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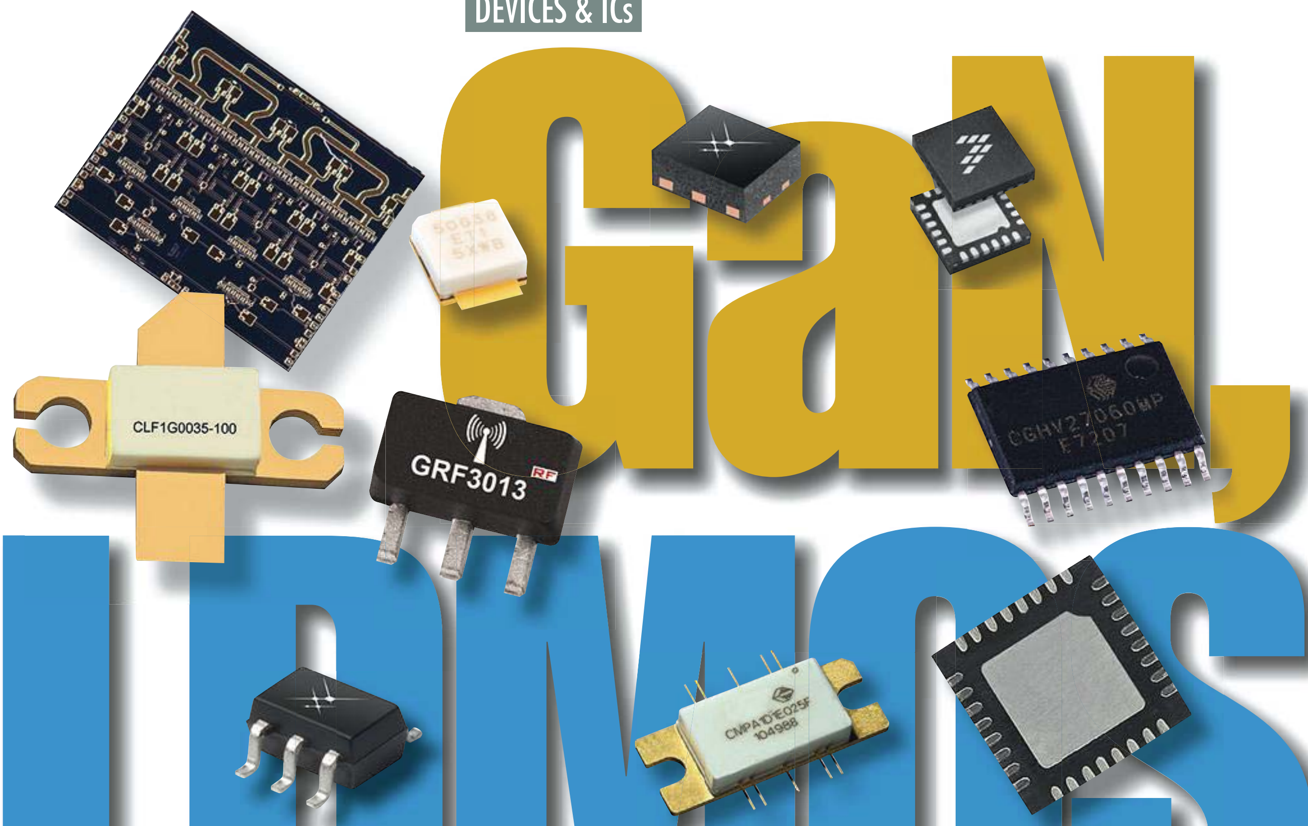

