions of parameter L_6, only the resonant frequency of the upper notched band moves upward. To obtain the desired frequencies for the notches, $f_{notch\text{-}lower}$ can be tuned by adjusting the length of L_5; varying the length of parameter L_6 controls $f_{notch\text{-}upper}$. The two notched bands can be independently tuned for desired notch frequencies.

The UWB BPF with dual notched bands was fabricated on RT/duroid 5880 printed-circuit-board (PCB) material from Rogers Corp. (www.rogerscorp.com). The PCB material features a relative dielectric constant of 2.20 in the z-axis, measured at 10 GHz, with a thickness of 0.813 mm and loss tangent of 0.0027.

The optimal structural parameters for the UWB filter circuit (as illustrated in *Fig. 1*) were selected as follows: $L_1 = 7.0$ mm; $L_2 = 6.7$ mm; $L_3 = 5.0$ mm; $L_4 = 6.2$ mm; $L_5 = 5.1$ mm; $L_6 = 3.8$ mm; $L_7 = 2.4$ mm; $W_1 = 0.3$ mm; $W_2 = 0.2$ mm; $W_3 = 0.6$ mm; $W_4 = 8.0$ mm; $W_5 = 7.0$ mm; $W_6 = 4.8$ mm; $W_7 = 1.4$ mm; $D_0 = 0.1$ mm; $D_1 = 0.5$ mm; $D_3 = 0.6$ mm; and $D_4 = 0.1$ mm.

The fabricated UWB BPF with dual notched bands was measured with the 8722ES vector network analyzer (VNA)



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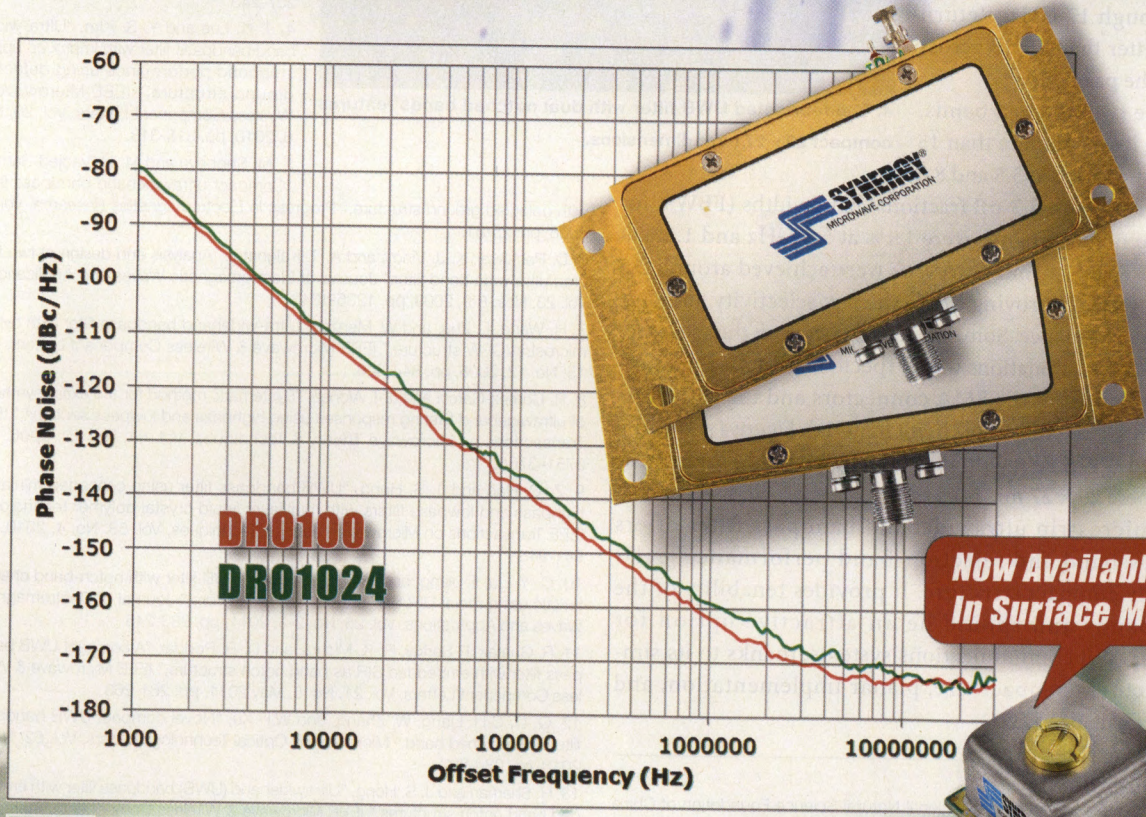

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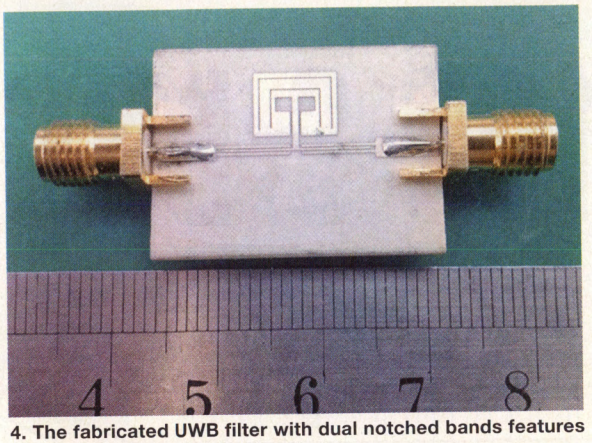
"To minimize the effects of interference, ultrawideband badpass filters with multiple notched bands are needed to reject the unwanted signals."

from Agilent Technologies (now Keysight Technologies; www.keysight.com). The simulated and measured S-parameters for the filter are in close agreement *(Fig. 3)*. As The UWB BPF's passband, which ranges from 3.2 to 10.3 GHz, has an upper stopband with 10-dB attenuation through 17 GHz. Return loss is better than 15 dB across most of the passband.



4. The fabricated UWB filter with dual notched bands features compact 20 × 27 mm² dimensions.

For the two notched bands, insertion losses of more than 15 dB were measured at 5.8 and 8.0 GHz. The measured 3-dB fractional bandwidths (FBWs) for these two notched bands were 1.1% at 5.8 GHz and 1.2% at 8.0 GHz. Two transmission zeros were achieved around 2.3 and 11.6 GHz, improving the frequency selectivity and out-of-band performance. Some deviations between the measurements and the simulations were expected, due to factors such as reflections from the SMA connectors and the finite loss capabilities of the substrate circuit material. *Figure 4* shows the fabricated UWB BPF with dual notched bands, which measures a mere 20 × 27 mm².

The microstrip ultrawideband bandpass filter offers good passband and rejection-band performance levels in a fairly compact structure. It provides tenability of the notch bands and should be an attractive option for modern UWB communications systems, thanks to its simple structure, compact size, planar implementation, and high performance. MW

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China under Grant No. 51164033, the Jiangxi province Ground Plan of Science and Technology for Institution of Higher Education Grant No. KJLD12050, and the Jiangxi Province Science and Technology supporting project No. 20123BBE50116. It also received support from the Jiangxi province Natural Science Foundation of China under Grant No. 20132BAB206021. Other support came by way of the Scientific Research Fund of Jiangxi province Nos. 12747, 11739, and 12748; the Scientific Research Fund of Hunan Provincial Education Department under Grant No. 13C022; and the Hunan Province Nature Science Foundation of China under Grant No. 14JJ2118.

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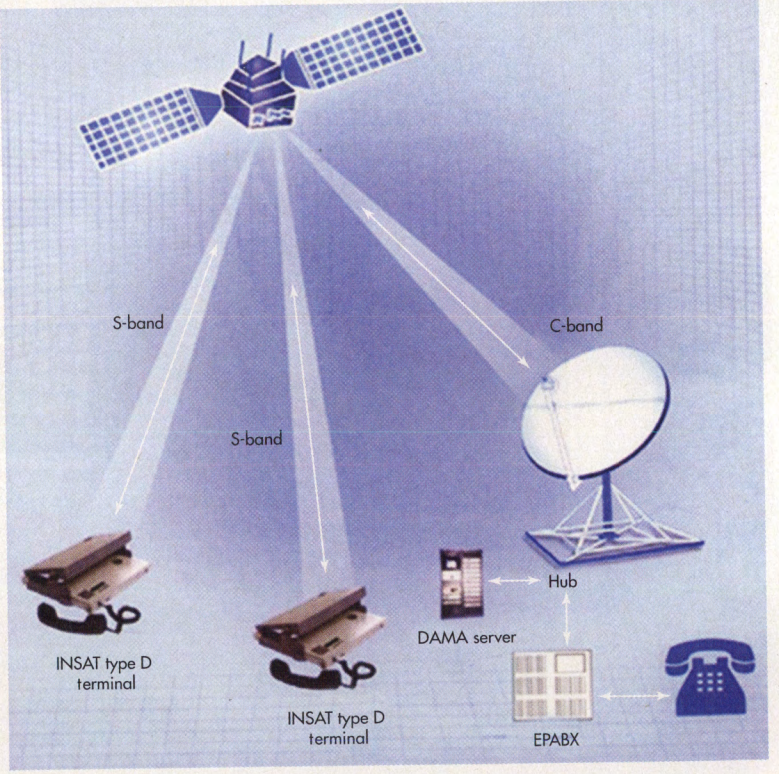
An alternative approach to existing satcom methods promises to eliminate feeder links and save considerable frequency spectrum.

Congestion of multiple signals in different locations around the world calls for intelligent use of available frequencies, and the S-band portion of the spectrum holds great promise for a number of applications. India, for example, enjoys many applications for S-band mobile-satellite-system (MSS) equipment. Demand from private and government sources for more S-band bandwidth on satellites for MSS services increases day by day.

These MSS services are currently provided by means of S × C-band and C × S-band bent-pipe transponders onboard geosynchronous orbit (GEO) satellites. Mobile terminals at S-band frequencies are connected to a hub or control center by satellite transponders using C-band or Ku-band feeder links. Accordingly, any use of S-band frequencies for MSS services requires equal bandwidth at C- or Ku-band frequencies. Optimum utilization of available bandwidth has become a significant challenge in moving these communications systems forward.



1. This is a conceptual view of a conventional MSS system, for data and voice communications, as it is used with Indian National Satellite System (INSAT) satellites.

Present MSS services adapt access techniques—such as time-division-multiple-access (TDMA) and frequency-division-multiple-access (FDMA) methods— to forge the connectivity needed for data, voice, and video transfers. These systems require centralized control centers, often referred to as hubs, to assign frequency and/or time slots to users automatically as needed. However, to achieve more optimum use of the available RF bandwidth without requiring feeder links (so as to avoid the need for additional C- or Ku-band frequencies), a new scheme

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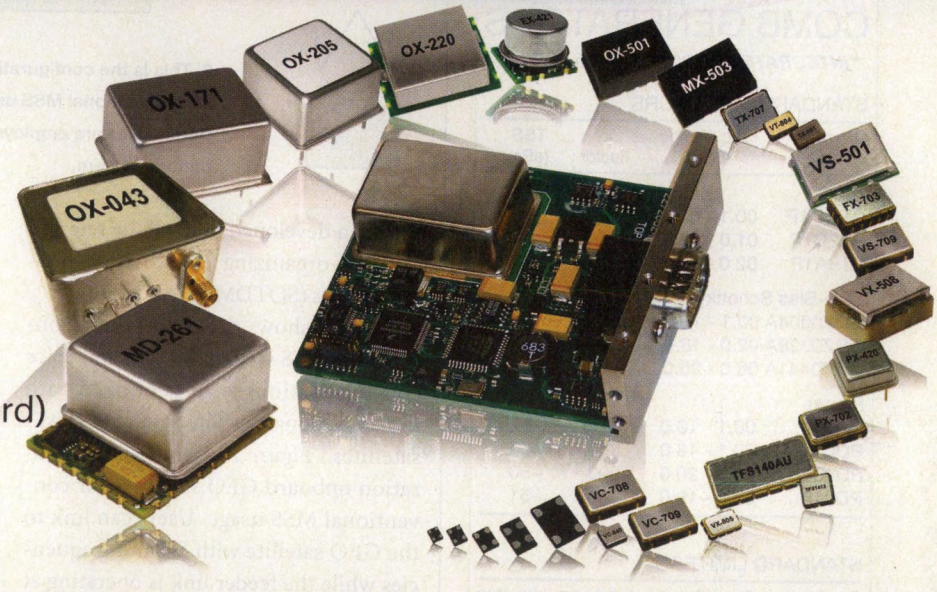

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Schottky Turn-on			
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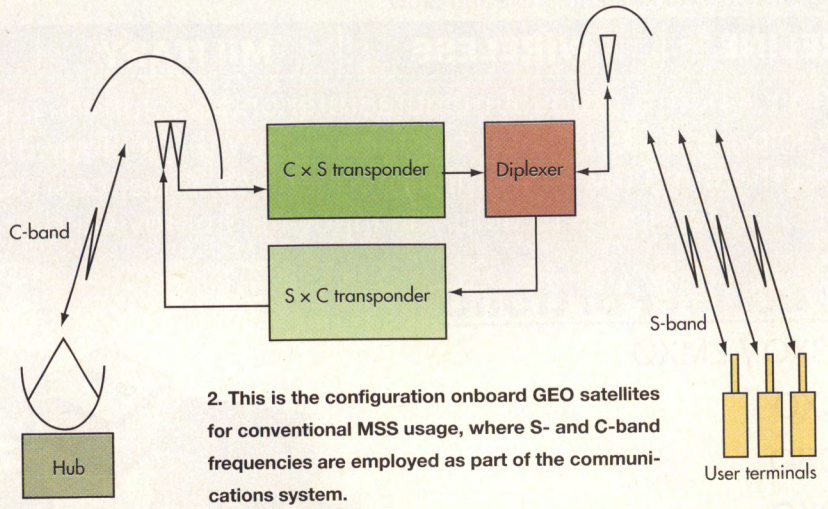

2. This is the configuration onboard GEO satellites for conventional MSS usage, where S- and C-band frequencies are employed as part of the communications system.

has been developed that will be referred to as self-organizing time-division-multiple-access (SOTDMA) technology.

Figure 1 shows the concept of a conventional MSS system, for data and voice communications, as it is utilized with Indian National Satellite System (INSAT) satellites.[1] *Figure 2* provides a configuration onboard GEO satellites for conventional MSS usage. Users can link to the GEO satellite with S-band frequencies while the feeder link is operating at C-band frequencies.

The satellite is configured with S × C and C × S transponders. An S-band antenna is designed to cover the required area and fed with an appropriate power level to achieve the required effective isotropic radiated power (EIRP) level to maintain a good satcom link. The C-band link is supported by a relatively large antenna—a paraboloid design with greater than 6-m diameter—with high gain-to-noise-temperature (G/T) performance at the control center (hub). The system requires a large bandwidth equal to the sum of the users' uplink S-band carriers' bandwidth for the C-band feeder/hub link.

An alternative to the current MSS scheme is based on the use of the SOTDMA concept[2-4] and does not require a feeder link. The SOTDMA approach allows large number of users to share a single narrowband radio channel by synchronizing their data transmission to an exact timing standard. SOTDMA is based on allowing a user terminal to create a local replica of a current TDMA frame and find a time slot randomly from available vacant slots when the data can be transmitted. GPS timing signals are used to synchronize the time slots at the user terminals, and all terminals in the visible region will receive the transmitted packets in this scheme.

This SOTDMA concept is a possible option for conserving RF spectrum while also serving a large number of MSS users. An Automatic Identification System (AIS) data/frame structure is assumed for an MSS application.[5,6] In practice, any other format can be adopted suitably.

The proposed SOTDMA-based MSS approach offers solid performance within a 25-kHz bandwidth, including a data rate of 9.6 kb/s and 256-b message length using Gaussian minimum-shift-keying (GMSK) modulation and MF-TDMA access. It uses 2250 slots/min in a carrier and CSTDMA/SOTDMA slot allocation with GPS time synchronization. Assuming a detection probability of 90%, the number of users per carrier is estimated at approximately 2000 (2250 ×0.9) with 1-min reporting. In effect, 1000 simultaneous calls can be made per carrier in a 25-kHz bandwidth.

Normally, each user transmits in one slot. A user can reserve more slots to transmit more data if required. Of course, this will affect the number of users possi-

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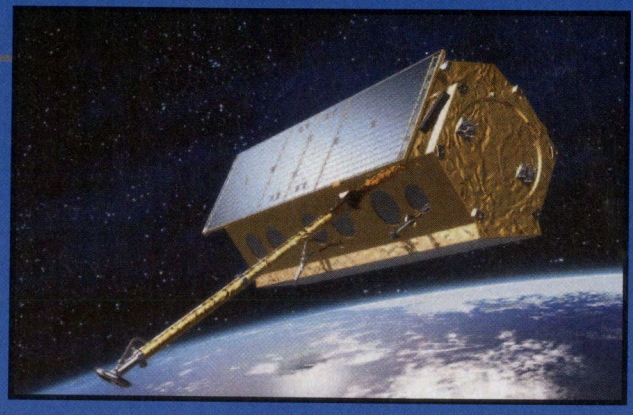

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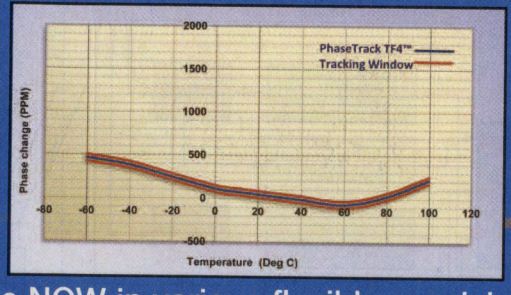

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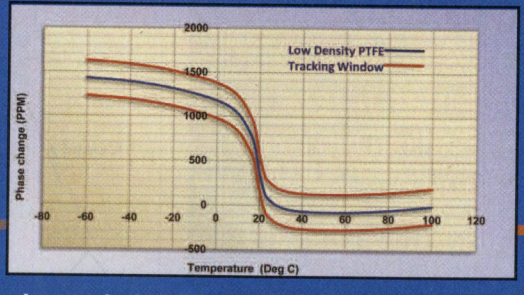

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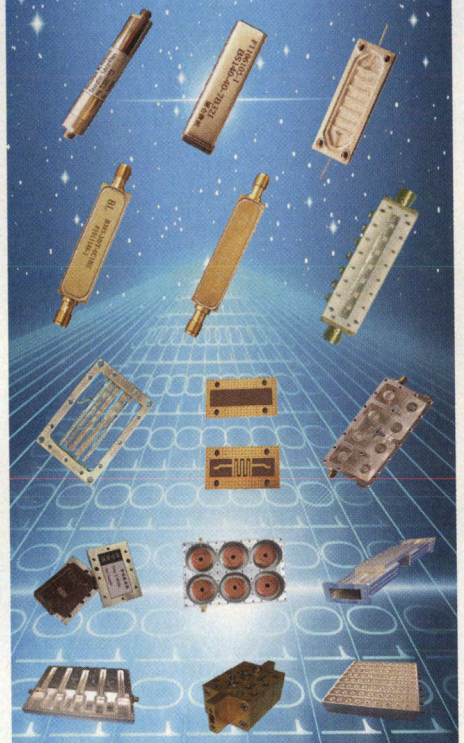

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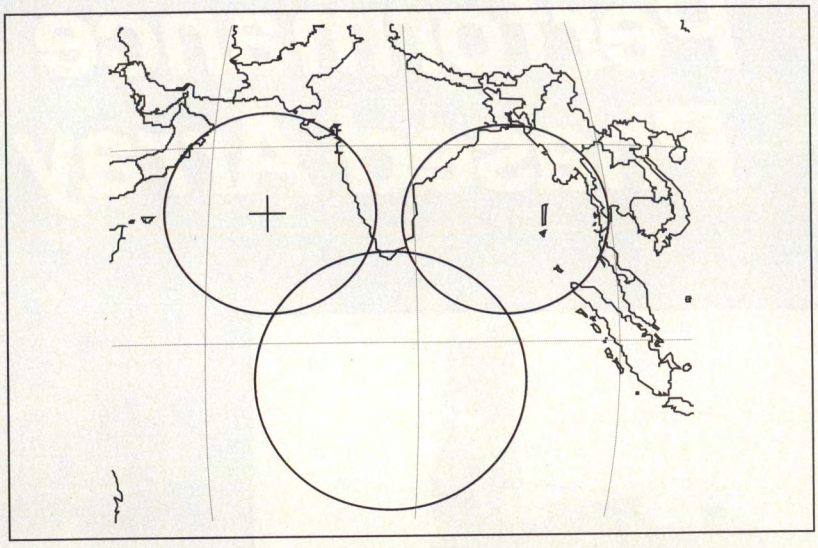
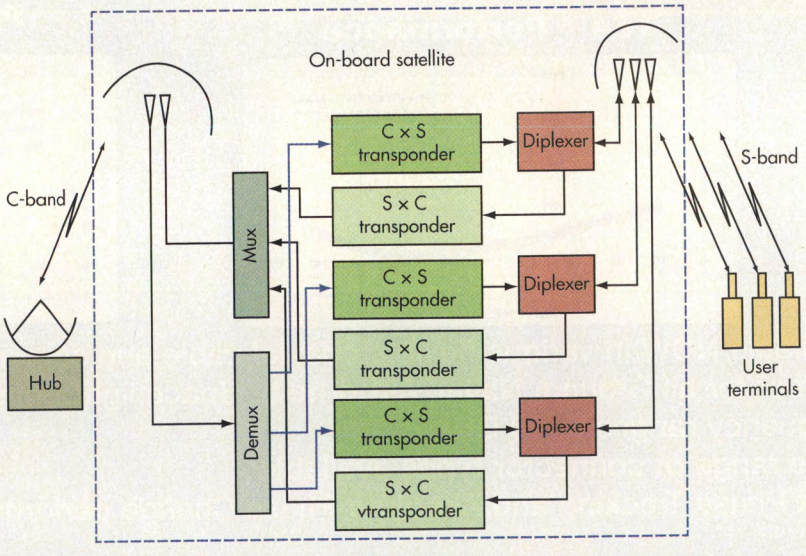


3. A 3.5- × 4-m antenna onboard a satellite can generate the three beams needed for satcom coverage in India.

ble. Polling can also be incorporated as an added service. With the implementation of the FDMA concept along with SOTDMA, a 1-MHz bandwidth suffices for 40 simultaneous carriers, thereby supporting around 40,000 simultaneous calls. To support 40 simultaneous carriers, a satellite transponder must be designed with sufficient EIRP and G/T, even if greater bandwidth is considered. The proper antenna onboard the satellite can provide the required coverage and can serve all users if it delivers adequate EIRP and G/T performance.