Take Devices to the Highest Power p | 35

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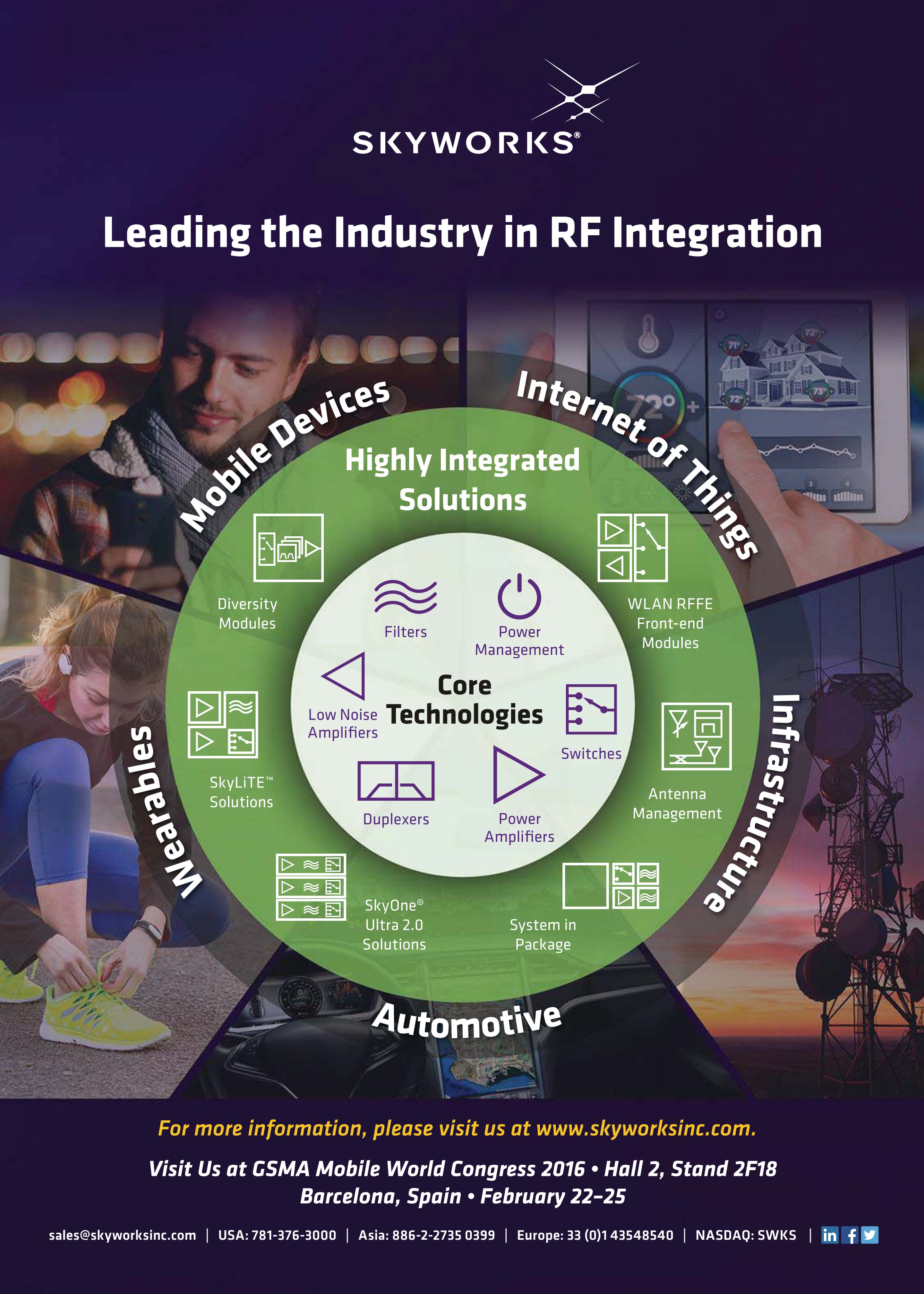
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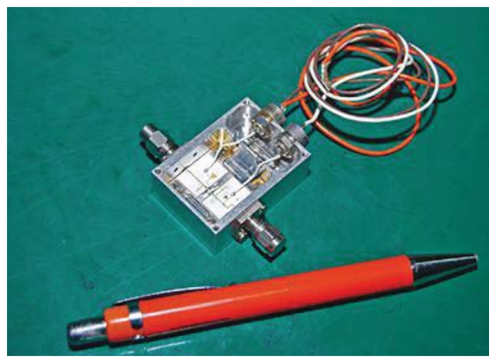

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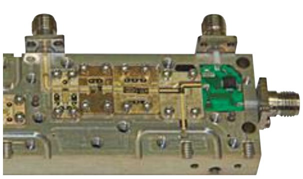
NEW HaLOW TARGETS IoT AND M2M

http://mwrf.com/blog/new-wi-fi-version-halow-targets-iot-and-m2m

HaLow is the name given by the Wi-Fi Alliance to one of the IEEE's newer standards, 802.11ah. It is one of a growing number of wireless technologies that promise longer-range communication than what is currently available from standard Wi-Fi, Bluetooth, ZigBee, Z-Wave, and others. For more on this new standard, read Lou Frenzel's blog and see the news story on page 20 of this issue.

MM-WAVE PRODUCTS ENABLE THE NEXT FRONTIER

http://mwrf.com/active-components/mm-wave-products-enable-next-frontier



Millimeter-wave technology has become more widespread, as evidenced by the large number of higher-frequency products available today. With 5G on its way, millimeter-wave bands will generate even greater interest as a means to enable future technology.

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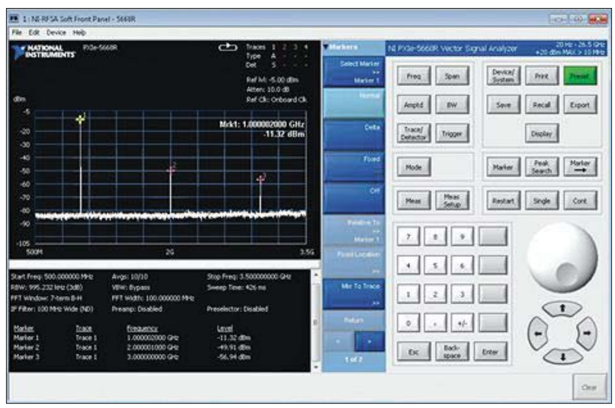
GIVING WI-FI A MAKEOVER

http://mwrf.com/blog/new-company-gives-wi-fi-makeover

One new company, Ignition Design Labs, is determined to improve the Wi-Fi experience. Its gameplan for doing so involves revolutionizing the Wi-Fi router. The company believes its technology can dramatically reduce congestion and provide a much faster Internet experience. Read about it in Tech Editor Chris DeMartino's new blog, "Filtering Noise."



VSAs CAN SIMPLIFY HARMONIC MEASUREMENTS

http://mwrf.com/test-measurement-analyzers/vsa-helps-simplify-harmonic-measurements

Controlling harmonic energy from communications transmitters is essential for minimizing interference in modern wireless communications systems. A vector signal analyzer is a powerful tool for measuring the harmonic signal levels of wireless communications standards with complex, wideband modulation formats.

Editorial

JACK BROWNE
Technical Contributor
jack.browne@penton.com

Doctors Will Depend More on RF Devices

With respect to the many forms of machine-to-machine (M2M) and Internet of Things (IoT) applications, high-frequency semiconductors with wireless communications capabilities are being projected for strong growth markets for years to come. Perhaps one of the more significant "submarket" areas within these high-growth markets is in medical electronics.

Advances in RF/microwave integrated circuits (ICs) have made possible tremendous progress in both implanted and external devices for monitoring and controlling bodily functions, such as neurostimulators and heart-rate monitors. With the high-data-rate communications possible over wireless radio bands, medical devices like blood-pressure and heart-rate monitors can now be worn externally.

Some of the same design requirements that are driving the development of sensor-based RF ICs for IoT applications—e.g., the "smart home" and "smart office"—are leading to the performance improvements needed for medical applications, including low-power consumption and long operating lifetimes. By building applications around some of these new, low-power ICs, key health-monitoring functions can be performed while drawing only microamperes of current.

With the expected simultaneous growth in medical electronic and wireless IoT markets, RF/microwave IC developers willing to engage in medical electronic markets can leverage many of the requirements for IoT applications (extreme miniaturization and conservation of energy, to name two) into medical electronic solutions.

Potential solutions range from audio-frequency transceivers that can aid the hearing-impaired to pill-sized cameras that can be swallowed for endoscopic imaging and analysis. The use of implantable, low-power wireless transceivers has been touted by many researchers around the world as a means of extending life when used to communicate with, as well as control, the heart and lungs. It can also enable control of robotic limbs in place of injured or nonfunctioning ones.

Among the challenges facing IC developers for medical applications are the extreme miniaturization of these circuits and the long-term reliability. Nevertheless, advances in semiconductor technology are poised to provide medical electronic solutions that will contribute to the longevity and quality of life for many patients. mw

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EDITORIAL

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LOST IN THE CLOUD?

Lately, a great deal of attention has been paid lately to what companies such as Microsoft refer to as "the cloud" and how it will change the way that we use computing and communications technologies. I was happy to see that you provided some coverage on the cloud and the Internet of Things (IoT) in your January 2016 issue *(see "Making Connections in the IoT Cloud," p. 46).*

While your article explored how cloud computing and communications will work largely with wireless communications standards like IEEE 802.15.4, it only really detailed the consumer and commercial sides of this topic. It did not examine the implications of cloud coverage for industrial or even military and aerospace applications. I applaud this coverage, but it barely scratches the surface of what will be an enormous market in the years to come, and one that perhaps your magazine should cover on a regular basis.