The satellite range is about 41,000 km (the maximum range if the user terminal "sees" the satellite at a 10-deg. elevation). The total propagation delay of the signal to travel back and forth, or 2 × 41,000 km, will be about 275 ms—or to be conservative, 500 ms including other possible delays, which translates to about 19 slots



4. As an example of satcom coverage of India, a conventional MSS setup links each beam to a common hub/control center. Every beam requires both independent C × S-band and S × C-band transponders.

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of the TDMA frame. This may cause collision/overlapping of some time slots if they are synchronized to 60-s periods.

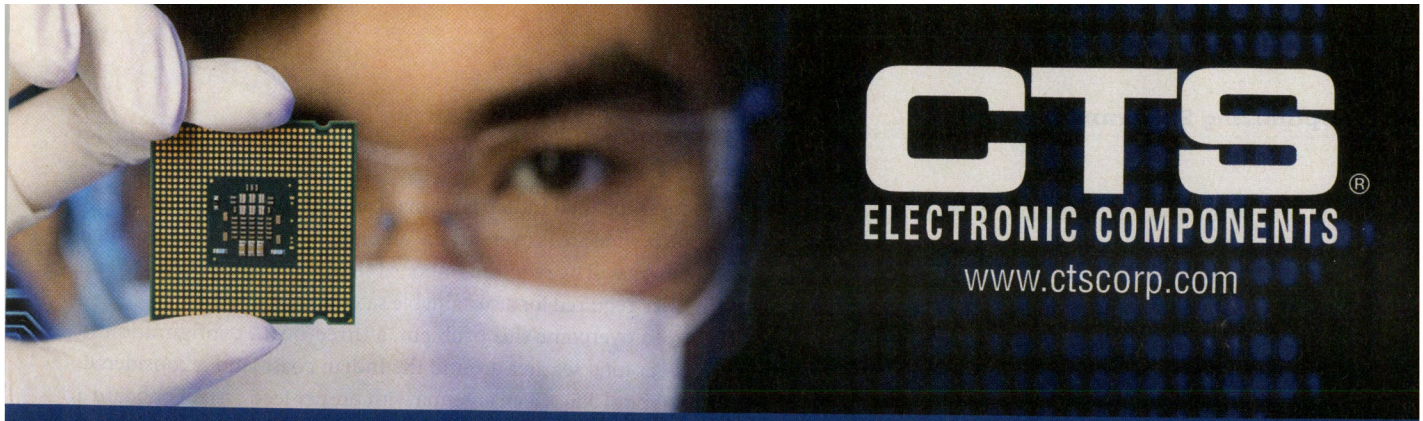
This can be corrected by allowing a 500-ms guard band between frames. Each receiver would synchronize with a GPS reference every 60.5 s and transmit in one of the 2250 slots selected randomly. This built-in discipline among users will avoid overlapping of slots. Proper random sequencing can minimize the chance of two users selecting the same slot for transmission simultaneously. Greater than 90% probability is normally achievable with proper random sequencing for slot selection.

With the assumption of 90% detection probability, 2000 users can transmit, or 1000 simultaneous calls per carrier of 25-kHz bandwidth can occur, in a 60.5-s time period instead of a 60-s time period using the standard AIS format. A 500-ms time gap in data reception does not pose a problem with current digital communications techniques. But since all users receive the data, appropriate encryption/coding must be implemented to maintain confidentiality. This scheme has some clear advantages: Feeder link carriers are not required and slot allocation is not by hub, so two-way communications for slot synchronization is unnecessary.

In a conventional MSS setup, a high-gain ground antenna for feeder links helps to maintain overall carrier-to-noise ratio (C/N) with relatively less satellite EIRP and lower G/T at S-band. In contrast, sufficiently high EIRP must be provided onboard the satellite for an SOTDMA-based MSS setup, as will be shown by an example. The main drawback of requiring more EIRP onboard the satel-

TABLE 1: LINK ESTIMATIONS FOR CONVENTIONAL MSS AND SOTDMA-BASED MSS

	Conventional MSS		SOTDMA-based MSS
	Hub to satellite to user terminal (C × S transponder)	User terminal to satellite to hub (S × C transponder)	User terminal to satellite to user terminal (S × S transponder)
Uplink			
Frequency (MHz)	6460	2680	2680
Data rate (kb/s)	9.6	9.6	9.6
Transmit power (with carrier)	1	1	2
EIRP (dBW)	49	3	6
Path loss (dB)	200	192.4	192.4
Satellite antenna (m)	1.2	3.5 x 4	3.5 x 4
Satellite G/T (dB/K)	–5	12	12
U/LC/No (dB)	72	50	53
Downlink			
Frequency (MHz)	2510	3690	2510
Transmit power (W)	140	15	250
Satellite EIRP (dBW)	60	30	62
Path loss (dB)	191.8	195	191.8
Receive G/T (dB/K)	–22	26	–22
D/LC/No (dB)	48	52	50
Overall C/N (dB)	48	47.8	48.2
C/No required (dB)	45	45	45
Margin (dB)	3	2.8	3.2



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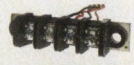

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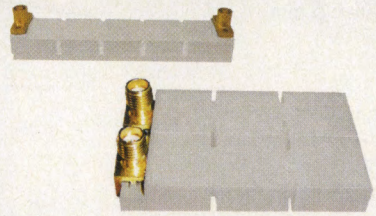

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lite compared to a conventional MSS is offset by saving feeder link bandwidth.

Various techniques are being implemented for ship-to-ship and ship-to-shore communications for civilian and naval ships. As an example, consider a typical satellite providing MSS services over the area of sea surrounding the Indian land mass. A single S-band antenna can be designed for the GEO satellite to cover the total Indian land mass and surrounding sea area. For such wide area coverage, the antenna gain will be less and high power will be required onboard the satellite for good G/T and EIRP required for a sustainable satcom link.

To overcome this problem, a three-beam configuration to cover total sea area around the Indian coast land is considered. A typical 3.5- × 4-m antenna with proper feed system onboard a satellite can provide three beams covering the complete coast line and ocean around India *(Fig. 3)*.

Figure 4 shows a typical configuration of a conventional MSS for this example. Each beam is linked to a common hub/control center in the conventional MSS system. Each beam requires independent C × S-band and S × C-band transponders, complicating the onboard hardware. The bandwidth required in the feeder link will equal the sum of the bandwidths of all S-band uplink carriers. A satellite configured with S × S-band transponders in the MSS frequency band with adequate EIRP can support MSS applications using the SOTDMA concept while avoiding the need for feeder links, eliminating the need for RF spectrum at C- or Ku-band frequencies. *Figure 5* shows the configuration of a SOTDMA-based MSS.

With the SOTDMA concept, the satellite would have three S × S-band bent-pipe transponders to cater to the three beams. All users would synchronize transmissions to a GPS time standard. User terminals would receive the transmitted signals from satellite, map the received signal frame, and transmit the data in a randomly selected vacant slot. For the example chosen, all users transmit every 60.5 s at an uplink frequency.

The sizing of the power amplifiers for these satcom systems depends upon the bandwidth, the amount of data, and the number of users. *Table 1* offers typical link estimations for conventional and SOTDMA-based MSS systems. For a similar margin of around 3 dB, a conventional MSS system requires 140 W transmit power for an S-band downlink. A SOTDMA-based MSS system requires 250-W transmit power for the S-band downlink. *Table 2* provides a compari-

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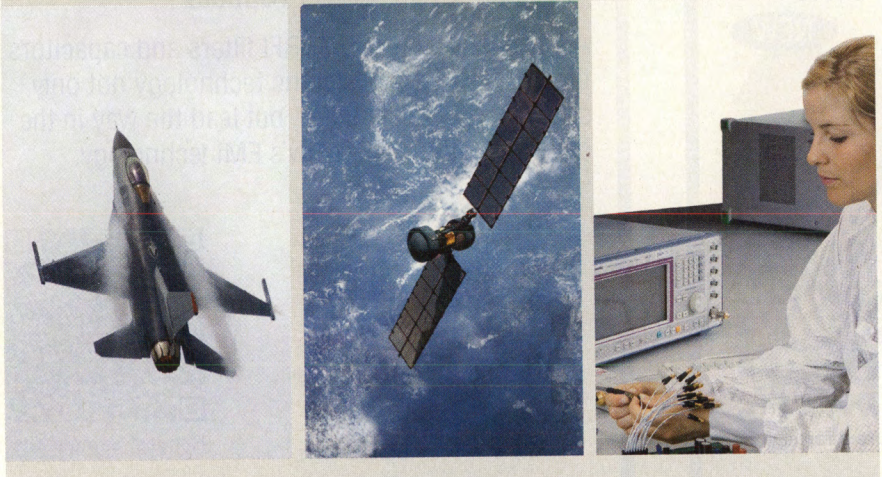

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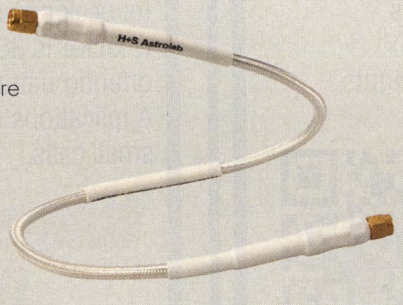

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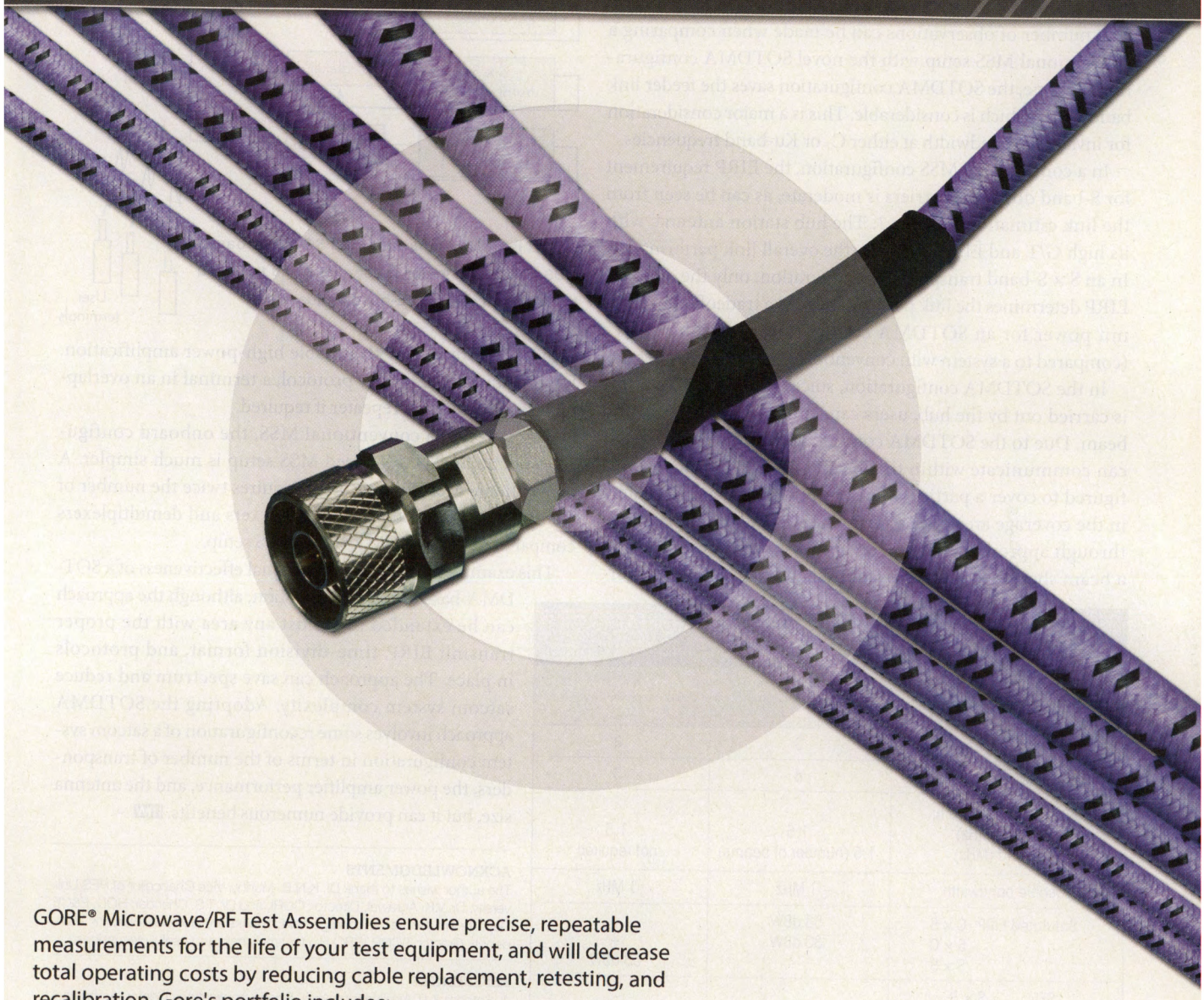

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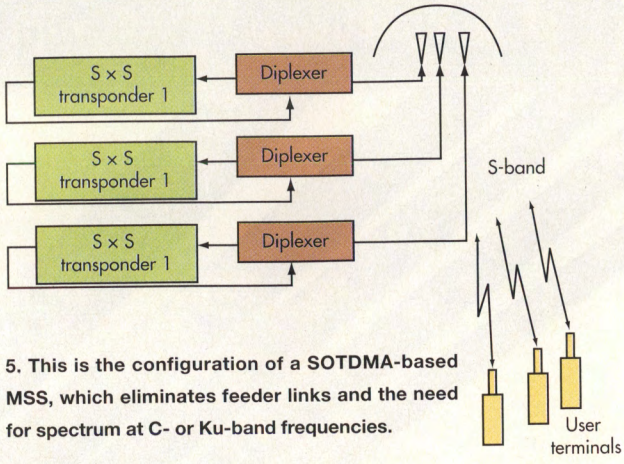
son of the performance levels of a typical bandwidth-equivalent conventional MSS system and an SOTDMA-based MSS system.

A number of observations can be made when comparing a conventional MSS setup with the novel SOTDMA configuration. For one, the SOTDMA configuration saves the feeder link bandwidth, which is considerable. This is a major consideration for invaluable bandwidth at either C- or Ku-band frequencies.

In a conventional MSS configuration, the EIRP requirement for S-band downlink carriers is moderate, as can be seen from the link estimation in *Table 1*. The hub station antenna, with its high G/T and EIRP, improves the overall link performance. In an S × S-band transponder configuration, only the onboard EIRP determines the link performance. As a tradeoff, the transmit power for an SOTDMA configuration must be higher (compared to a system with conventional MSS transponders).

In the SOTDMA configuration, since switching and control is carried out by the hub, users can contact other users in any beam. Due to the SOTDMA concept, users covered by a beam can communicate within that beam only. Each beam is configured to cover a particular area. Monitoring/control centers in the coverage area can facilitate interbeam communications through appropriate terrestrial networks and protocols, and a beam shaped to meet the required coverage area can overcome this limitation with suitable high-power amplification. Equipped with the proper protocol, a terminal in an overlapping zone can act as a repeater if required.



5. This is the configuration of a SOTDMA-based MSS, which eliminates feeder links and the need for spectrum at C- or Ku-band frequencies.

Compared to a conventional MSS, the onboard configuration of an SOTDMA-based MSS setup is much simpler. A conventional MSS configuration requires twice the number of transponders and additional multiplexers and demultiplexers compared to the SOTDMA-based MSS setup.

This example has shown the potential effectiveness of a SOTDMA-based MSS configuration, although the approach can be extended to almost any area with the proper transmit EIRP, time-division format, and protocols in place. The approach can save spectrum and reduce satcom system complexity. Adopting the SOTDMA approach involves some reconfiguration of a satcom system configuration in terms of the number of transponders, the power amplifier performance, and the antenna size, but it can provide numerous benefits. mw

TABLE 2: COMPARING CONVENTIONAL AND SOTDMA-BASED SYSTEMS

Parameter	Conventional MSS	SOTDMA-based MSS
Number of beams	3	3
Number of active transponders	6	3
Occupied bandwidth: S-band (MHz) Ku-band (MHz)	 1.5 1.5 (number of beams)	 1.5 not required
Usable bandwidth	1 MHz	1 MHz
Saturated EIRP: C × S S × C S × S	53 dBW 30 dBW --	-- -- 53 dBW
SFD: S × S C × S S × C	 −87 dBW/m^2 −123 dBW/m^2	 −145 dBW/m^2
G/T: S × S C × S S × C	 −5 dB/K 4 dB/K	 4 dB/K
Onboard antenna: S-band C-band	4 × 3.5 m (34 dB gain) 1-m parabolic	4 × 3.5 m (34 dB gain) not required
TWTA: S-band C-band	140 W 15 W SSPA	250 W not required
HUB antenna	>6 m parabolic	not required
Capacity per beam	40 carriers of 25 kHz bandwidth (39 carriers for data and one carrier for TDM signaling)	40 carriers of 25 kHz bandwidth

ACKNOWLEDGMENTS

The author wishes to thank Dr. K.N.B. Murthy, Vice Chancellor of PES University, Dr. V.K. Agrawal, Director, CORI, and Dr. T.S. Chandar, HOD, E&CE Department, for their encouragement. Thanks are also due to Dr. P.K. Jain, deputy director, SCNP, ISRO HQ for timely help and useful discussions.