Jacob Newman

FROM THE EDITOR

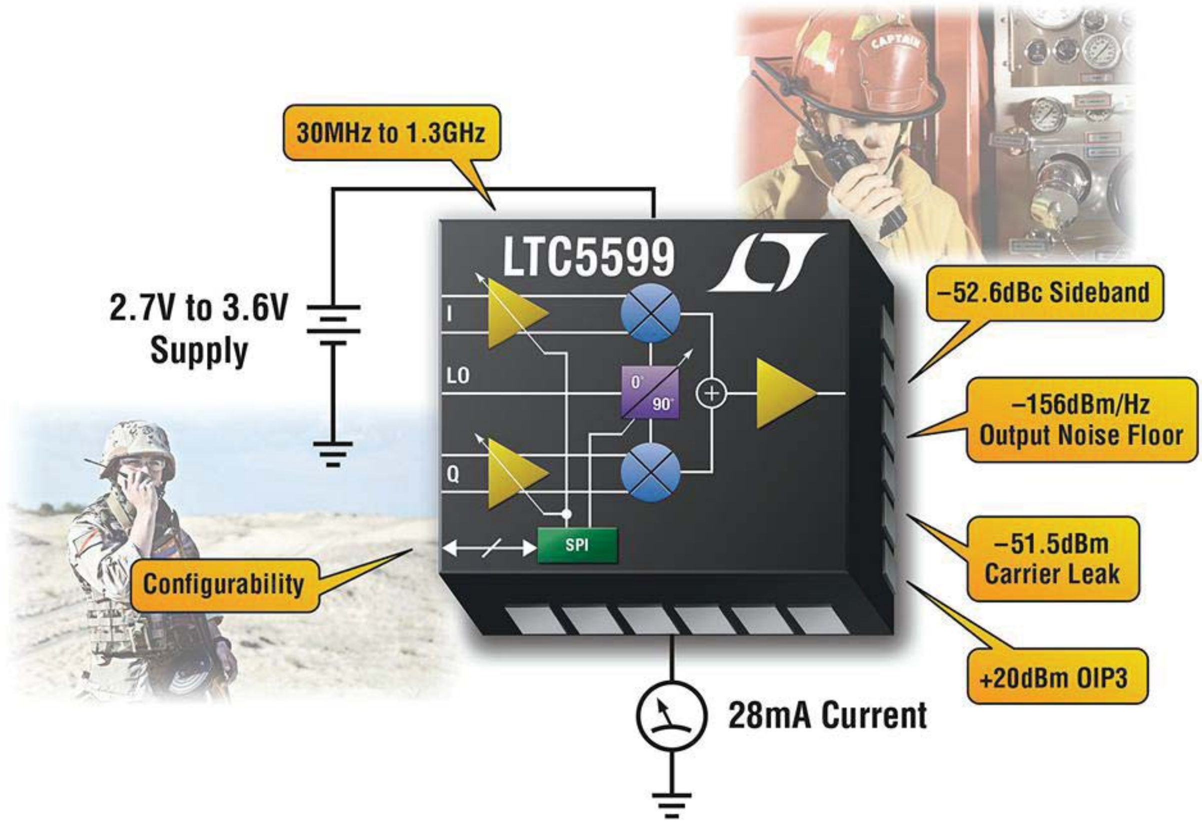
Anyone who has owned a newer, sensor-equipped automobile with modern safety features knows the value of having a network (in this case, the automobile) armed with data from the right sensors. Low-cost sensors not only warn of low air pressure in a car's tires or an aging battery, but motion-detecting sensors can save accidents and even lives. The strong attraction of IoT technology is in having the benefits of such sensors in homes, offices, factories, and throughout daily life.

But the convenience of such sensors comes at a cost, and that cost is the enormous amount of data that will be generated by the sensors—an amount that will continue to grow. Transferring and processing the data will pose real challenges for any communications technology and networks, and the cloud has emerged as a name for a kind of worldwide network that will link computers, wireless telephones, and billions of sensors. The Cloud and IoT technologies paint an intriguing picture of the future, but handling all of that data will not be easy. And it will not be solved by a single communications technology.

Microwaves & RF will regularly cover the cloud and IoT technology, both in its pages and online. The upcoming March issue, for instance, will feature coverage of industrial applications for IoT sensors. Future reports will also examine practical communications solutions formed of "hybrid" technologies, such as metal cables, optical cables, and wireless systems.

Jack Browne
Technical Contributor

90mW I/Q Modulator



Powered from a single supply from 2.7V to 3.6V, the LTC®5599's 28mA supply current extends battery run time. The modulator offers superb –52.6dBc sideband and –51.5dBm carrier suppression—without the need of calibration. Its low noise floor of –156dBm/Hz and 20dBm OIP3 capability ensure outstanding transmitter performance. The LTC5599's built-in configurability allows users to optimize performance from 30MHz to 1.3GHz, minimizing external components and saving costs.

Features

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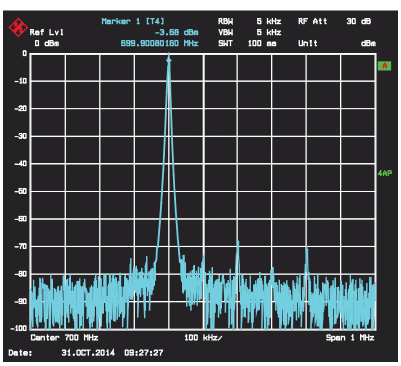
- Reduces Carrier Leakage from –51.5dBm to –60dBm

Output Spectra (Optimized)



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News

THE DOWN LOW ON HaLOW:
Wi-Fi for the Internet of Things

A NEW VERSION of Wi-Fi is trying to alter the perception that it is not suited for the industrial sensors, wearables, and smart-home devices that will keep the Internet of Things (IoT) connected. The Wi-Fi Alliance, the organization that maintains this technology, said that the new version will have greater versatility and reliability than traditional Wi-Fi.

Called HaLow, the new standard is designed to consume significantly lower power and have twice the range as 2.4 GHz Wi-Fi, which is also notorious for straining battery life. Edgar Figueroa, president of the Wi-Fi Alliance, says that HaLow is meant for devices equipped with small batteries, but expected to stay on for long periods of time. These range from battery-powered wearables to tiny sensors that gather data in smart cities and factories.

The new capabilities are possible because HaLow operates over the 900 MHz band. Aside from supporting smaller data payloads and lower power consumption, this frequency band also helps signals travel through walls and other obstacles more effectively than the 2.4 and 5 GHz Wi-Fi bands. Now, Wi-Fi will operate over all three bands.

The Wi-Fi Alliance first proposed its 900-MHz version in late 2013, when the latest Wi-Fi standard, 802.11ah, was in the early stages of development. In recent years, the enthusiasm around the IoT has sprouted a huge number of standards and technologies to rival Wi-Fi. These technologies are seeking to beat out cellular and other proprietary networks in connecting the billions of devices expected to flood infrastructure, factories, and smart homes in the future.

Many of these rival technologies are well-established

(continued on p. 26)

HaLow, the new version of Wi-Fi, is designed to consume significantly lower power and have twice the range as traditional Wi-Fi, making suitable for the tiny sensors that will gather data in future smart cities. *(Image courtesy of EFF Photos/Flickr)*

QUALCOMM AND TDK Form New Company Around RF Filters and Front-Ends

Qualcomm's booth at the 2016 CES show. *(Image courtesy of Maurizio Pesce and edited from the original by Microwaves and RF)*

QUALCOMM IS FORMING A new company with Japan's TDK Corp. to develop RF filters, front-end modules, and other wireless components for navigating multiple frequency bands. Qualcomm plans to spend around $3 billion over the next three years to move TDK's filter and module manufacturing to the new company. That money will also be used to purchase several TDK patents.

The transaction is Qualcomm's latest attempt to expand its portfolio of wireless components and integrated RF chipsets. For years, Qualcomm has been one of the largest suppliers of cellular communication chips, but the fabless chipmaker has recently branched out into power amplifiers, antennas, and other wireless components used in mobile phones. It has also been working to move these technologies—along with its Snapdragon processors—into new products, especially smart-home devices and cars.

Last September, Qualcomm acquired Cambridge Silicon Radio, a UK-based company that designs chipsets for smartphones and Internet of Things devices, for about $2.4 billion. In 2011, it purchased Wi-Fi chipmaker Aetheros Communications for around $3.1 billion, the largest transaction in the company's history.

Filters are new territory for Qualcomm, but they have long been a central component in smartphones. In 2014, most smartphones contained around 35 filters, according to statistics gathered by Resonant Inc., a startup company that has developed ultra-small filters with support for three different frequency bands on the same chip. Christiano Amon, the head of Qualcomm's chip division, said in an interview with *The Wall Street Journal,* that that number is now closer to 50. Early smartphones, on the other hand, were only equipped with three or four.

Such filters help smartphones tune into different frequency bands. This allows them to support multiple network technologies, ranging from 2G to 4G LTE, Wi-Fi, satellite communications, Bluetooth, and others. The number of filters in smartphones and other wireless devices is only expected to rise with the development of LTE-Advanced and 5G communications. By 2020, they could potentially contain as many as 100 filters.