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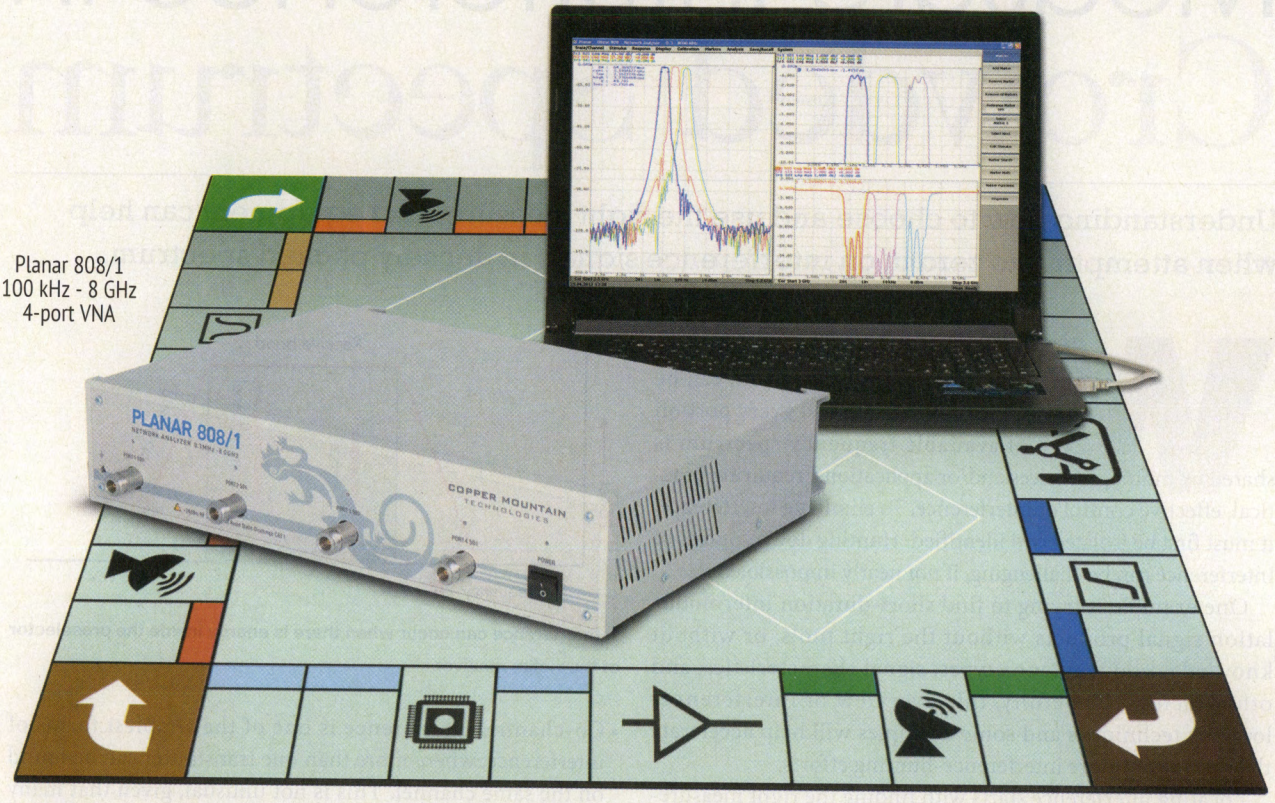

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Measure Interference in Crowded Spectrum

Understanding how to choose and use the right measurement equipment can help when attempting to zero in on interference signals in densely packed spectrum.

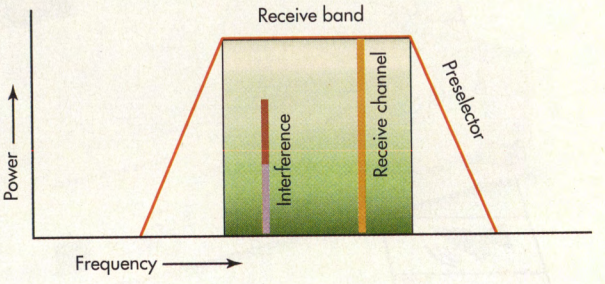
Wireless technology is so widespread that the frequency spectrum can be quite crowded. Almost every portion of available frequency spectrum is shared by multiple services and/or applications, requiring practical, effective control of interference. To eliminate interference, it must first be isolated and identified. Hunting down sources of interference can be challenging, if not nearly impossible.

One example is trying to find short-duration intermodulation signal products without the right tools, or without knowledge about antenna types, signal characteristics, and other factors. Hopefully, this overview of interference-locating techniques and some examples will help accelerate the success of future interference-hunting efforts.

Locating interference starts with finding the right measurement tool, a process that can be aided by understanding the differences between different spectrum analyzer types. Two common types are swept-tuned spectrum analyzers and real-time spectrum analyzers. Swept-tuned spectrum analyzers are typically based on a superheterodyne receiver architecture, in which signals are mixed with a tunable local oscillator (LO) to cover a bandwidth of interest from a starting frequency to a stop frequency.

A real-time spectrum analyzer samples a portion of the frequency spectrum and uses digital-signal-processing (DSP) techniques to analyze the captured spectrum. Filtering occurs in both approaches, and filtering helps set an analyzer's resolution bandwidth (RBW), by which signals closely spaced in frequency can be isolated and identified.

Interference can cause degraded system performance. For example, the unwanted energy may be causing coverage, reception, or access problems for a communications system. Problems can include an adequate signal but poor reception; an adequate signal but intermittent or no access; or a poor signal and no reception. Three basic types of interference are the most common:



1. Interference can occur when there is energy inside the preselector of the victim receiver.

- Co-channel interference is one of the simplest forms of interference, where more than one transmitter can be found on the same channel. This is not unusual, given that many frequencies and frequency bands are at least partially shared by numerous applications or users.
- Adjacent-channel interference results from energy originating from a transmitter other than the one intended. Such a secondary transmitter could be geographically close or close in operating frequency, and operate at a much higher power level than the intended transmitter.
- Intermodulation-based interference occurs when energy from two or more transmitters mixes together to create spurious signal products or frequencies. In general, third-order spurious products are the most common intermodulation interference caused by only two sources, although this type of interference can be triggered by more than two sources. Transmitters that produce this type of interference are usually close together and at higher power levels.

Figure 1 shows the simplified function of a preselector filter within a receiver. Although the filter is tuned to remove interference, interference can occur in a receiver when there is energy inside the preselector's filter bandwidth. Suitable energy within the preselector bandwidth can impact receiver

Directional / Bi-Directional

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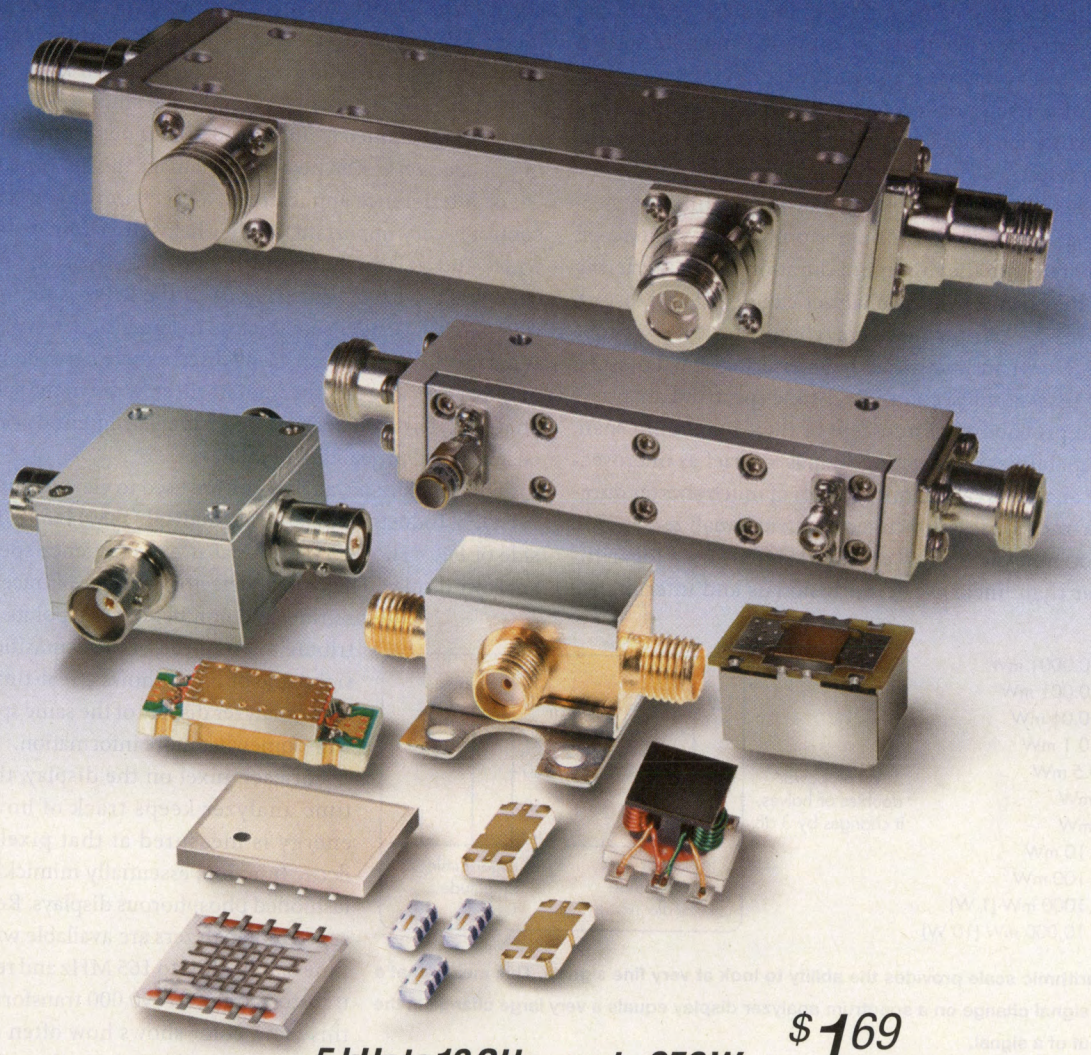

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performance; it does so by blocking the receiver directly from detecting a desired signal, or else through a form of desensitization in which lower-level signals are not detected.

Protocol-based test tools have often been used to identify interference. While they are useful in finding interference, such tools are also limited in providing insight into how a system might be affected by interference and in identifying the types of interference that can cause the most harm to a system. For such purposes, a spectrum analyzer provides a clear view of a given portion of spectrum, thus pinpointing where interference might fall relative to a communications system of interest.

When seeking a spectrum analyzer for finding interference, a key specification to consider is probability of intercept. This simply refers to the minimum duration of an interfering signal and the chance that the analyzer can detect and display it. Swept-tuned spectrum analyzers typically have a low probability of intercept, meaning that the interfering signal must be present for tens of milliseconds. Real-time spectrum analyzers have a high probability of intercept to their maximum span, with the capabilities of detecting signals as brief as microseconds. Such analyzers can identify signals of much shorter duration than a traditional swept-tuned spectrum analyzer.

Spectrum analyzers show captured signals on a logarithmic (rather than linear) scale, with signals and interference displayed in decibels (dB) or decibels relative to 1 mW (dBm) power. The logarithmic scale makes it possible to show a much wider dynamic range on an analyzer's screen than a linear scale.

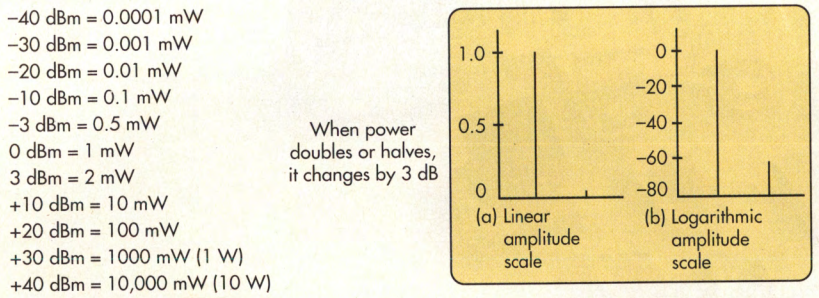
There are a few tricks to relate dBm values to a linear difference *(Fig. 2)*. Because it is logarithmic, every 10-dB change in power is a power of 10 change in wattage. Similarly, a 3-dB change in power represents a doubling (up 3 dB) or halving (down 3 dB) of wattage. Measurement of +30 dBm is the same as measuring 1 W, while measuring +33 dBm is the same as measuring 2 W. This can be significant, since most spectrum analyzers are limited to about +30 dBm input power, and feeding an analyzer excess power can damage the instrument.

For interference applications, a spectrum analyzer's RBW control is very important. A filter helps discriminate between wide- and narrow-bandwidth signals in the same span by changing the RBW value *(Fig. 3)*. If the RBW is set too wide [*Fig. 3 (left)*], smaller signals close to larger signals will be lost. A narrow RBW filter can easily discriminate between two signals that are close together, but it will slow down the spectrum analyzer. This requires a longer measurement duration to ensure signal probability of intercept.

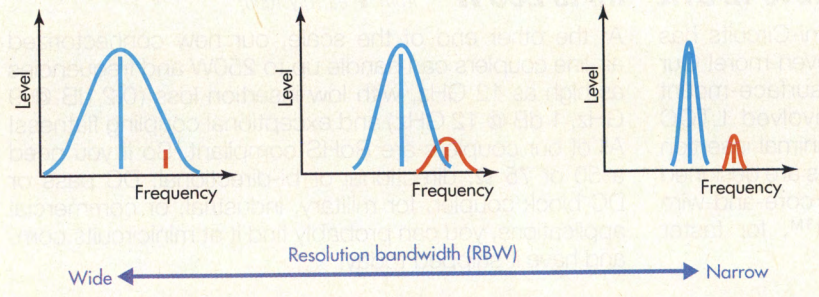
For a comparison, analyzers were used to view activity in the 2.4-GHz Industrial-Scientific-Medical (ISM) band. The left side of *Fig. 4* shows a traditional swept-frequency spectrum-analyzer display. The type of detector, number of traces, RBW setting, and number of trace points all contribute to the speed of the acquisition. The right side of *Fig. 4* shows a real-time spectrum analyzer display of the same spectrum with somewhat more information.

For each pixel on the display, the real-time analyzer keeps track of how often energy is measured at that pixel with a decay function, essentially mimicking old-fashioned phosphorous displays. Real-time spectrum analyzers are available with real-time bandwidths to 165 MHz and real-time transform rates to 390,000 transforms/s. In this view, color shows how often a signal appears, with red indicating the noise floor and blue the Wi-Fi signal.

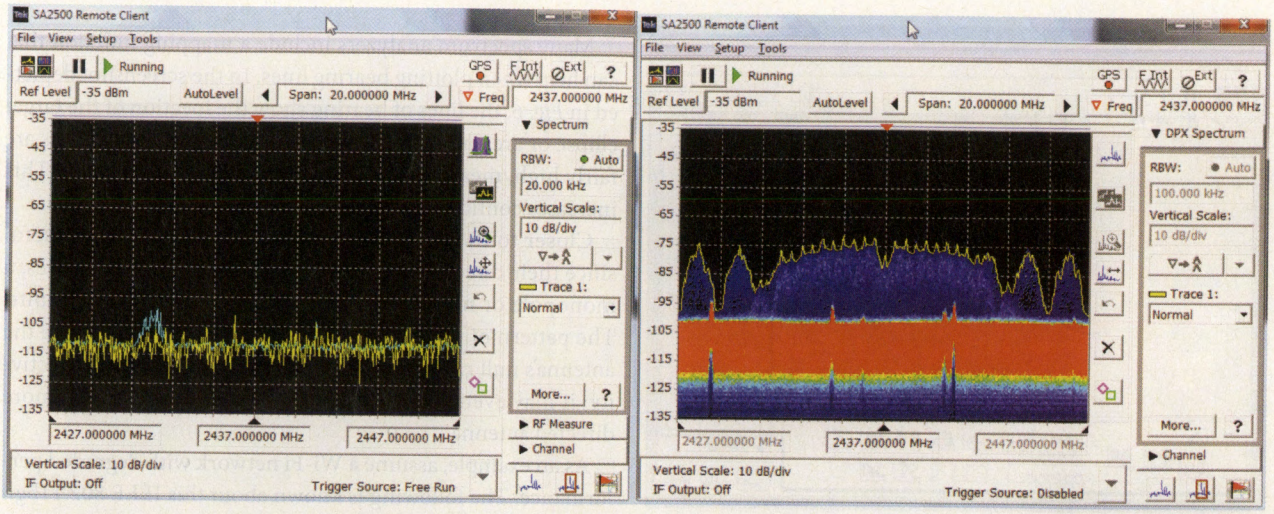
Another powerful tool available with a real-time spectrum analyzer is the spectrogram. It is akin to adding time as a third dimension to a traditional power-versus-frequency plot, providing the spectrum analyzer with a history of previous measurements in the frequency domain. As each spectrum measurement is made, the result is "turned on edge" and added to the bottom of the spectrogram. This pushes the



2. The logarithmic scale provides the ability to look at very fine signals. This means that a very small signal change on a spectrum analyzer display equals a very large change in the linear output of a signal.



3. This shows why RBW setting are important for interference applications. Wide RBW is faster, but may lead to missed signals.



4. A real-time spectrum analyzer display shows much more information than a traditional display.

older spectra up the display. Each line of the spectrogram is made in this way.

The horizontal axis is frequency, exactly as in the spectrum display. The power of each signal (represented by vertical height in the spectrum display) is now represented by different colors. The vertical axis is now time, with each line representing the time required for the FFT to be performed. As shown in *Fig. 5*, the spectrogram can record spectrum for long periods of time and the user can then playback any problem periods.

Measuring and locating interference is often a matter of situational awareness. Enough must be known of the surroundings to determine whether an analyzer display is showing a system problem or an interference problem. Gaining an understanding of the frequency band of interest is essential, learning, for example, whether it is licensed or license-free spectrum; what the band plan is for the spectrum; and whether co-channel services are in use. Various channel plans may be based on a class of service, with different power levels for each.

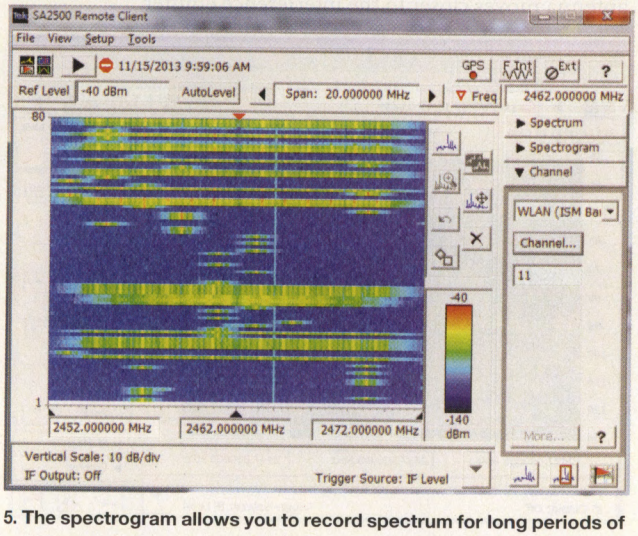
A spectrum display may show much different power levels regarding whether a portion of the spectrum is used for uplink or downlink functions. The class of service also dictates emission bandwidth and modulation type. In addition, certain digitally modulated signals can have much higher crest factors than their analog counterparts.