Mobile Experts, a research firm that examines the market for RF components, predicts that front-end modules will represent an $18 billion market by 2020. The majority of that revenue can be traced to the filters packaged inside them. By itself, the RF filter market is expected to grow from $5 billion in 2015 to around $12 billion in 2020, according to Mobile Experts research.

The new company, which will be called RF360 Holdings, will compete with other large suppliers of RF filters, such as Avago Technologies, Skyworks, and Qorvo, whose stock prices tumbled following the joint-venture announcement. Among its RF front-end and other components, RF360 Holdings will develop surface acoustic wave (SAW), temperature-compensated surface acoustic wave (TC-SAW), and higher-performance bulk acoustic wave (BAW) chips.

The joint venture will be based out of Singapore. Qualcomm expects the transaction to be finalized in early 2017, at which point it will take 51% of the new company. After about three years, Qualcomm will have the option to purchase TDK's remaining interest. ■

RESILIENT HETNETS NEED Test Equipment to Match

WIRELESS INFRASTRUCTURE is growing more complex, with small cells and other technologies starting to form patchwork quilts of coverage with traditional cellular base stations. In cities, Wi-Fi small cells and distributed antenna systems (DASs) help to connect office buildings, subways, and other public spaces. In rural areas, cellular base stations are more prevalent, covering a wide area without encountering the same interference as in cities.

The problem of keeping people connected as they switch between these access technologies has contributed to the growth of networks that incorporate small cells, picocells, and large cellular base stations. But as they have become more widespread, these heterogeneous networks (HetNets) have proven difficult to test quickly and accurately.

A recent study from Frost & Sullivan, a test equipment research firm, finds that most engineers are using multiple instruments to test handoffs between access points. In an attempt to reduce testing times, wireless carriers have begun to invest

(continued on next page)

Wi-Fi repeater mounted on a streetlight, providing public Internet access. Wi-Fi access points are part of heterogeneous networks that incorporate many different access technologies. *(Image courtesy of Silicon Valley Power)*

in more sophisticated and integrated options for testing quality of service. The report says that the market for HetNet test equipment is expected to reach $2.56 billion by 2022, up from $1.50 billion in 2014.

The patchwork nature of HetNets can make for serious vulnerabilities. As people travel between different access technologies, they might experience dropped calls, lagging video and data applications, and even lost connections as a result of unsuccessful handoffs to small cells. Specifically, the report notes that HetNets still suffer from glitches when handing off between cellular and small-cell Wi-Fi networks. It also recommends that user authentication, roaming, and traffic prioritization be improved.

Olga Yashkova, a Frost & Sullivan program manager, says that test vendors are working more closely with equipment manufacturers, service companies, and individual enterprises to stay on top of the industry's test requirements. And Vivek Reghu, a senior research analyst with the firm, adds that more integrated HetNet test equipment—which can support a wide range of measurements—is growing in demand.

In particular, Reghu notes that engineers are favoring instruments that combine intelligence and hotspot maps "to present field engineers with real-time data for interference source identification." Live performance reports will speed the testing process, he adds, allowing engineers "to obtain a snapshot of the data that the will help adjust an antenna tilt, for example."

In the United States, nationwide carriers are expected to sharply increase their small-cell installations over the next few years. Fran Shammo, the chief financial officer at Verizon, said in a conference call to investors early last year that his company planned to invest nearly $500 million in small cells, while analysts predict that Verizon will add tens of thousands of small cells this year. AT&T, Sprint, and T-Mobile are expected to follow suit, though not as aggressively.

These changes will clearly have an impact on the test equipment market in the United States, the largest region for small-cell installations. The Small Cell Forum, an industry organization promoting the technology, reported last year that North America added around 1.01 million small cells in 2014. However, it is unclear how the upcoming Federal Communications Commission (FCC) spectrum auction in March could change the small-cell strategies of nationwide carriers.

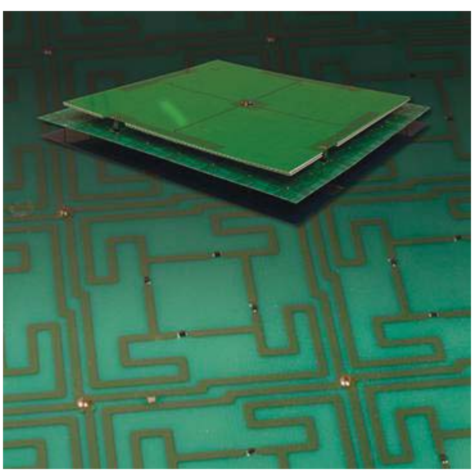
The Frost & Sullivan study says that the largest market over the next few years will be in China and other parts of Asia, which are in the process of installing more LTE and LTE-Advanced technology. ■

METAMATERIAL-BASED ANTENNA GRASPS at Lower Frequencies

ENGINEERS FROM PENN State University have developed a new material that allows them to control the frequency response and polarization of extremely small satellite antennas. Their experiments could result in the development of high-performance antennas that can switch between low- and high-frequency bands.

This project represents one of the latest advances in the study of metamaterials—synthetic materials whose unique properties have astounded and frustrated scientists trying to exploit them. The properties of metamaterials are the result of tiny internal structures, rather than just the atomic or molecular interactions that define how natural materials act. Metamaterials can be used to control light, sound, and—in this case—radio waves.

Publishing their results in the journal *Advanced Electronic Materials,* the



When combined with a software-defined radio, a new tunable metamaterial can extend an antenna with narrow instantaneous bandwidth across an entire communications band. *(Image courtesy of Penn State University)*

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www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com 455 rev J engineers outlined a metamaterial-based antenna that can operate over an unprecedented bandwidth. The engineers found that by simultaneously tuning the metamaterial and a software-defined radio, they could operate the antenna across a wider bandwidth than would normally be possible.

"Metamaterial-based antennas often suffer a stigma of impractically narrow operating bandwidths, just like small antennas," says Clinton Scarborough, who worked on the project. "The laws of physics dictate that a small metamaterial antenna will have a small bandwidth."

Scarborough says the tunable metamaterial can extend an antenna with narrow instantaneous bandwidth across an entire communications band. His experiments showed that, combined with a software-defined radio, the metamaterial antenna had similar performance to a large broadband antenna.

Douglas H. Werner, a study co-author and professor of electrical engineering at Penn State, says that tuning "the metamaterial and antenna in tandem provides a dynamic operating channel, with a tunable, nearly arbitrary polarization response as an added benefit."

Werner says that the new system could be the first step toward building low-frequency metamaterial antennas—a prospect that has long challenged the study of these man-made materials. Because lower frequencies require larger antennas, the challenge is getting the metamaterial antennas to operate over low frequencies while keeping them extremely small. ■

SONY BUYS MODEM CHIPS in Latest Bid for Cellular Internet of Things

SONY CORP. HAS AGREED to purchase Altair Semiconductor, an Israeli company that makes modem chips and software for LTE technology, for around $212 million. In addition to broadband processors used in smartphones and other devices, Altair also makes low-power chips designed for the Internet of Things (IoT).

The transaction is the latest sign that chipmakers and wireless carriers are trying to adapt LTE technology, which has long been used in smartphones, to the unique demands of sensors, wearables, home appliances, and connected vehicles. Today, most of these gadgets connect using Bluetooth or Wi-Fi, which are less expensive and consume less power than cellular LTE networks.

Over the last year, however, support has been growing for a new LTE standard that fulfills the low-power and low data-rate requirements of the IoT. In September, Intel partnered with Nokia and Ericsson to develop the low-power Narrowband-LTE (NB-LTE). It was promptly challenged by a competing proposal from Huawei and Vodafone, also known as Narrow-Band Cellular IoT (NB-CIoT).

While implicitly acknowledging that it must be updated for the next generation, these programs are also leveraging the fact that LTE technology is so widespread. Intel's NB-LTE, for instance, is designed to use existing infrastructure to reduce the startup costs of IoT devices. In addition, the LTE standard has the benefit of being able to connect multiple devices simultaneously. This capability could make it suitable for industrial systems gathering huge amounts of sensor data.

At least in the short term, LTE technology will have to compete with an enormous number of long-range, low-power networks. These networks—including SigFox, LoRa,

(continued on p. 26)

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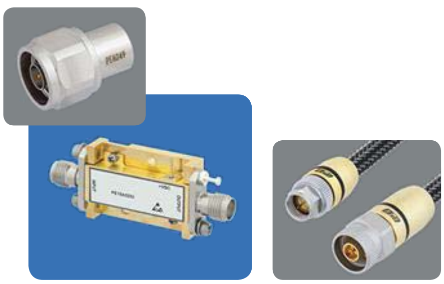

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(continued from p. 24)
and Ingenu's Random Phase Multiple Access, among many others—are fighting with cellular communications and each other to become the standard for IoT devices.