Spectrum shape is important, too. This is equivalent to occupied bandwidth. Much can be learned about an unknown signal by its spectrum signature. Occupied bandwidth, crest factor, and duration are unique properties that can help identify an unknown signal.

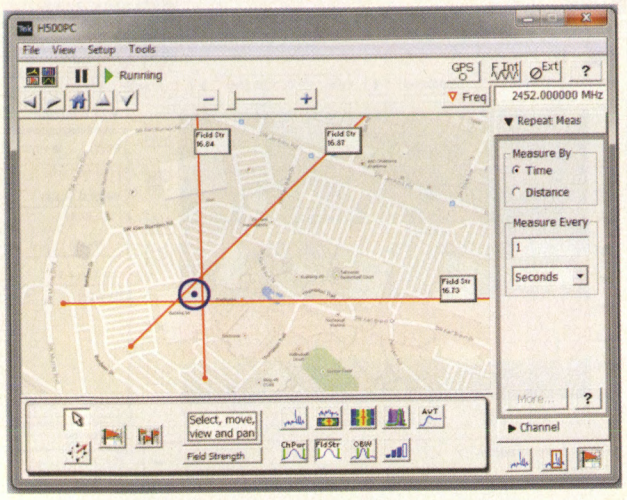
In terms of their effects on signals, environment factors are difficult to classify. Signals can be affected differently. A communications system, for instance, may be surrounded by buildings or in a wooded area. Even more, the impact of a wooded area can change depending on the time of year. Signal and environmental factors must be understood when analyzing potential interference, and maintaining logs of signal activity can help to discover when interference actual occurs.

Locating a signal involves triangulation. The basic principle behind triangulating a signal is straightforward: determine bearings; measure azimuth and signal strength from two different locations; then plot the bearings on a map. In theory, the interference is originating from the location on the map where the two bearings intersect. But in practice, it can be somewhat more complicated to locate the source.

Antennas can cause some of the triangulation complexity. A multiband, directional antenna has different directivity characteristics based on frequency, which can be plotted on a chart. The back of the antenna also has a pattern, resulting in a front-to-back ratio. Such directivity characteristics can



5. The spectrogram allows you to record spectrum for long periods of time and playback problem periods.



6. Lines of bearing on a map show the target ellipse or area of uncertainty.

impact any attempts to locate a signal source. Understanding an antenna's pattern can ultimately help to achieve optimum results with that antenna.

The radio horizon of a subject receiver can complicate interference investigations. Cities, in particular, can pose difficulties because of their large numbers of reflections. Obtaining as many lines of bearing as possible can minimize the problems, with an increase in the lines of bearing helping to reduce the amount of uncertainty in an interference search.

For any sweep of the horizon, a good practice is to have an external attenuator connected between the antenna and the spectrum analyzer, so that attenuation can quickly and easily be added to the receive signal path. Spectrum analyzers often have more sensitivity than required, and the additional attenuation can help minimize the effects of RF clutter as the antenna moves closer to the interference emitter.

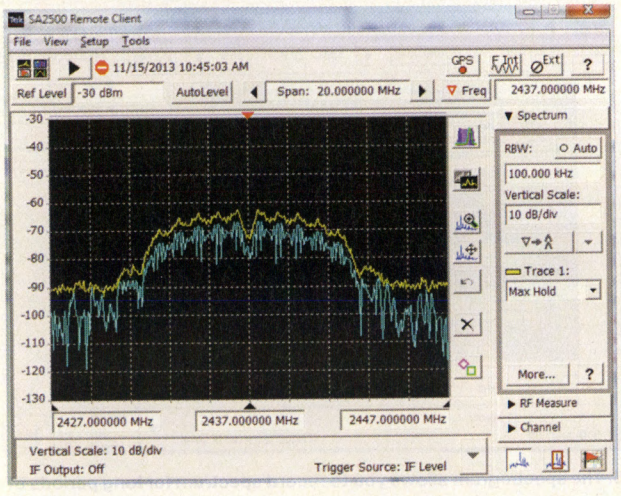
Many spectrum analyzers include a mapping function that can help when plotting bearing lines. In the screenshot depicted in *Fig. 6*, the lines of bearing show the location of the target ellipse or area of uncertainty. In this case, the power levels are fairly high, meaning the area of intercept is fairly small. This increases confidence that the target is actually in that area.

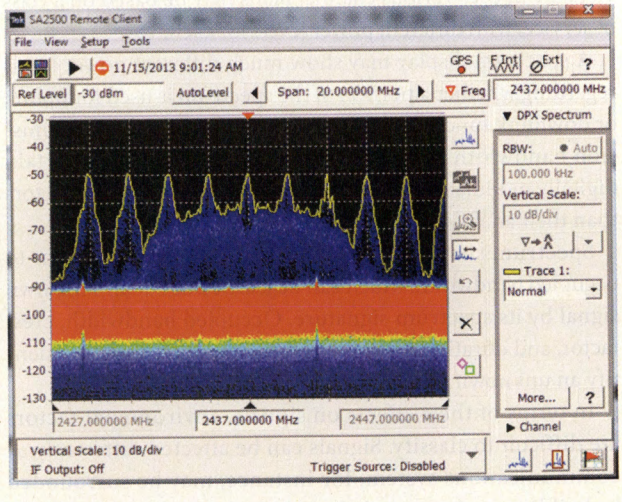
Closer to the target, directional antennas are less useful since their directivity is more compromised. In such cases, a monopole or near-field antenna can provide better results. The pattern of the near-field antenna is of interest, since the antenna's null rather than its peak can provide more directivity; it may even provide more directivity than a larger, more directed antenna.

As an example, assume a Wi-Fi network with degraded performance. The following is known about this IEEE 802.11bgn Wi-Fi network. It operates within the license-exempt, 2.4-GHz ISM band. It maintains co-channel operation with other electronic products, including cordless telephones, baby monitors, and Bluetooth devices. Wi-Fi is a time-division-duplex (TDD) network, with transmission and reception both occurring on the same channel. Furthermore, it employs a channel plan with 11 discrete channels (with only three clear channels: 1, 6, and 11).

When interference is suspected as a problem, an SSID scanner may be used to determine if there are co-channel issues, and how many access points are visible from the current operating location. In this case, a protocol scanner identified three access points, with channel 6 showing as the strongest.

When a traditional spectrum analyzer was used to view channel 6, conditions appeared reasonable, even with the instrument's "max hold" and "averaging" functions turned on and with a triggered acquisition that performs measurements only when a specific signal power level has been reached. A real-time spectrum analyzer view of this same channel 6





7. The real-time display shows a number of fast signals not visible in the traditional spectrum analyzer display.

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Transformers			
Model Number	**Frequency (MHz)**	**Impedance Ratio**	**Schematic**
TM4-0	0.2 - 350	4:1	
TM1-0	0.3 - 1000	1:1	
TM1-1	0.4 - 500	1:1	
TM1.5-2	0.5 - 550	1.5:1	
TM2-1	1 - 600	2:1	
TM1-6	5 - 3000	1:1	
TM2-GT	5 - 1500	2:1	
TM4-GT	5 - 1000	4:1	
TM8-GT	5 - 1000	8:1	
TM4-1	10 - 1000	1:4	
TM4-4	10 - 2500	1:4	
TM1-2	20 - 1200	1:1	
TM1-9	100 - 5000	1:1	
TM1-8	800 - 4000	1:1	

Couplers			
Model Number	**Frequency (MHz)**	**Coupling**	**Coupling Flatness**
GC6-2	1 - 700	6 dB ±0.5 dB (Nom.)	±1.0 dB
GC6-1	10 - 500	6 dB ±0.5 dB (Nom.)	±1.0 dB

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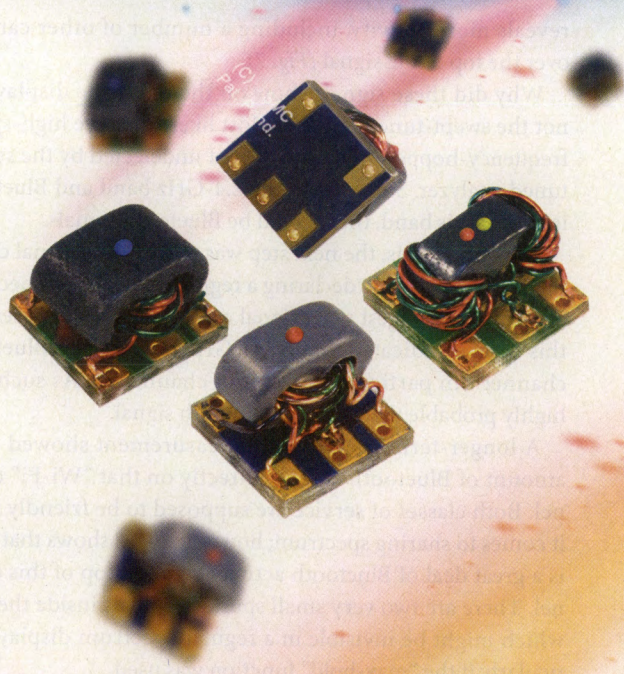

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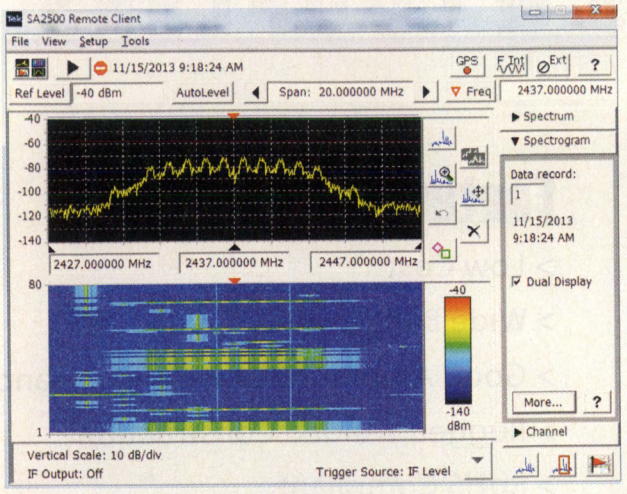
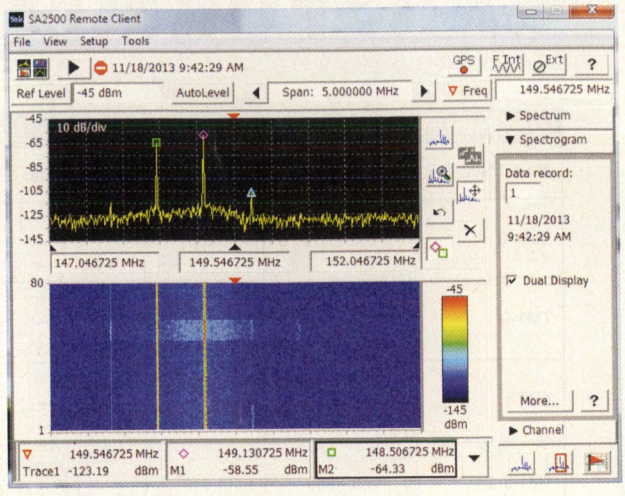


8. This spectrogram display shows the Bluetooth activity that represents interference for Wi-Fi systems operating in the same portion of spectrum.



9. Using a spectrogram display over time can confirm the presence of intermodulation signal products.

reveals more activity, including a number of other carriers over the top of the signal *(Fig. 7)*.

Why did these signals show on the real-time display and not the swept-tuned display? Most likely they are high-speed, frequency-hopped signals that went undetected by the swept-tuned analyzer. Since this is the 2.4-GHz band and Bluetooth is part of this band, these could be Bluetooth signals.

To confirm this, the next step was to turn on a signal classification database. By declaring a region in a signal, a spectrum analyzer can suggest what signal activity might be present. In this case, it indicated that 2.441 GHz is actually a Bluetooth channel—in particular, Bluetooth channel 39. As such, it is highly probable that this is a Bluetooth signal.

A longer-term spectrogram measurement showed a fair amount of Bluetooth activity directly on that "Wi-Fi" channel. Both classes of service are supposed to be friendly when it comes to sharing spectrum; however, *Fig. 8* shows that there is a great deal of Bluetooth activity right on top of this channel. There are two very small spurious signals inside the span which might be invisible in a regular spectrum display, particularly if the "max-hold" function was used.

As another example, consider an antenna farm with multiple transmitters facing system degradation of some form. The frequency of the victimized receiver is 149.77 MHz. The VHF land-mobile frequency plan has no defined frequency separation for transmit/receive functions, unlike applications at UHF and 800 MHz. Also, depending upon the time of year and location, there could be a great deal of propagation at this frequency.

In general, VHF applications are typically very narrow bandwidth, with occupied channel bandwidths as narrow as 6 kHz. Hence, radio receivers will be very sensitive compared to WiMax, LTE, or Wi-Fi stations.

An initial analysis suggested that the interference consisted of frequency-shift-keying (FSK) signals from the image of the class of service, and it is apparent that two frequency hops are clearly defined. A spectrogram analysis shows a point in time when another signal occurs on top of the initial signal. This additional signal is wider but of shorter duration, possibly resulting from intermodulation.

For intermodulation to occur, two or more sources are required. In this case, two sources are higher in power level but lower in frequency. For analysis, the next step involves examining the intermodulation mix to determine if the signal product would impact the system of interest. By using the spectrogram to study a longer period of time, it is possible to identify an intermodulation product, shown as the center line in the spectrogram display in *Fig. 9*.

The power of frequency number one is changing; it is actually increasing. And when the power increases, the result is an intermodulation product between the two frequencies on top of the assigned frequency.

With so many different electronic devices producing signals, it would be difficult to imagine that interference simply does not exist for a particular band. A real-time spectrum analyzer can help isolate and identify interference, with a much higher probability of intercept than possible with a traditional swept-tuned spectrum analyzer. For analysis, a spectrogram can offer assistance when studying spectrum activity over a time period of interest.

Because of the ever-changing wireless signal environment, as shown by the Wi-Fi example, traditional spectrum analyzers do not provide the capability to reliably detect and identify interference, but real-time spectrum analyzers have proven to be quite useful tools for finding interference. MW

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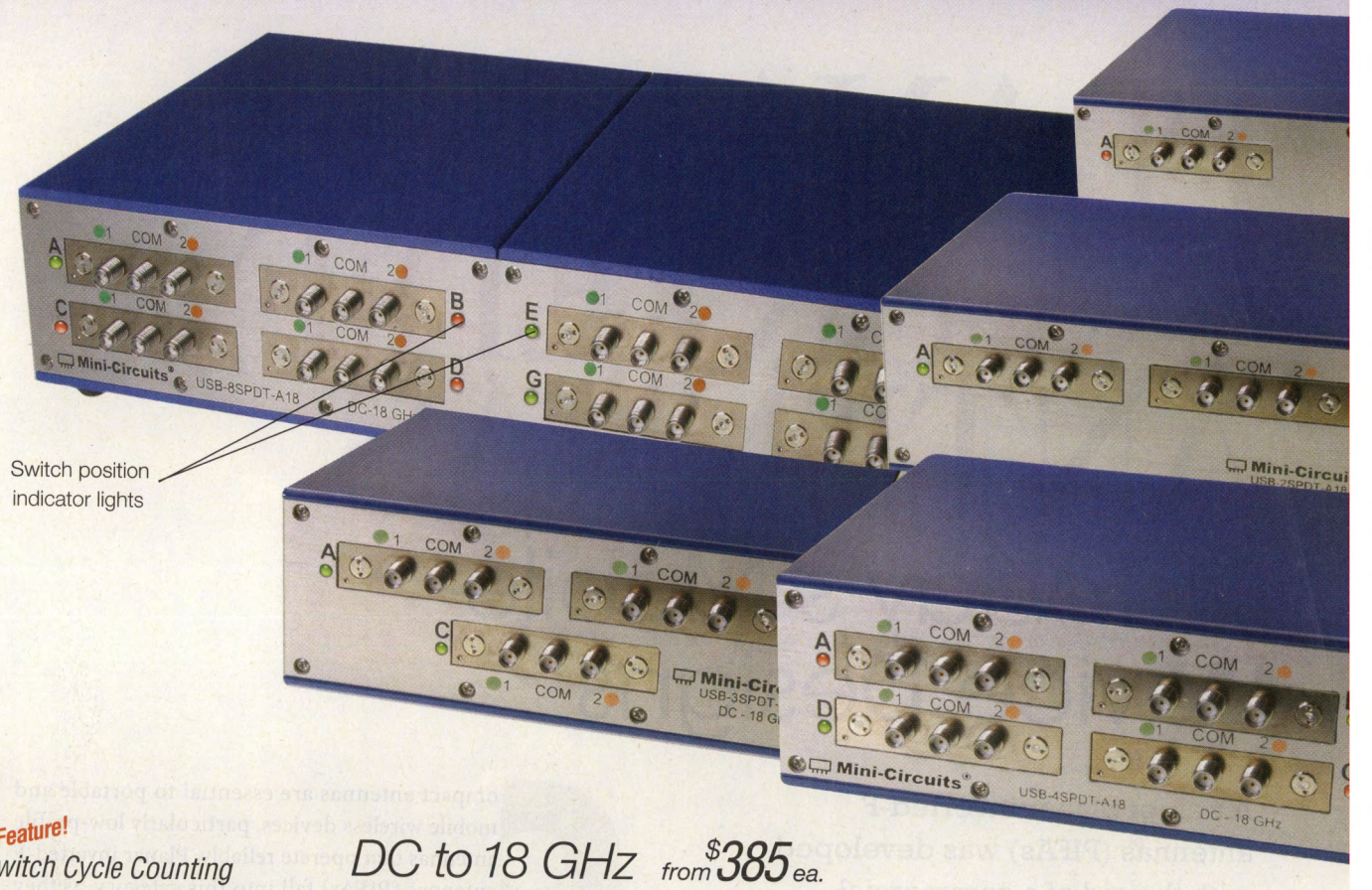

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USB-2SPDT-A18	2	0.25	1.2	85	10	685.00
USB-3SPDT-A18	3	0.25	1.2	85	10	980.00
USB-4SPDT-A18	4	0.25	1.2	85	10	1180.00
USB-8SPDT-A18	8	0.25	1.2	85	10	2495.00

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RC-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	895.00
RC-1SPDT-A18	1	0.25	1.2	85	10	485.00
RC-2SPDT-A18	2	0.25	1.2	85	10	785.00
RC-3SPDT-A18	3	0.25	1.2	85	10	1080.00
RC-4SPDT-A18	4	0.25	1.2	85	10	1280.00
RC-8SPDT-A18	8	0.25	1.2	85	10	2595.00

*The mechanical switches within each model are offered with an optional 10 year extended warranty. Agreement required. See data sheets on our website for terms and conditions. Switches protected by US patents 5,272,458; 6,650,210; 6,414,577; 7,633,361; 7,843,289; and additional patents pending.

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Design Feature

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PLANAR INVERTED-F ANTENNAS

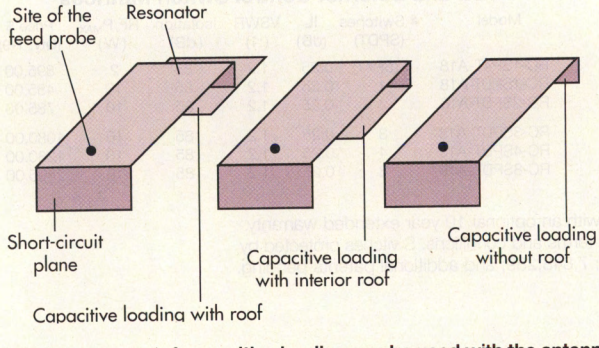
Fit Today's Mobile-Device Designs

A pair of planar inverted-F antennas (PIFAs) was developed with the aid of a commercial software simulator to cover several telecommunications standards.

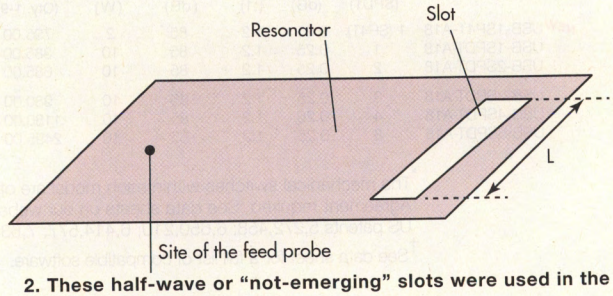
Compact antennas are essential to portable and mobile wireless devices, particularly low-profile antennas that operate reliably. Planar inverted-F antennas (PIFAs) fall into this category, as they can be fabricated in small structures.

However, developing miniature PIFA components for the latest mobile/wireless products requires wide bandwidths to support multiple frequency bands. Engineers attacked the problem by applying the formation of slots along with capacitive loading. It led to encouraging results for broadband PIFA design development.

PIFAs have traditionally been too narrow in bandwidth to cover multiple wireless communications bands, prompting



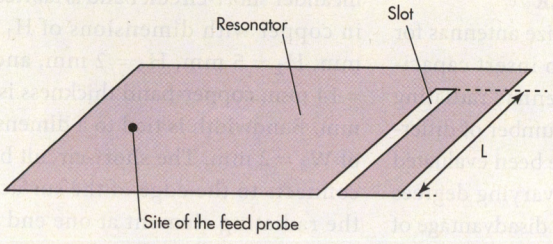
1. Different types of capacitive loading can be used with the antenna.



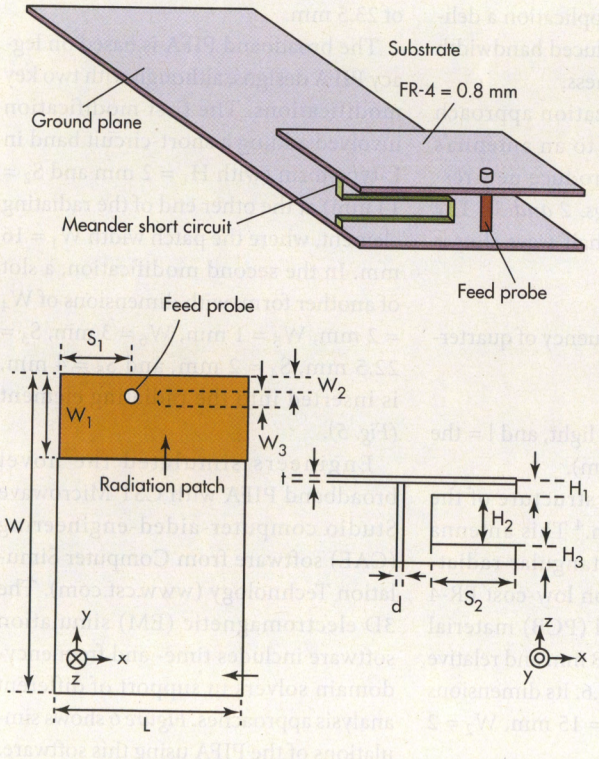
2. These half-wave or "not-emerging" slots were used in the design of the PIFA antenna.

> **"However, developing miniature PIFA components for the latest products requires wide bandwidths to support the devices' multiple frequency bands."**

investigations into ways to increase PIFA bandwidth. Some of these methods increased the size of the PIFA radiation patch,[1] although this increases the size of the antenna. In addition, an impedance bandwidth of 16% was achieved with a PIFA using a T-form ground plane.[2] However, this bandwidth is still too narrow for many modern applications, and it may be impractical to produce the required ground plane structure for a realistic antenna product.



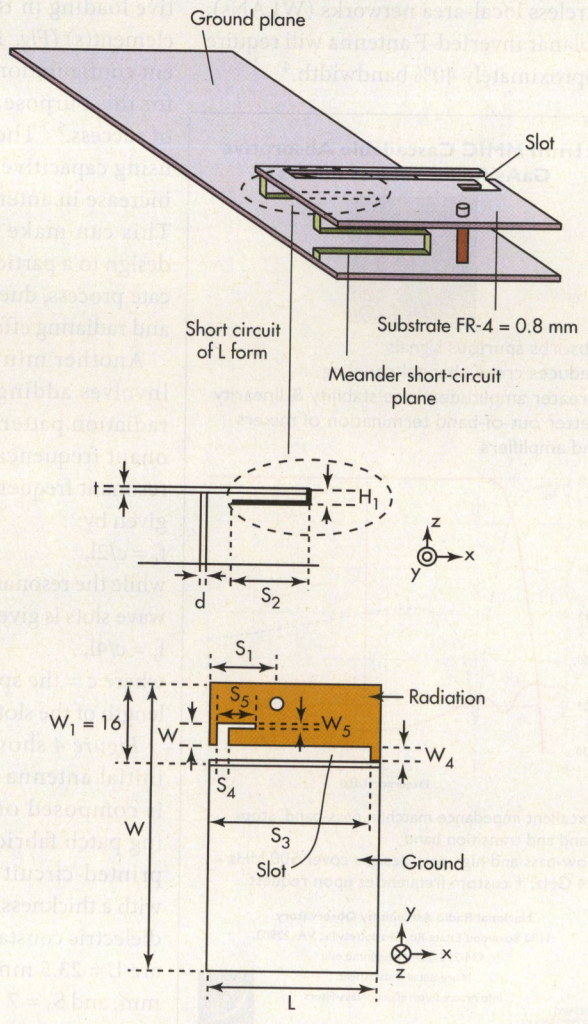
3. These quarter-wave or "emerging" slots were integrated into the design of the PIFA antenna.



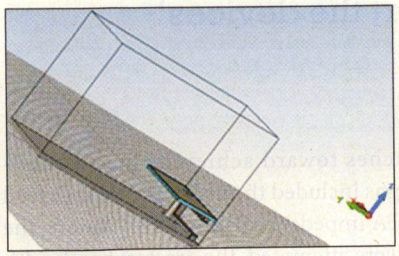
4. The initial design of the proposed PIFA antenna employed this structure.

Additional approaches toward achieving broad bandwidths with PIFA designs included the use of the various feed dishes to widen the PIFA impedance bandwidth.[3] Among the various methods that were attempted, the greatest bandwidth achieved was 24.1% (for a VSWR of less than 2.0:1) for a bi-triangular feed dish. To date, the proposed approaches to increase these bandwidths[1-3] have topped out at 25% improvement for PIFA return-loss (S_{11}) performance of better than –10 dB.

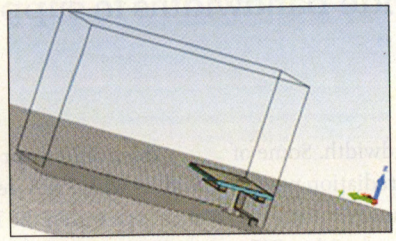
Unfortunately, a PIFA requires much wider bandwidth to support today's array of popular wireless, mobile applica-



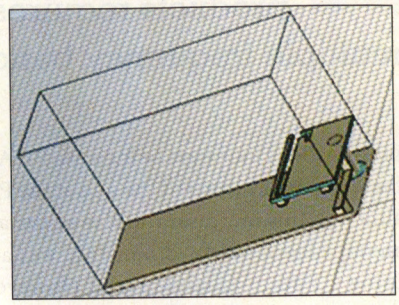
5. The diagrams show the basic structure of the proposed PIFA antenna.



(a) Initial antenna



(b) Addition of a short-circuit band



(c) Insertion of a slit of another form

6. Using CST Microwave Studio EM simulation software, these designs were developed for the initial antenna (a), the antenna with the addition of a short-circuit band (b), and with the insertion of a slot (c).

tions. For example, for 1710- to 1880-MHz DCS1800, 1920- to 2170-MHz IMT-2000, and 2400- to 2483-MHz wireless local-area networks (WLANs), a planar inverted-F antenna will require approximately 40% bandwidth.[4]

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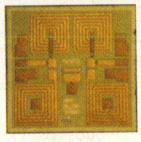

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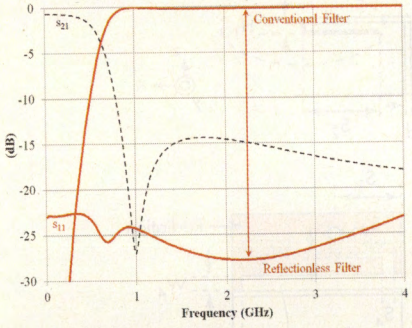

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MAKE THEM SMALLER

One way to miniaturize antennas for these applications is to insert capacitive loading in the antenna's radiating element(s) *(Fig. 1)*. A number of different configurations have been evaluated for this purpose, with varying degrees of success.[5-7] The main disadvantage of using capacitive loading relates to the increase in antenna quality factor (Q). This can make adapting an antenna design to a particular application a delicate process, due to reduced bandwidth and radiating effectiveness.

Another miniaturization approach involves adding slots to an antenna's radiation pattern to produce new resonant frequencies *(Figs. 2 and 3)*. The resonant frequency of half-wave slots is given by:

$f_r = c/2l$,

while the resonant frequency of quarter-wave slots is given by:

$f_r = c/4l$,

where c = the speed of light, and l = the length of the slot (in mm).

Figure 4 shows the structure of the initial antenna design.[4] This antenna is composed of a rectangular radiating patch fabricated on low-cost FR-4 printed-circuit-board (PCB) material with a thickness T = 0.8 mm and relative dielectric constant of 4.6. Its dimensions are L = 23.5 mm, W_1 = 15 mm, W_2 = 2 mm, and S_1 = 7 mm.

A coaxial feed probe with diameter d = 1.7 mm and meander short-circuit band are connected to the patch. The meander short-circuit band is fabricated in copper with dimensions of H_1 = 2 mm, H_2 = 5 mm, H_3 = 2 mm, and S_2 = 14 mm; copper-band thickness is 0.3 mm. Bandwidth is tied to a dimension of W_3 = 2 mm. The short-circuit band connects to the edge of the surface of the radiating element at one end and to the side of the ground plane at the other end. The chosen ground plane had a width (W) of 62.5 mm and length (L) of 23.5 mm.

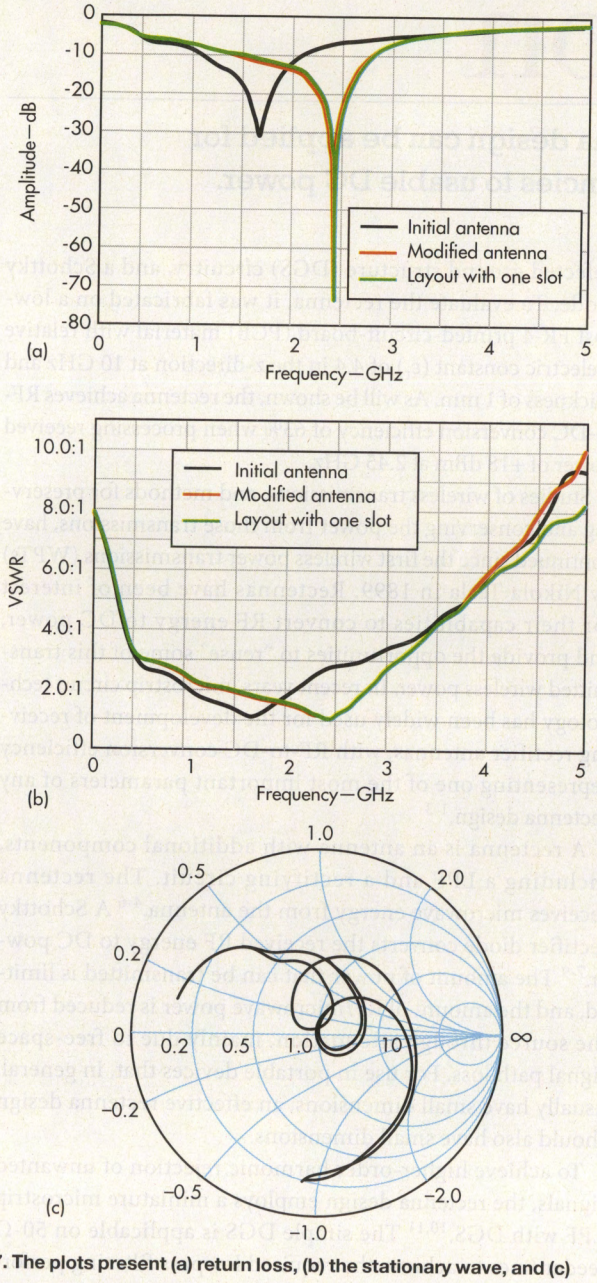
The broadband PIFA is based on legacy PIFA designs, although with two key modifications. The first modification involved adding a short-circuit band in L-type form (with H_1 = 2 mm and S_2 = 14 mm) at the other end of the radiating element, where the patch width W_1 = 16 mm. In the second modification, a slot of another form, with dimensions of W_4 = 2 mm, W_5 = 1 mm, W_6 = 3 mm, S_3 = 22.5 mm, S_4 = 2 mm, and S_5 = 4 mm, is inserted into the radiating element *(Fig. 5)*.

Engineers simulated the novel broadband PIFA with CST Microwave Studio computer-aided-engineering (CAE) software from Computer Simulation Technology (www.cst.com). The 3D electromagnetic (EM) simulation software includes time- and frequency-domain solvers in support of different analysis approaches. *Figure 6* shows simulations of the PIFA using this software.

Figures 7(a), (b), and (c) present documentation for the PIFA's return loss,

> "One way to miniaturize antennas for these applications is to insert capacitive loading in the antenna's radiating element(s). A number of different configurations have been evaluated for this purpose..."

stationary wave behavior, and input impedance, respectively, for three simulated antenna designs. As evidenced in the different figures, the global antenna was able to provide broadband characteristics.



7. The plots present (a) return loss, (b) the stationary wave, and (c) the input impedance for the antenna.

The antenna designs began with a simple broadband PIFA structure having an impedance bandwidth of 61.15% for return loss (S_{11}) of less than −10 dB from 1.08 to 2.109 GHz. Bandwidth was enhanced by simply reforming the PIFA short-circuit band into a meander band. The broadband PIFA can serve applications in 1570- to 1580-MHz Global Positioning Systems (GPS), 1710- to 1880-MHz DCS1800, 1850- to 1990-MHz Personal Communication Services (PCS) systems, and 1900- to 2025-MHz IMT-2000.

The addition of an L-form short-circuit structure improves antenna performance, featuring return loss of −53.04 dB at 2422 MHz. However, the impedance bandwidth antenna, at 55.21%, is less than earlier versions of the antenna for S_{11} (return loss) of better than −10 dB from 1462 to 2799 MHz. This antenna design, with such wide impedance bandwidth, can cover GPS, DCS, PCS, IMT-2000, and Bluetooth (2400.0 to 2483.5 MHz) applications.

In the modified PIFA designs, insertion of a slot on the radiating element allows the return loss to reach a peak level of −73.37 dB at a resonant frequency of 2442 MHz. The impedance bandwidth is 51.96 dB from 1530 to 2799 MHz, for a VSWR of less than 2.0:1.

The Smith chart plot *[Fig. 7(c)]* shows that input impedance locations are located at the center of the abacus for the three antenna designs. This indicates good frequency coverage for the target frequency ranges. The PIFA designs employ a coaxial probe as the feed method with effective results across the wide operating bandwidth for these multiple wireless and mobile-communications applications. MW

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Design Feature

SHUAI JI | Engineer HUA QI | Engineer HUIFENG ZHANG | Engineer

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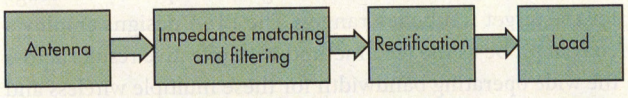
Rectenna Serves 2.45-GHz Wireless Power Transmission

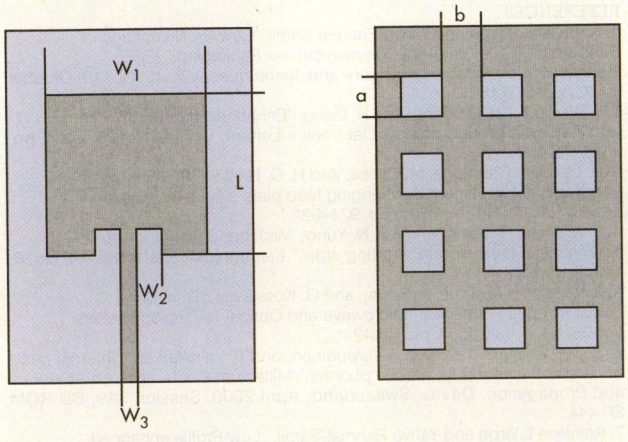
This fairly simple and straightforward rectenna design can be applied for conversion of energy at RF/microwave frequencies to usable DC power.

Wireless applications inject a great deal of excess electromagnetic (EM) energy into the environment—energy that can be reused if properly recovered. A rectifying antenna, or rectenna as it is popularly known, is one such means for recovering that energy. To demonstrate the capabilities of such a design, a novel rectenna was developed for low-power operation at a single Industrial-Scientific-Medical (ISM) frequency of 2.45 GHz.

The rectenna consists of a highly efficient photonic-band-gap (PBG) structure, a microstrip lowpass filter (LPF) with defected ground structure (DGS) circuitry, and a Schottky diode. To evaluate the rectenna, it was fabricated on a low-cost FR-4 printed-circuit-board (PCB) material with relative dielectric constant (ε_r) of 4.4 in the z-direction at 10 GHz and thickness of 1 mm. As will be shown, the rectenna achieves RF-to-DC conversion efficiency of 63% when processing received power of +18 dBm at 2.45 GHz.



1. This diagram shows the main function blocks of the rectenna circuit.



2. This schematic diagram presents the linearly polarized PBG antenna for use at 2.45 GHz.

Studies of wireless transmissions, and methods for preserving and conserving the power from those transmissions, have continued since the first wireless power transmissions (WPTs) by Nikola Tesla in 1899. Rectennas have been of interest for their capabilities to convert RF energy to DC power, and provide the opportunities to "reuse" some of this transmitted wireless power. In recent years, microstrip circuit technology has been widely used for the development of receiving rectifier antennas, with RF-to-DC conversion efficiency representing one of the most important parameters of any rectenna design.[1-3]

A rectenna is an antenna with additional components, including a LPF and a rectifying circuit. The rectenna receives microwave energy from the antenna.[4-6] A Schottky rectifier diode converts the received RF energy to DC power.[7-9] The amount of power that can be transmitted is limited, and the amount of RF/microwave power is reduced from the source through attenuation, mainly due to free-space signal path loss. For use in portable devices that, in general, usually have small dimensions, an effective rectenna design should also have small dimensions.

To achieve higher-order harmonic rejection of unwanted signals, the rectenna design employs a miniature microstrip LPF with DGS.[10,11] The simple DGS is applicable on 50-Ω feeder lines to achieve the required lowpass filtering performance. The LPF with DGS can suppress and isolate second-

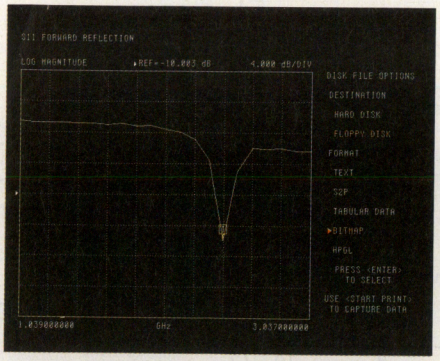
and third-order harmonic signals from the rectifying circuitry, allowing the rectenna to achieve its target high RF-to-DC conversion efficiency without processing unwanted signals.

RECTENNA DESIGN

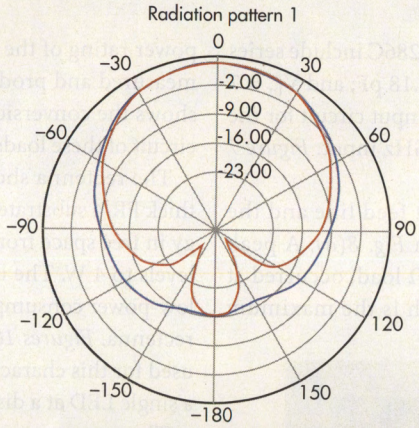
Figure 1 shows a block diagram of the proposed rectenna design. In developing this design, the PBG antenna, DGS LPF, and rectifier circuits were all first designed, fabricated, and characterized separately. Then they were combined to realize a complete rectenna.

The linearly polarized PBG antenna was fabricated on 1-mm-thick FR-4 substrate with a relative dielectric constant of 4.4 at 10 GHz in the z-direction of the material *(Fig. 2)*. The dimensions of the 50-Ω feed line were 20 × 1.9 mm. The dimensions of the PGB antenna were 30 × 31 mm. The photonic-band-gap (PBG) structure in the ground is designed to improve the gain as well as the directionality of the antenna. This increase in gain corresponds to improved power transmitting efficiency.

The square hole in the ground is designed for the PBG structure and it measures 6.6 × 7.0 mm. For some measure of the PGB antenna performance, *Fig. 3* shows the antenna's return loss while *Fig. 4* offers its gain characteristics.



3. The plot offers measured results of return loss for the PBG antenna.



Name	Theta	Ang	Mag
m_1	360.0000	-0.0000	3.6908
m_2	180.0000	180.0000	-12.3883

4. These are computer-simulated results of the gain for the PBG antenna.

The rectenna's DGS LPF was also designed and fabricated on FR-4 substrate material with relative dielectric constant of 4.4. With the U-slot added to it, the DGS offers good low-pass characteristics with improved harmonic-suppression characteristics in the high-frequency stopband. The proposed DGS LPF exhibits sharp filter cutoff characteristics, with low in-band insertion loss, wide stopband, compact size, and relatively easy fabrication. The U-shaped slot is combined with a rectangular groove measuring 3.8 × 5.5 mm and a pair of gaps measuring 0.50 × 7.25 mm.

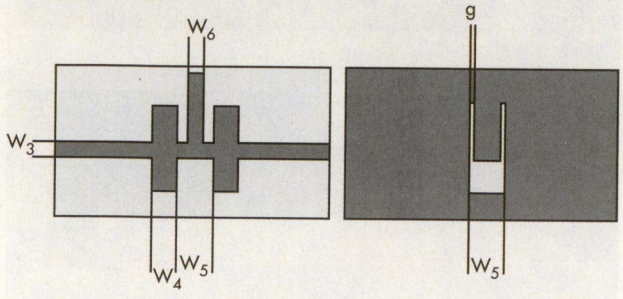
To achieve enhanced performance from the LPF, symmetric stubs were introduced to increase the filter's bandstop suppression in the high-frequency band. *Figure 5* presents the structure of the DGS LPF used in the rectenna. The optimal dimensions for the DGS LPF are as follows: W_4 = 3.6 mm; W_5 = 5.5 mm; W_6 = 1.5 mm; and g = 0.5 mm. For good bandstop characteristics, the length of the symmetric stubs can be of great importance.

As can be observed, the value of L greatly influences the band-notched frequency, as shown in *Fig. 6*. The bandstop frequency varies from 3.0 to 6.0 GHz as the value of L is varied from 0 to 18 mm.

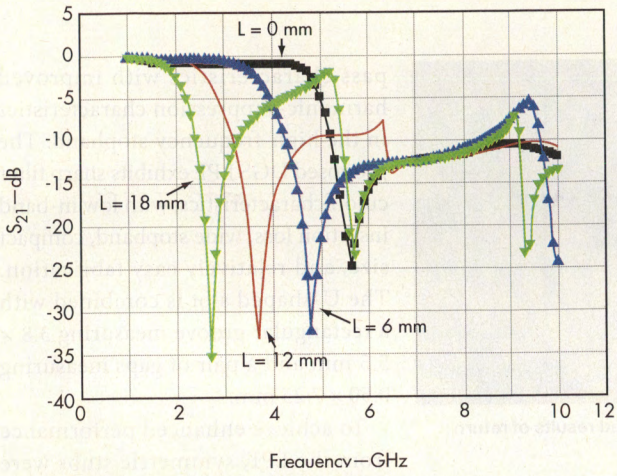
In the rectenna design, the purpose of the rectifier is to directly convert RF/microwave energy into DC electrical energy. For this purpose, Schottky diodes are the preferred means of conversion for their low-voltage drops and high-speed response and processing capabilities. In addition, Schottky diodes consume the least amount of power due to conduction and switching of alternative RF-to-DC conversion approaches.

The commercial Schottky diode chosen for use in the rectenna design was model HSMS-286C from Avago Technologies (www.avagotech.com). This is a compact lead-free, surface-mount semiconductor that is usable from 915 MHz to 5.8 GHz. It features high detection sensitivity of as good as 50 mV/μW at 915 MHz, 35 mV/μW at 2.45 GHz, and 25 mV/μW at 5.8 GHz. The miniature surface-mount package helps save PCB space.

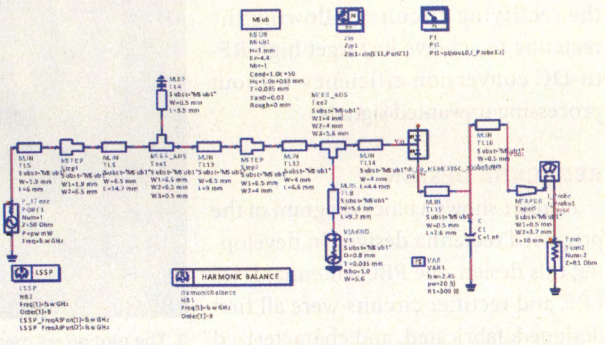
Within the rectifier circuit, the Schottky diode exhibits low parasitic circuit elements through about 6 GHz. High performance was achieved by modifying the basic parasitic circuit values and comparing them against the return-loss characteristics contained in the data sheet for the HSMS-



5. The schematic diagram represents the DGS LPF in the rectenna design.



6. The curves show simulated values of S_{21} for different values of L.



7. This schematic diagram represents the model used for the rectenna's impedance matching input circuit.

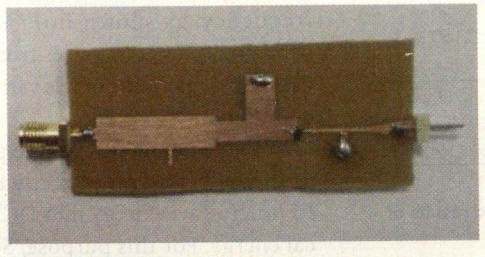
286C. The main parameters for the HSMS-286C include series resistance, R_s = 5 Ω; capacitance of C_{j0} = 0.18 pF; and V_{br} = 7 V. The next step was to create a matching input circuit for the diode, with matching done for the 2.45-GHz input. *Figure 7* shows the simulated circuit module.

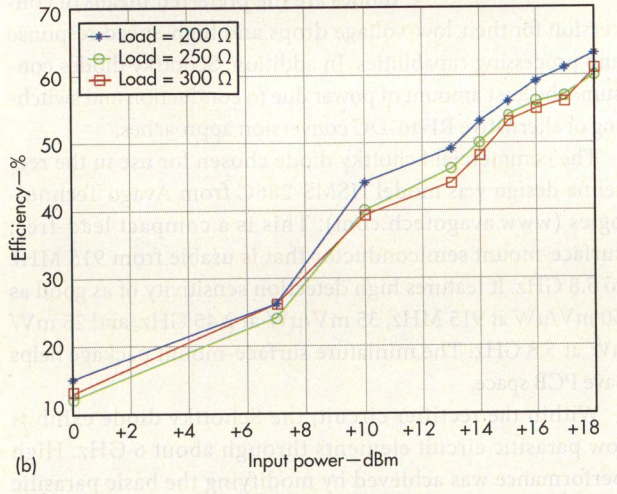
A matching circuit between the 50-Ω feed line and the RF-to-DC rectifying circuit is shown in *Fig. 8(a)*. A peak efficiency of 63%, measured with a 250-Ω load, occurred at roughly +18 dBm received power, which is the maximum power rating of the diode. Loads of 200 and 300 Ω were also measured and produced nearly identical results. *Figure 8(b)* shows the conversion efficiency for the RF-to-DC rectifying circuit of these loads.

The rectenna shown in *Fig. 9* was fabricated on a 1-mm-thick FR-4 substrate. It is designed to receive microwave energy in free space from a horn antenna with transmitted power levels to 4 W. The light-emitting diode (LED) is used as the low-power consumption load to verify the performance of the rectenna. *Figures 10 and 11* offer glimpses of the test system used for this characterization. The rectenna was used to drive a single LED at a distance of 1 m and a voltage of +1.7 VDC.

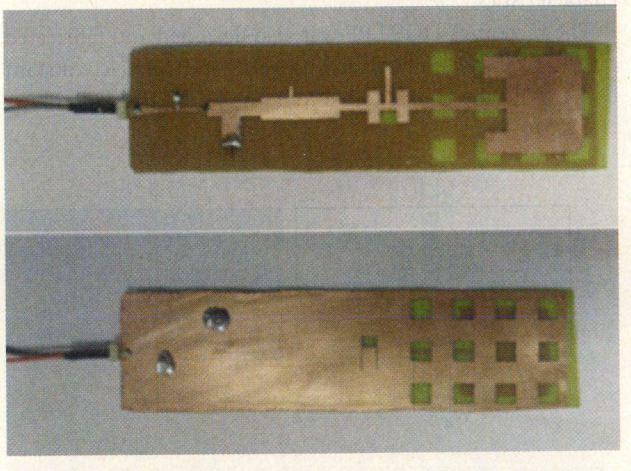
The energy received by the rectenna was +7.3 dBm, which translates to an efficiency of 13.9%. The rectenna also drove an LED array formed by three LEDs at a distance of 75 cm and voltage of +1.8 VDC. The efficiency of the rectenna in this case can reach as high as 45.5%.

The rectenna with PBG antenna operating at the single ISM-band frequency of 2.45 GHz represents a fairly simple





8. The proposed (a) matching circuit for the rectenna is shown next to its (b) measured electrical behavior



9. The proposed rectenna was fabricated on a 1-mm-thick FR-4 substrate.

design and an effective means of converting RF signals to DC energy at that frequency. The gain of the rectenna is 4.29 dBi at 2.45 GHz, with RF-to-DC conversion efficiency of as high as 63%. This particular rectenna design can operate effectively with low-power loads at these ISM frequencies using a low-cost LED to aid in the conversion.

This rectenna design can contribute to low-power energy-harvesting applications at the ISM frequency band of 2.45 GHz. It was fabricated on relatively low-cost circuit substrate material with effective results, with the LED serving to assist in the operational stability while also indicating the proper operation of the rectenna circuitry. With its high gain and high RF-to-DC conversion efficiency, the rectenna represents a simple circuit addition for ISM-band products and an efficient means of reusing some of the energy that might otherwise have been lost. For compact and portable products, ideally the rectenna can be made with relatively small dimensions and at low cost.

This simple and straightforward conversion design can be applied to achieve power supplies for low-power loads, and can be useful in powering such applications as radio-frequency identification (RFID), wireless sensor networks, and micro-mechanical systems. MW

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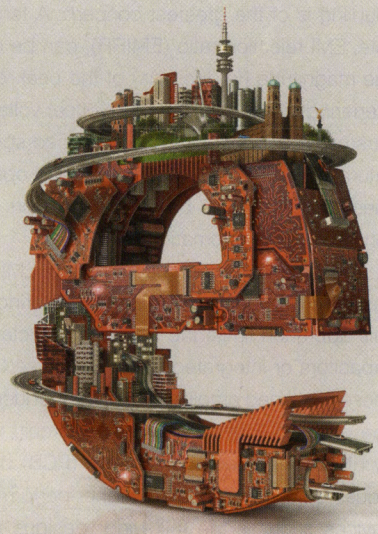

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GET A CLUE ABOUT GaN'S THERMAL BEHAVIOR

THE MICROWAVE INDUSTRY has long sought power amplifiers (PAs) with extremely high-frequency capability at wide bandwidths and with high power output. Recently, such PAs have become feasible with gallium-nitride (GaN) technology. Unfortunately, significant thermal stress is a natural side effect of high frequency and power operating in a small area. Both device manufacturers and designers are seeking to understand and predict the thermal stresses of GaN devices. They also need a process to perform these predictions. In the white paper, "GaN Thermal Analysis for High-Performance Systems," TriQuint discusses a process that can be used to reliably analyze a GaN device's thermal behavior.

A nonlinear modeling technique for field-effect transistors (FETs) is used to construct the baseline thermal model. This technique is used to generate estimates of heat and the initiation prediction of thermal performance. After fabrication, testing is performed with empirical thermal data and micro-Raman measurements to create a finite-element-analysis (FEA) model. Multiple testing and model-refinement iterations are needed to provide satisfactory correlation with the various geometries' material stackups. The results of this effort are used to generate thermal-analysis simulations all the way to system-level designs.

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The note emphasizes that designers must both understand and accurately describe boundary conditions. This step is critical to achieving a reliable design with these models. Using multiple methods for thermal analysis will aid in accurately describing the thermal effects and developing a sophisticated model. In addition, doing RF testing on an operational design can help to evaluate sensitivity to temperature while offering the design team a more complete picture of the process' thermal behavior.

Another important factor to consider is the die-attach method. As the note explains, an assumption based on material datasheet parameters may not reflect the actual bond formed. A bond material, such as epoxy, may have thermally variable effects that are not described in a material datasheet. As a result, the material could significantly deviate from the expected performance. The note concludes with a discussion about several packaging materials and methods, which could provide benefits for different applications of GaN devices. Examples include GaN on copper and GaN in plastic packages.

EMI-HARDENED OP AMPS MAKE A PREEMPTIVE STAND

ELECTROMAGNETIC INTERFERENCE (EMI) is an ever-present concern with electronic devices. Conduction and radiated EMI ingress into a system can be very difficult to prevent. Thankfully, designing components, such as amplifiers, with EMI mitigation techniques could improve the performance and robustness of many systems. Microchip Technology reports these techniques in an application note titled, "Solutions for Radio Frequency Electromagnetic Interference in Amplifier Designs."

The note states that the impedance of an EMI filter is highly reactive. It provides a higher resistance as the frequency of the signal increases. This attenuation can degrade the strength of the signal to the input device. As a result, a growing trend is to integrate the EMI filter with the active components of the input device. To enhance the performance of EMI filtering while maintaining signal integrity, another step is to incorporate the EMI-filter design in the input of an active circuit, such as an operational amplifier.

EMI can be either radiated or conducted. It can be created by a man-made device or occur naturally. EMI also may appear continuously or as an impulse of noise in a narrow or broadband spectrum. Common-mode and differential-mode coupling is of the greatest concern. A term described in the note, EMI rejection ratio (EMIRR), can be defined as the voltage magnitude (in decibels) of the peak amplitude of the RF interfering signal over the input-offset voltage shift. Using this parameter, amplifiers can be designed specifically to provide naturally high EMIRR or EMI-hardened operational amplifiers. These amplifiers can be used in sensors and other applications to provide automatic EMI filtering.

The note recommends using an EMI-hardened op-amp design to avoid degrading the EMI filtering circuit's capability. This approach limits the parasitic inductance of the discrete capacitors or integrated trace leads used in the filter design. These hardened amplifiers also can reduce the DC offset voltage at the output of an op-amp circuit, which is generated by EMI. For printed-circuit-board (PCB) designs, these techniques also could enable higher-performing EMI-resistance devices such as the following: designs using the high/low-frequency decoupling of amplifier power leads; reduction of common impedance; use of low-impedance electrolytic capacitors; use of low-inductance bypasses; and optimally designed, ground-continuous groundplanes.

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	ZVE-3W-83+	2000-8000	35	2	3	1295
	ZVE-3W-183+	5900-18000	35	2	3	1295
NEW	ZHL-4W-422+	500-4200	25	3	4	1570
NEW	ZHL-5W-422+	500-4200	25	3	5	1670
	ZHL-5W-2G+	800-2000	45	5	6	995
	ZHL-5W-1	5-500	44	8	11	1020
	ZHL-10W-2G	800-2000	43	10	13	1295
•	ZHL-16W-43+	1800-4000	45	13	16	1595
•	ZHL-20W-13+	20-1000	50	13	20	1395
•	ZHL-20W-13SW+	20-1000	50	13	20	1445
	LZY-22+	0.1-200	43	16	32	1495
	ZHL-30W-262+	2300-2550	50	20	32	1995
	ZHL-30W-252+	700-2500	50	25	40	2995
	LZY-2+	500-1000	47	32	38	2195
	LZY-1+	20-512	42	37	50	1995
•	ZHL-50W-52+	50-500	50	40	63	1395
•	ZHL-100W-52+	50-500	50	63	79	1995
•	ZHL-100W-GAN+	20-500	42	79	100	2395
	ZHL-100W-13+	800-1000	50	79	100	2195
	ZHL-100W-352+	3000-3500	50	100	100	3595
	ZHL-100W-43+	3500-4000	50	100	100	3595
	LZY-5+	0.4-5	52.5	100	100	1995

Listed performance data typical, see minicircuits.com for more details.

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SDR APPROACH Seizes 6 GHz

This clever combination of software with analog and digital components results in a radio system that can handle a wide variety of transmission and reception formats through 6 GHz.

SOFTWARE-DEFINED-RADIO (SDR) TECHNOLOGY provides the flexibility that allows a well-designed radio to adapt to many different conditions. The Crimson SDR from Per Vices (www.pervices.com) is an excellent example of that technology, fueled by effective analog and digital circuitry, along with the frequency range and wide operating transmit and receive bandwidths to 6 GHz.

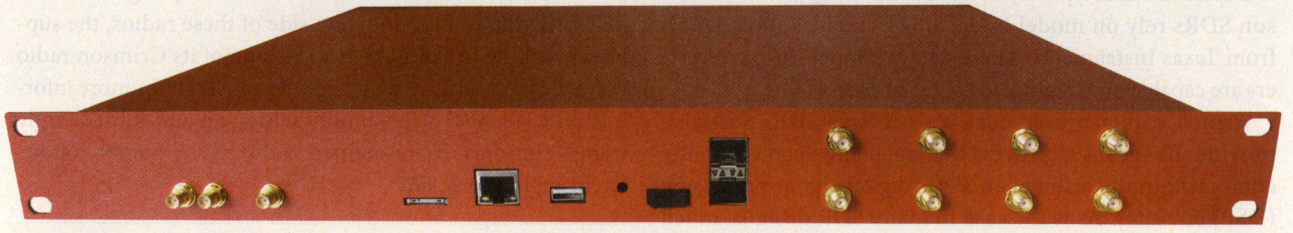
The compact, efficient radio features four independent receive chains and four independent transmit chains to handle applications for commercial, industrial, and military users with outstanding performance levels and high reliability. The independent channels are also well suited for multiple-input, multiple-output (MIMO) communications systems.

Communications systems based on SDRs offer great flexibility due to their programmability. Because such radio designs combine RF/microwave, analog, and digital circuitry, they can be programmed in the field (even remotely) to handle a wide range of carrier frequencies, carrier bandwidths, and even advanced modulation formats. Software is a vital part of the effective operation of these radios, and software can still be one of the costlier components in assembling an SDR system. [Those seeking background information on SDRs can find it within the earlier articles "SDR Technology Targets Flexibility and Security" (June 2013) and "SDRs Leap Ahead" (June 2014).]

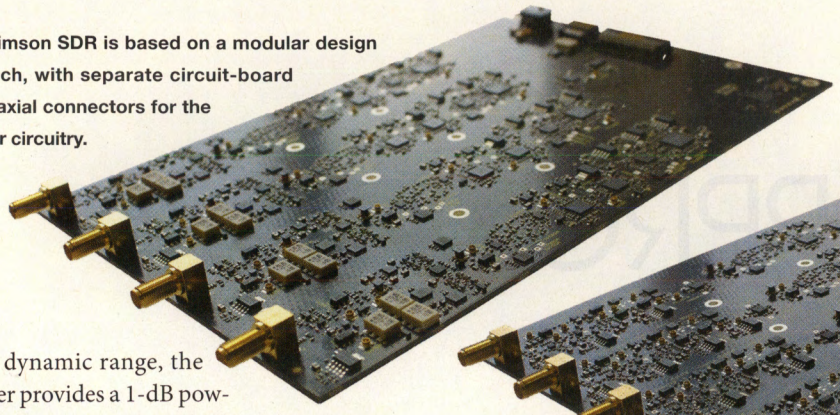
The Crimson radio combines the latest advances into an SDR with a great deal of flexibility and processing power (*Fig. 1*). The radio is housed in a relatively small enclosure for ease of integration with other systems. It handles a total operating frequency range of 100 kHz to 6 GHz using multiple signal channels and processors. It can tackle as much as 800-MHz bandwidth by means of four independently controllable receive channels and as much as 800-MHz bandwidth using four independently controllable transmit channels.

Frequency stability starts with an internal reference source based on a 10-MHz clock oscillator with ±5-ppb stability. The reference oscillator is designed to hold that frequency stability across a wide operating temperature range, enabling the radio to provide reliable communications under realistic operating conditions—even on the battlefield.

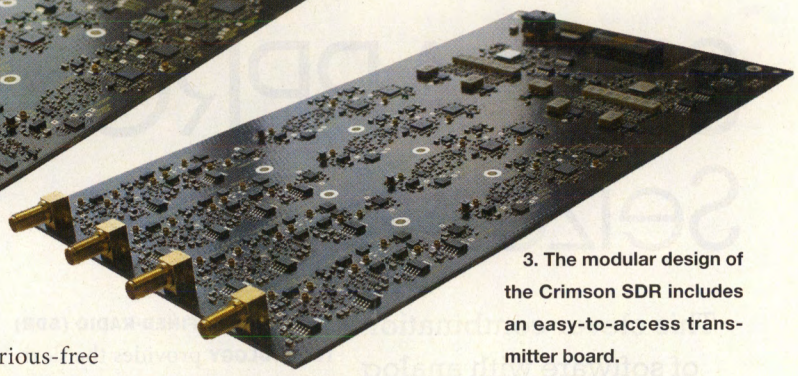
The Crimson receive section (*Fig. 2*) achieves small-signal gain of 67 dB. The high gain enables the SDR to detect even low-level signals with a typical sensitivity of −110 dBm. At the high end



1. A Crimson software-defined radio (SDR) employs advanced hardware and software to achieve flexible radio performance through 6 GHz in a compact package.



2. A Crimson SDR is based on a modular design approach, with separate circuit-board and coaxial connectors for the receiver circuitry.



3. The modular design of the Crimson SDR includes an easy-to-access transmitter board.

of the dynamic range, the receiver provides a 1-dB power compression point (P1dB) of typically –11 dBm. It boasts a signal-to-noise ratio (SNR) as good as 73 dB with a spurious-free dynamic range (SFDR) of 55 dB at 200 MHz.

The SDR's transmit section (*Fig. 3*) achieves maximum transmit power of +10 dBm at 6 GHz, with a typical P1dB of +14 dBm. The transmitter offers a spurious-free dynamic range of 61 dB from DC to 500 MHz. As shown in the printed-circuit boards (PCBs) for the SDR's receive and transmit sections, the radio is based on a modular architecture that helps greatly simplify assembly during production and—later, if necessary—maintenance of different portions of the SDRs.

Of course, data converters are vital to the success of any SDR, and the Crimson radio builds upon analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) from Texas Instruments (www.ti.com). Among other traits, data converters for SDRs should provide high resolution and operate with low power consumption, especially in support of portable radios. For example, on the receive side, the SDR features a model ADC16DX370 dual 16-b ADC capable of a 370-MSample/s rate and generating 7.4-Gb/s JESD204B-compatible outputs.

This ADC achieves a typical full-scale SNR of 69.6 dB and full-scale SFDR of typically 88 dB. On the transmit side, Crimson SDRs rely on model DAC38J84 current-source DACs from Texas Instruments. These quad-channel, 16-b converters are capable of operating to 2.5 GSamples/s.

Armed with captured data, an effective SDR must also provide the means to process that data, and such capability comes within the realm of an SDR's digital-signal-processing (DSP) circuitry. As is the case in many SDR designs, much of the DSP actions are taken on by a field programmable gate array (FPGA). In the case of Crimson, the FPGA is an Arria V (model 5ASTMD3E3F31I3N) from Altera (www.altera.com), with an on-chip dual-core Cortex-A9 processor from Advanced RISC Machines (ARM).

This processing power is fueled by the SDR's high-stability 10-MHz reference clock. The internal signal processing power in the Crimson SDR is invaluable for flexible, reliable, high-speed communications, but it also enables backhaul and other types of connections to existing wired and wireless communications networks, by means of dual 10-Gb/s Ethernet backhaul connections on board the Crimson radio.

> "The compact radio features four independent receive chains and four independent transmit chains to handle applications for commercial, industrial, and military users with outstanding performance levels."

Crimson SDRs are ideal for any number of different applications, including for mobile backhaul connections and wireless base stations; spectrum allocation analysis; signal recording and spectrum monitoring in different communications systems; and near real-time signal analysis in practical systems and in research setups. The radios are equipped for commercial, industrial, medical, and military use, where flexibility is an asset and maintaining communications security is a primary concern.

For those who may be hesitant about adopting SDR technology because of the software side of these radios, the supplier is willing to share the beta version of its Crimson radio user interface (visit www.pervices.com/userio/ for more information). This will help simplify setting up and subsequently using Crimson sofware-defined radios in any number of different applications. MW

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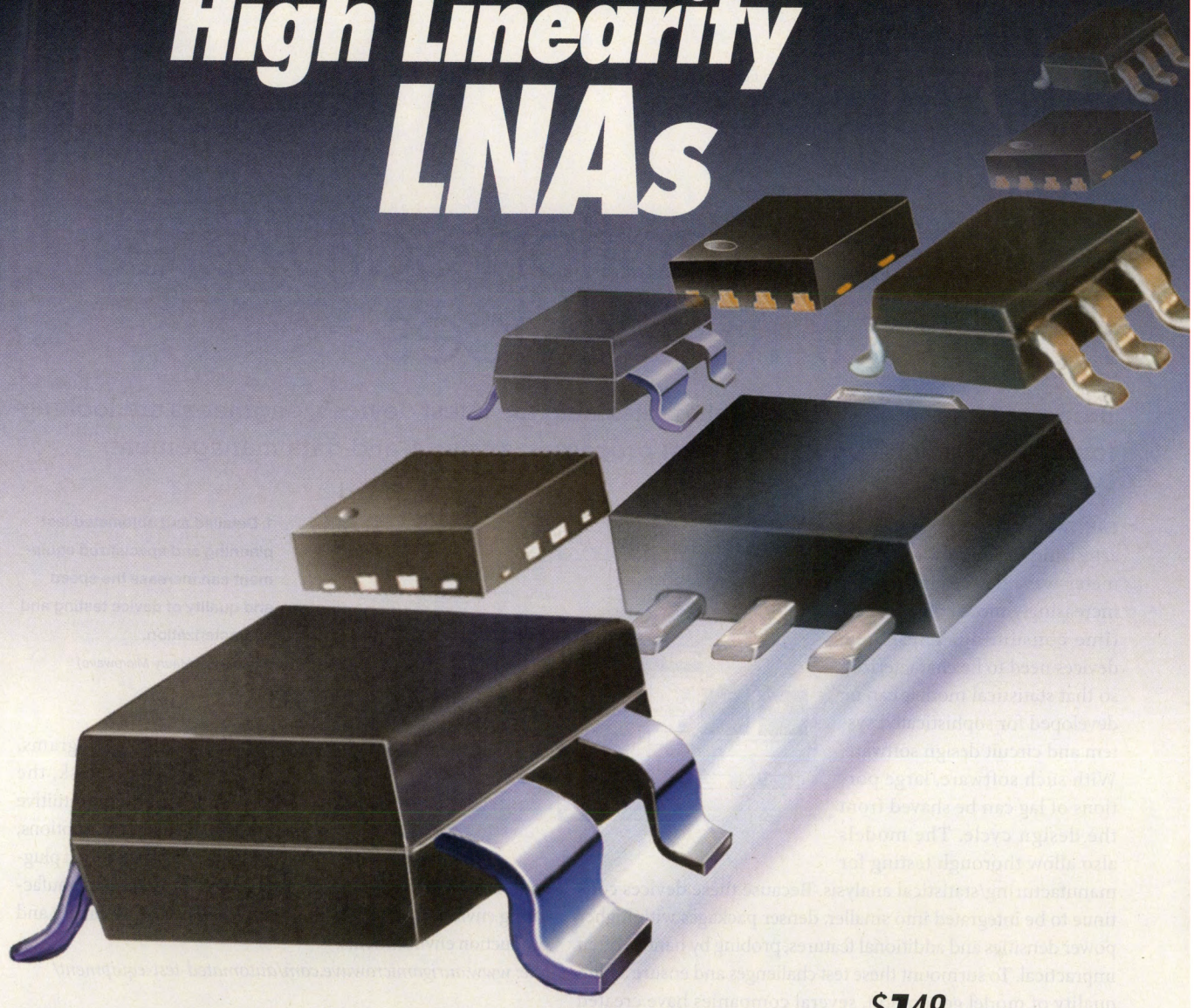

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PMA2-162LN+	700-1600	22.7	0.5	30	20	55	2.87
PMA-5452+	50-6000	14.0	0.7	34	18	40	1.49
PSA4-5043+	50-4000	18.4	0.75	34	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	0.8	33	19	40	1.49
PMA-5451+	50-6000	13.7	0.8	31	17	30	1.49
PMA2-252LN+	1500-2500	15-19	0.8	30	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	0.9	33	22	158	4.95
PMA-5454+	50-6000	13.5	0.9	28	15	20	1.49



PSA PMA PGA

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
PGA-103+	50-4000	11.0	0.9	43	22	60 (3V) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	0.7	37	20	60	1.49
PSA-5453+	50-4000	14.7	1.0	37	19	60	1.49
PMA-5456+	50-6000	14.4	0.8	36	22	60	1.49
PMA-545+	50-6000	14.2	0.8	36	20	80	1.49
PSA-545+	50-4000	14.9	1.0	36	20	80	1.49
PMA-545G1+	400-2200	31.3	1.0	34	22	158	4.95
PMA-545G2+	1100-1600	30.4	1.0	34	22	158	4.95
PSA-5455+	50-4000	14.4	1.0	32	19	40	1.49

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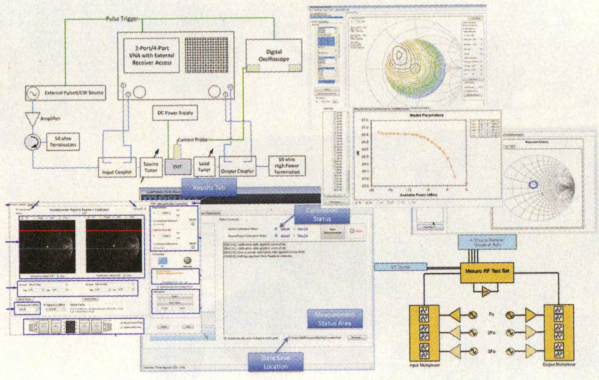
JEAN-JACQUES DELISLE | Technical Engineering Editor

Characterization Softwares For Your RF Devices

Burdened by the challenge of characterizing the latest devices, engineers are looking for solutions to streamline their test processes, analysis, and data management.



1. Detailed and automated test planning and specialized equipment can increase the speed and quality of device testing and characterization.
(Courtesy of Maury Microwave)

THE TASK OF testing and characterizing RF/microwave/millimeter-wave devices is growing increasingly more complex and time consuming. These new devices need to be characterized so that statistical models can be developed for sophisticated system and circuit design software. With such software, large portions of lag can be shaved from the design cycle. The models also allow thorough testing for manufacturing/statistical analysis. Because these devices continue to be integrated into smaller, denser packages with higher power densities and additional features, probing by hand is often impractical. To surmount these test challenges and ensure a high quality of model generation, several companies have created software-enhanced test systems. These systems provide automation, ease of testing, data analysis, data management, or even model development.

AURIGA WIZARD-BASED INTEGRATED DEVELOPMENT ENVIRONMENT (WIDE)

The Auriga Component Test System (CTS-4) uses a combination of third-party measurement hardware to enable faster speeds and greater accuracy for in-depth RF/microwave measurements. As a fully automated test system, the CTS-4 is designed to provide multiple-measurement testing in low- to high-volume development and manufacturing. Auriga's CTS-4 is designed to test base stations; local multipoint distribution systems (LMDSs); multichannel multipoint distribution systems (MMDSs) for customer premise equipment (CPE); and transmit and receive modules for commercial and military modules or monolithic microwave integrated circuits (MMICs).

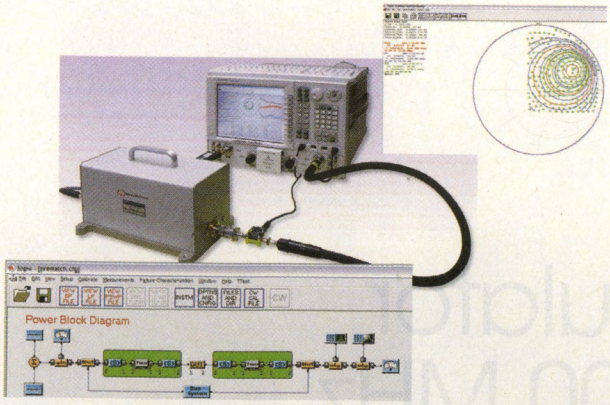
The software backbone of the CTS-4 is the Auriga WIDE. The goal of the WIDE environment is to enable skilled and unskilled users to develop scripts for complex test routines that can even run as standalone programs. To accomplish this task, the wizard provides many intuitive measurements, control options, and a library of pre-coded plug-and-play modules. The WIDE can be used for R&D or manufacturing environments to test continuity between development and production environments.

Site: www.aurigamicrowave.com/automated-test-equipment/

FOCUS DEVICE CHARACTERIZATION SUITE (FDCS)

Focus Microwaves' FDCS is actually a range of software packages that support the detailed characterization of key device parameters. FDCS is composed of a graphics tool, GraphEX, which supports the processing of x-y plots, current-voltage (IV) data, S-parameters, and many more characterization data plots. It also enables file conversion to common formats like Keysight's Advanced Design System (ADS), Keysight's Genesys, NI/AWR's Microwave Office, and CST's Microwave Suite. A tuner calibration and control package, CalEX, performs standard, thu-reflect-line (TRL), and three termination S-parameter measurements, as well as tuner in-situ calibration. A load-pull package also is included. Dubbed LPEx, it is capable of input power, output power, gamma, gain, and more. The NPEx suite enables noise-parameter measurements. It has been installed on systems that cover 0.3 to 67.0 GHz. Pulsed signals are handled by the MPIV package, which enables standalone pulsed current-voltage (IV) projects, pulsed DC biasing, and pulsed current-voltage curves.

Site: www.focus-microwaves.com/focus-device-characterization-suite-fdcs



2. The complexities of modern test often require many different software suites with test application specific focus. *(Courtesy of Mesuro)*

KEITHLEY AUTOMATED CHARACTERIZATION SUITE (ACS)

Keithley's ACS is designed to create and manage a wide variety of test and measurement results for modern discrete semiconductor components and devices with semi-automatic or fully autonomous probes. The software is capable of in-depth testing and parameter extraction. It offers three levels of software geared toward different users. The ACS Basic Edition is designed for manual or single device testing, while the ACS Standard Edition is compatible with multi-DUT testing and even wafer-level-reliability (WLR) testing with the ACS-2600-RTM option. On-wafer die or known-good-die (KGD) testing functionality also is offered to speed testing throughput with multi-DUT statistics and binning analysis during run-time.

The ACS suite also supports two devices: the 4200-SCS Parameter Analyzer and the S500 Integrated Test System. The 4200-SCS is an integrated parameter analyzer based on a modular configuration for the electrical characterization testing of processes, semiconductor devices, and materials. This analyzer is capable of measuring standard IV and capacitance-voltage (CV) measurement sweeps, as well as ultra-fast pulsed IV, waveform capture, and transient IV. The S500 is an integrated and configurable instrument-based test system.

Site: www.keithley.in/products/semiconductor/characterization-software/

MAURY MICROWAVE AUTOMATED TUNER SYSTEM (ATS)

To increase the comprehensiveness and usability of its ATS RF/microwave device-characterization software suite, Maury Microwave has released its fifth version (ATSv5). Among the many measurements that can be performed with ATSv5 are S/X, power, and noise parameters as well as intermodulation distortion (IMD), harmonics, and other key device characteristics. The test results recorded in the ATSv5 environment can be ported to Keysight's ADS for simulation. They also can be ported to Maury Microwaves' dynamic-link library (DLL) for use with ATS hardware, which boasts custom test and measurement applications. There are currently 15 ATSv5 software suite models for different applications ranging from active load pull to DC IV curve options.

The first two software-suite models support power characterization and noise characterization. They can be purchased in a combined package. Another package accounts for intermodulation distortion, adjacent-channel power, and error vector magnitude. There are several models for programmers, system control, and tuner library options.

Site: www.maurymw.com/MW_RF/ATS_Automated_Tuner_Software.php

MESURO VITESSE, WAVEFORM, AND CARDIFF MODEL LITE

Mesuro offers RF device-characterization software to aid with load-pull testing, device process analysis, power-amplifier (PA) design, and model development. The load-pull solution, VITESSE, uses a vector receiver approach to enable engineers to perform calibrated gamma and power measurements. Mesuro's WaveForm solution couples with patented hardware, a radio-frequency test-stand (RFTS)/multiplexer assembly, and other test equipment to make terminal voltage and current measurements in real time, delivering feedback to discover optimum performance. To provide high-quality models, large-signal parameters are used with a polyharmonic, distortion-based, behavioral-model formulation using the harmonic superposition principle in the Cardiff Model Lite software. This software offers calibration, characterization setups, and measurement configurations. As a result, the device model can be extracted even under RF and DC pulse conditions.

Sites: www.mesuro.com/articles/products/vitesse-load-pull-solutions
www.mesuro.com/articles/products/waveform-engineering-solutions
www.mesuro.com/articles/products/cardiff-model-lite

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Sites: www.ni.com/labview
www.ni.com/lwcvi MW

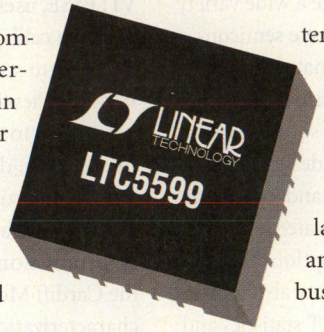
Product Feature

JACK BROWNE | Technical Contributor

Miniature Modulator Drives 30 to 1300 MHz

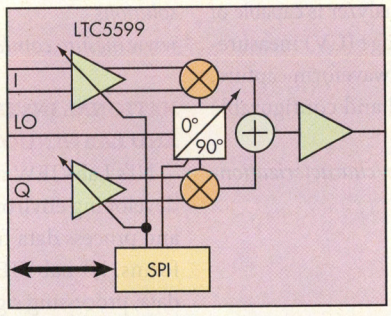
This compact direct-conversion I/Q modulator minimizes power consumption in a wide range of battery-powered communications applications from 30 MHz to 1.3 GHz.

DESIGNERS OF BATTERY-POWERED, portable communications devices continue to aim for lower-power operation even as the devices increase in complexity. One illustration of this trend is Linear Technology's model LTC5599 direct-conversion in-phase/quadrature (I/Q) modulator, which provides excellent performance from 30 MHz to 1.3 GHz in spite of requiring a mere 28-mA current from a supply of +2.7 to +3.6 VDC. Housed in a 24-lead, 4-×-4 mm QFN package, the compact I/Q modulator is suitable for low-power use among an extended range of applications, which include wireless microphones; commercial and military software-defined radios (SDRs); battery-powered military and commercial radios, satellite-communications (satcom) systems; and wireless networks.



1. The compact model LTC5599 low-power direct-conversion I/Q modulator provides a wide dynamic range for carrier frequencies from 30 to 1300 MHz.

The model LTC5599 I/Q modulator *(Fig. 1)* is designed for direct modulation of differential I and Q signals onto an RF carrier signal. By applying 90-deg. phase-shifted signals to the I and Q signals, single-sideband (SSB) or sideband- and carrier-suppressed upconversion can be achieved. As shown in a simple block diagram of the modulator *(Fig. 2)*, it is essentially a pair of RF mixers and a power combiner, but includes control of I and Q baseband input channels and a serial peripheral interface (SPI) bus. The modulator consumes very little energy from low-voltage sources and can be used with sine-wave or square-wave local oscillator (LO) drive.



2. The block diagram shows some of the basic component functions, including mixers and amplification, contained within the packaged LTC5599 IC.

The SPI bus provides control of modulator gain, and can optimize LO carrier feedthrough and sideband suppression. The modulator integrated circuit (IC) even includes a thermometer that can be activated to compensate for gain variations with temperature to maintain stable modulation levels across wide operating-temperature ranges. The packaged modulator also provides a continuous analog gain-control pin (V_{CTRL}) for high-speed control of power levels.

In terms of performance, the LTC5599 modulator provides reliable control of desired signals and helps minimize undesired signals. The SPI bus, for example, allows control of I/Q gain from −19 to 0 dB in 1-dB steps (with the gain level impacting the current consumption). LO carrier leakage of only −65 dBm. LO carrier leakage is typically just −51.5 dBm at 500 MHz, but can be lowered to −65 dBc with the I and Q offset adjustment. The sideband suppression is typically −52.6 dBc at 500 MHz, which can similarly be reduced by means of I/Q gain and phase adjustment to a mere −60 dBc.

The LTC5599 I/Q modulator provides healthy output third-order-intercept-point (IP3) of +20.8 dBm at 500 MHz. It features low RF output noise floor of −156 dBm/Hz at 6 MHz offset from the carrier, when measured with an RF output power level of +3 dBm. The modulator's excellent image rejection and carrier suppression help improve wireless transmitter performance while the low-power operation can help extend battery operating time. With the SPI bus and the modulator's adjustable gain, it can also help to minimize the need for additional external components, contributing to lower costs. mw

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JACK BROWNE | Technical Contributor

Chips Steer 77-GHz Automotive Radars

This millimeter-wave chipset provides scalable performance for automotive safety systems for cruise control, braking systems, and numerous other functions.

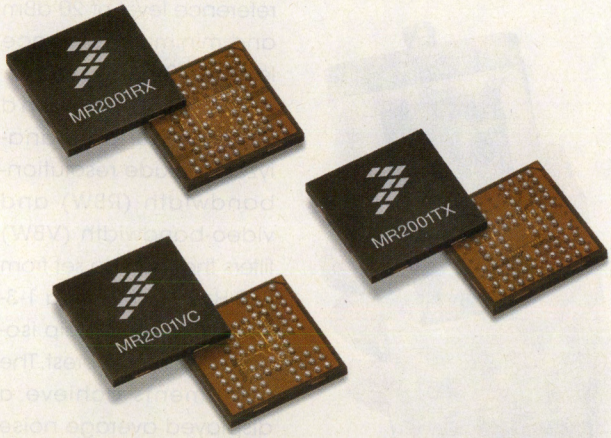
MILLIMETER-WAVE FREQUENCIES WERE once considered the realm of relatively exotic applications, most notably space exploration. These days, more and more designers are discovering that some of these frequencies are well suited for applications right here on the ground.

The latest of these is the model MR2001 high-performance 77-GHz radar transceiver chipset from Freescale Semiconductor, which embodies the front-end section for radar-based automotive safety systems at those high frequencies. The packaged front-end chip set can be teamed with the firm's MPC577xK family of microcontrollers to create an automotive radar system capable of a wide range of safety functions—including adaptive cruise control (ACC), emergency braking systems, lane departure warning, and blind-spot detection.

Growing use of 77-GHz signals in commercial vehicles can only make the roads safer as drivers are warned of impending trouble spots by these low-power, millimeter-wave signal reflecting off targets on and off the road. The MR2001 radar transceiver chipset is readily scalable for multiple-channel operation so that a single radar platform can perform various functions.

The MR2001 radar chipset *(see photo)* consists of receiver, transmitter, and voltage-controlled-oscillator (VCO) devices that are scalable to support as many as four transmit and 12 receive channels. A typical radar module would combine the three MR2001 chips with a microcontroller, such as an MPC577xK unit. Millimeter-wave signals are generated with the aid of a 38-GHz on-board local oscillator (LO) produced by the VCO chip, which links the receiver and transmitter chips. In the system, the microcontroller unit (MCU) and its transmit and receive components are stabilized by means of a 40-MHz crystal clock oscillator.

Individual control of the chips is achieved by means of a Serial Peripheral Interface (SPI) bus, with the MCU providing integrated analog-to-digital converters (ADCs) and additional signal-processing capabilities, such as fast Fourier transforms (FFTs). In addition, the transmit devices include biphase modulator circuitry while the receivers boast integrated baseband (BB) filters and variable-gain amplifiers (VGAs).



The packaged devices contain transmitter, receiver, and tunable oscillators for 77-GHz automotive safety systems.

Not only does the integration of these components simplify system design, but it also helps to reduce bill-of-materials (BOM) costs when designing and implementing a 77-GHz automotive radar system. In spite of the advanced signal processing and comprehensive functionality, the three-chip 77-GHz radar transceiver solution achieves low power consumption of only 2.5 W for the entire transceiver.

The MR2001 radar chipset is housed within advanced packaging to limit consumption of space on an automotive printed-circuit board (PCB) and to minimize interference among different electronic devices when tightly packaged on a PCB within automotive applications. The 77-GHz radar devices are designed for high-speed modulation techniques using simultaneous active transmit channels for excellent spatial resolution and high detection accuracy across a wide field of view.

Given the scalability and flexibility of these devices, it will not be surprising to see them make their way into the electronic safety systems of multiple types of automobiles down the road. mw

FREESCALE SEMICONDUCTOR, INC., 6501 William Cannon Dr. W, Austin, TX 78735; *www.freescale.com/radar*

Palm-Sized Analyzers Scour 6-GHz Spectrum

SPECTRUM ANALYSIS AND management can be challenging and expensive, although sometimes a solution fits in the palm of the hand, such as the PSA3605 and PSA6005 portable spectrum analyzers from Saelig Co. The compact instruments provide frequency coverage from 10 MHz to 3.6 and 6.0 GHz, respectively, and are suited for in-field use, operating for 3 hr or more on a built-in rechargeable lithium-ion battery.

The handheld spectrum analyzers are built by European test manufacturer AIM-TTi (www.aimtti.com), and available from and supported by Saelig Co. Both instruments have Type-N coaxial connectors and a built-in frequency counter with resolution down to 10 Hz. Both can work with a maximum reference level of 20 dBm and minimum reference level of –40 dBm.



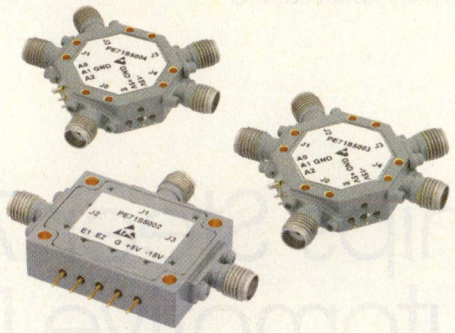
Model PSA 6005 is a portable, battery-powered spectrum analyzer that can capture and display signals from 100 MHz to 6 GHz on a color TFT screen.

The PSA3605 and PSA6005 portable analyzers include resolution-bandwidth (RBW) and video-bandwidth (VBW) filters that can be set from 300 Hz to 10 MHz in a 1-3-10 sequence to help isolate signals of interest. The instruments achieve a displayed average noise level (DANL) of better than –160 dBm/Hz, which, with a full-scale reference level of –40 dBm, allows signals as low as –120 dBm to be displayed.

They are supplied in an instrument case with rubberized buffer guards for shock protection and a built-in screen protector for field use. They include multiple detector modes and can demodulate AM and FM signals as well as extend the results to a time-domain display. The spectrum analyzers include an advanced filing system to manage test data.

The compact, handheld PSA Series 5 spectrum analyzers weigh only 20 oz (560 gm) and measure 3.6 in. (9.2-cm) wide, allowing them to fit in almost any portable RF/microwave service kit. They include almost 2 GB of built-in memory to save on instrument setups and captured test results, and feature a number of useful test functions like occupied-bandwidth (OBW) measurements.

SAELIG CO., 71 Perinton Pkwy., Fairport, NY 14450; (888) 772-3544, (585) 385-1750, FAX: (585) 385-1768, e-mail: info@saelig.com, *www.saelig.com*



PIN Diode Switches Command High Isolation

MAINTAINING HIGH PORT-TO-PORT isolation is often a critical requirement for RF/microwave switches, in addition to such performance parameters as fast switching speed and low "on state" insertion loss. For applications up to 12 GHz, a family of PIN-diode-based high-frequency switches from Pasternack delivers as much as 90-dB isolation across frequencies from 1 to 12 GHz.

The three members of the new high-isolation switch family include absorptive and reflective models. All three feature integrated silicon CMOS transistor-transistor-logic (TTL) drivers. Model PE71S5002 is single-pole, double-throw (SPDT) absorptive switch that limits insertion loss to 1 dB from 1 to 2 GHz and achieves 90-dB isolation across the frequency range. It exhibits 1.30:1 input/output VSWR. It handles input power levels to 32 dBm and achieves 75-ns switching speed, as defined by the time required to reach a 90% RF level from when a TTL command is issued. It measures a mere 1.2 × 0.9 × 0.35 in.

For higher-frequency applications, model PE71S5003 is a reflective single-pole, four-throw (SP4T) switch designed for applications from 2 to 6 GHz. It suffers just 1.8-dB insertion loss across that frequency range, and provides 80-dB isolation. It exhibits input/output VSWR of 1.50:1. This 2-to-6-GHz model boasts 35-ns switching speed (from TTL command to 90% RF level) and can handle input power levels as high as 0.5 W.

Finally, the highest-frequency PIN diode switch in the family, Model PE71S5004, is a SP4T reflective switch that operates from 6 to 12 GHz. Over that range, it maintains insertion loss of 2.5 dB or less with 75-dB isolation. It minimizes input/output VSWR to 1.60:1 across the frequency range and handles as much as 0.5 W input power. This PIN diode switch achieves 40-ns switching speed (from TTL command to 90% RF level).

These three high-speed PIN diode switch modules are supplied in rugged housings with SMA connectors, and will meet typical military requirements for vibration, shock, and humidity. All three switches operate with typical bias of 70 mA at 5 Vdc and 40 mA at –15 Vdc, and are designed for operating temperatures from –54 to 85°C.

PASTERNACK ENTERPRISES INC., 17802 Fitch, Irvine, CA 92614; (866) 727-8376, (949) 261-1920, *www.pasternack.com*

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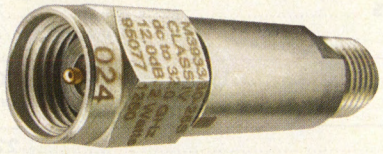
Fixed Attenuators Pad MIL-DTL-3933 Needs

FOR THOSE in need of attenuators meeting MIL-DTL-3933 requirements, a line of coaxial attenuators has been developed with 2.92-mm coaxial connectors for applications from DC to 32 GHz. The supplier was approved by the Defense Logistics Agency (DLA) as the only qualified products list (QPL) source for these components. The attenuators, which meet the environmental requirements of MIL-STD-202—and with connector interfaces in accordance with MIL-



PRF-39012—are available with attenuation values from 0.5 to 30.0 dB (additional attenuation values are available), with flat attenuation across the frequency range. Attenuator models exhibit 50-Ω nominal impedance with power ratings of 0.5 to 2.0 W average power and as much as 500 W peak power.

SV MICROWAVE, INC., 2400 Centrepark West Dr., West Palm Beach, FL 33409; (561) 840-1800, e-mail: sales@svmicro.com, *www.svmicrowave.com*

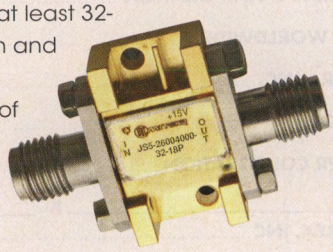
Power Limiter Handles 320 W

FOR HIGH-POWER applications, Richardson RFPD announced the availability and design support of a miniature power limiter from M/A-COM Technology Solutions capable of handling peak power levels to 320 W from 1 to 2 GHz. The model MADL-011014 limiter measures just 10.1 x 6.2 x 3.2 mm, but integrates the equivalent of 19 discrete diode and passive components into a single fully hermetic surface-mount-technology (SMT) package. Ideal for receiver protection in a variety of applications, including in air traffic management and radar systems, the limiter exhibits 0.35-dB insertion loss with 19-dB return loss from 1.2 to 1.4 GHz. It suffers +19-dBm flat leakage power and can handle +55 dBm peak power at +85°C.

RICHARDSON RFPD/ARROW RF & POWER, 40W267 Keslinger Rd., P. O. Box 307, LaFox, IL 60147; (800) 737-6937, (630) 208-2700, FAX: (630) 208-2662, *www.richardsonrfpd.com*

LNA Quiets 26- to 40-GHz Apps

MODEL JS5-26004000-32-18P is a low-noise amplifier (LNA) designed for applications from 26 to 40 GHz. It provides at least 32-dB small-signal gain across that bandwidth and suffers maximum noise figure of 3.2 dB. The amplifier boasts a minimum output power of +18 dBm at 1-dB compression. It is supplied in a compact, hermetically sealed package with field-replaceable K-connectors and is available in a RoHS-compliant version, as well as with MIL-STD-883 screening for use in military and aerospace applications. A number of other options are also available, including different gain, noise figure, and output-power ratings.



MITEQ, INC., 100 Davids Dr., Hauppauge, NY 11788; (631) 436-7400, FAX: (631) 436-7430, *www.miteq.com*

GaN HEMTs Run On +50 VDC

A PAIR of gallium-nitride (GaN) high-electron-mobility transistors (HEMTs) from Cree operate at +50 VDC, serving both continuous-wave (CW) and pulsed amplification duties. Model CGHV40030 provides 30-W typical output power and is usable to 6 GHz. An application circuit is available to demonstrate its performance from 960 through 1400 MHz. At 960 MHz, the typical gain is 15.6 dB with 29-W saturated output power and 62% drain efficiency. At 1400 MHz, the typical gain is 15.8 dB with 31-W saturated output power and 67% drain efficiency. Model CGHV40100 offers 100-W typical output power from DC to 3 GHz with an application circuit available for demonstrating performance from 0.5 to 2.5 GHz. The typical gain at 0.5 GHz is 17.6 dB with 147-W saturated output power and 68% drain efficiency. The typical gain at 2.5 GHz is 14.8 dB with 112-W saturated output power and 54% drain efficiency. Both devices are available in leaded flange or pill packages.

CREE, INC., 4600 Silicon Dr., Durham, NC 27703; (919) 313-5300, FAX: (919) 869-2733, *www.cree.com/rf*

Feed-Through Termination Links DC to 1.5 GHz

MODEL 851-054-FTT is a 50-Ω feed-through termination rated for applications from DC to 1500 MHz. It is well suited for matching 50-Ω components (such as amplifiers and filters) with high-impedance test equipment (like oscilloscopes). The termination exhibits maximum VSWR of 1.20:1 from DC to 1000 MHz and maximum VSWR of 1.40:1 from 1000 to 1500 MHz. It is rated for maximum input power to 1 W (+30 dBm) and can be supplied with SMA male or female coaxial connectors.

BROADWAVE TECHNOLOGIES, INC., 170 Airport Pkwy., Ste. A, Greenwood, IN 46143; (317) 888-8316, FAX: (317) 888-8593, *www.broadwavetechnologies.com*

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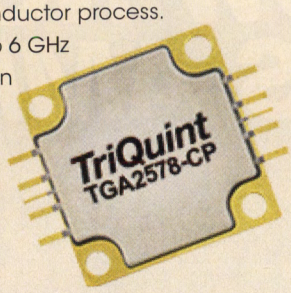
GaN Amp Drives 30 W at 6 GHz

MODEL TGA2578-CP is a power amplifier (PA) fabricated with a gallium-nitride-on-silicon-carbide (GaN-on-SiC) semiconductor process. It is suitable for wideband applications from 2 to 6 GHz and provides 30 W output power with better than 30% power-added efficiency (PAE). Designed for +28-VDC bias (and 400 mA current), the amplifier offers better than 26-dB small-signal gain in a package measuring just 15.2 x 15.2 x 3.5 m. Suitable for commercial and defense applications, the 50-Ω amplifier is lead-free and RoHS-compliant.



TRIQUINT SEMICONDUCTOR, 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (503) 615-9000, *www.triquint.com*

Multithrow Switches Control Signals to 4 GHz

A PAIR of high-isolation, multithrow switches based on UltraCMOS technology, models PE42442 and PE42452, handle signal-routing chores to 4 GHz. Model PE42442 is a single-pole, four-throw (SP4T) component usable from 430 MHz to 4 GHz. It exhibits 1.15-dB insertion loss at 2.7 GHz with 52-dB isolation at that frequency. It is designed to handle power levels to +52 dBm with excellent linearity, evidenced by an input third-order-intercept (IIP3) point of +58 dBm. Model PE42452 is a single-pole, five-throw (SP5T) switch that also operates from 450 MHz to 4 GHz, with 1.30-dB insertion loss and 52-dB isolation at 2.7 GHz. It handles input power levels to +33 dBm and has an IIP3 of +57 dBm. The low-cost switches operate with supply voltages of +2.3 to +5.5 VDC and function with control logic of 1.8 and 3.0 V. Both switches are rated for electrostatic-discharge (ESD) to 4 kV per the human body model (HBM) and are housed in 24-lead, 4 x 4 mm QFN packages.

PEREGRINE SEMICONDUCTOR CORP., 9380 Carroll Park Dr., San Diego, CA 92121; (858) 731-9400, FAX: (858) 731-9499, *www.psemi.com*

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A LINE of flexible cable assemblies has been developed to outperform traditional semirigid coaxial cable assemblies for a wide range of applications. These flexible assemblies combine advanced coaxial cables and proprietary VP90 expanded polytetrafluoroethylene (ePTFE) extrusion technologies to achieve low loss with outstanding phase stability. The cable assemblies are available in coaxial sizes from 16AWG through 52AWG, with most



cables suffering less than 1 dB/ft loss with little or no change in phase characteristics. The cable assemblies can be sized and tuned to meet the needs of a wide range of applications, from communications systems to test-and-measurement setups. Available connectors include Type-N, TNC, SMB, SMC, SMA, SMP, SMPM, SSMA, GPO, GPPO, G3PO, G4PO, MCX, and MMCX types.

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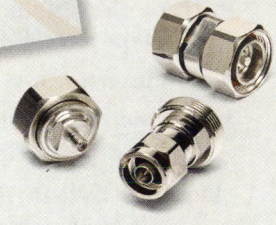

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