Meanwhile, Sony is planning to use Altair's chips in order to diversify its existing sensor technology. In a statement, Sony said that it intended to combine its navigation and image sensors with Altair's modem chips, with an aim toward making "a new breed of cellular-connected, sensing component devices." ■

Internet of Things

(continued from p. 20)
or have significant support. Bluetooth Smart, the low-power version of the personal area network technology, is expected to add several IoT features this year, including mesh networking and four times the transmit range. Thread, which is headed by Google's NEST smart-home division, is designed to connect smart-home devices. Other major standards in the smart-home fray are Z-Wave and ZigBee, which like Wi-Fi has the ability to connect devices to the internet.

For industrial systems, standards like Weightless-N are being designed for ultra-low power and low data-rate devices—allowing battery-powered sensors, for instance, to remain active for years at a time. This standard focuses more on wide coverage and low power consumption than its counterpart Weightless-P, which like other standards trades these benefits for higher throughput. A low-power version of LTE called Cat-M is also in development.

Despite long-held skepticism about Wi-Fi's impact on the IoT, some analysts are optimistic about HaLow. They say that Wi-Fi's widespread success has the potential to cut through all the competing standards and even lay the groundwork for a standard IoT technology. The Wi-Fi Alliance says that HaLow has the "ability to connect thousands of devices to a single access point," in addition to the security and interoperability already built into Wi-Fi.

More information about HaLow has not been released yet. HaLow will not start appearing in products until 2018. In the meantime, the Wi-Fi Alliance said that it has several ongoing projects to help incorporate Wi-Fi into more household objects, such as door knobs and vacuum cleaners. ■

HIGH POWER

5 - 500 WATTS PRODUCTS

POWER DIVIDERS

RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] ◦	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

◦ With matched operating conditions

HYBRIDS

RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ◦	Package
KFK-10-1200	10 - 1200	40 ±1.0	±1.5	0.4 / 0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322
KEK-1317	13000 - 17000	30 ±1.0	±0.5	0.4 / 0.6	30 / 15	30	387

* Add suffix - LF to the part number for RoHS compliant version.

◦ With matched operating conditions

Unless noted, products are RoHS compliant.

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Inside TRACK with Manuel Uhm,

ETTUS RESEARCH *(a National Instruments company)*

Interview by CHRIS DEMARTINO

MANUEL UHM, director of marketing at Ettus Research, a National Instruments (NI) company, is responsible for all marketing activities, including strategy, roadmapping, pricing, and promotions. Manuel is also the chair of the board of directors of the Wireless Innovation Forum (formerly the SDR Forum). Serving on the board since 2003, he has assumed various roles, including chair of the Markets Committee, chair of the User Requirements Committee, chief marketing officer, and chief financial officer.

CD: What are some of the advantages offered by a software-defined-radio (SDR) platform?

MU: SDR is defined by the Wireless Innovation Forum as a "radio in which some or all of the physical-layer functions are software defined." By this definition, SDR is a technology that applies to baseband processing, not RF. Cognitive radio (CR), on the other hand, is the common industry term that refers to a radio that can dynamically access spectrum across a wide RF bandwidth to improve transmit and receive performance by avoiding interference, as well as avoiding prohibited frequencies in that location. Most CRs use SDR technology to do the baseband processing after the RF front end.

SDR and CR technology provide a number of theoretical benefits, but two in particular have proven to be the most economically beneficial:

- The flexibility to use a common radio design or architecture to address multiple market segments, thus achieving better economics of scale and increasing the probability of the product being a success.
- The ability to reuse software when porting from one SDR design to another. The savings in development cost has actually

been one of the most tangible benefits realized by radio manufacturers, which is why most radios today are, in fact, SDRs, even though many of them don't market or explicitly identify their radios as SDRs. Most of the benefit accrues in engineering productivity, lower development cost, and faster time-to-market.

CD: What RF technology advances most benefitted SDRs in recent years?
MU: Wideband RF integrated circuits (RFICs), such as those from Analog Devices or Texas Instruments, have resulted in SDRs and CRs that are easier to design, smaller form factor, and cheaper to manufacture. This has enabled the proliferation of SDRs and CRs. A good example of this is the increase in COTS radios based on an RFIC+FPGA architecture, such as the credit-card-sized B200mini SDR from Ettus Research. Previously, a radio with such functionality would have required multiple discrete RF components, resulting in a larger, more expensive radio. At the same time, there is still a place for radios based on discrete RF components for applications that require greater bandwidth or better sensitivity than can be provided by current RFICs.

CD: How does current SDR performance compare with performance from 5-10 years ago?
MU: Both SDRs and CRs have improved tremendously in size, power, processing performance, and cost. This is the main reason why SDR is now the de facto industry standard for baseband processing (including commercial wireless, military, and industrial applications), and CR is gaining significant momentum on the RF side.

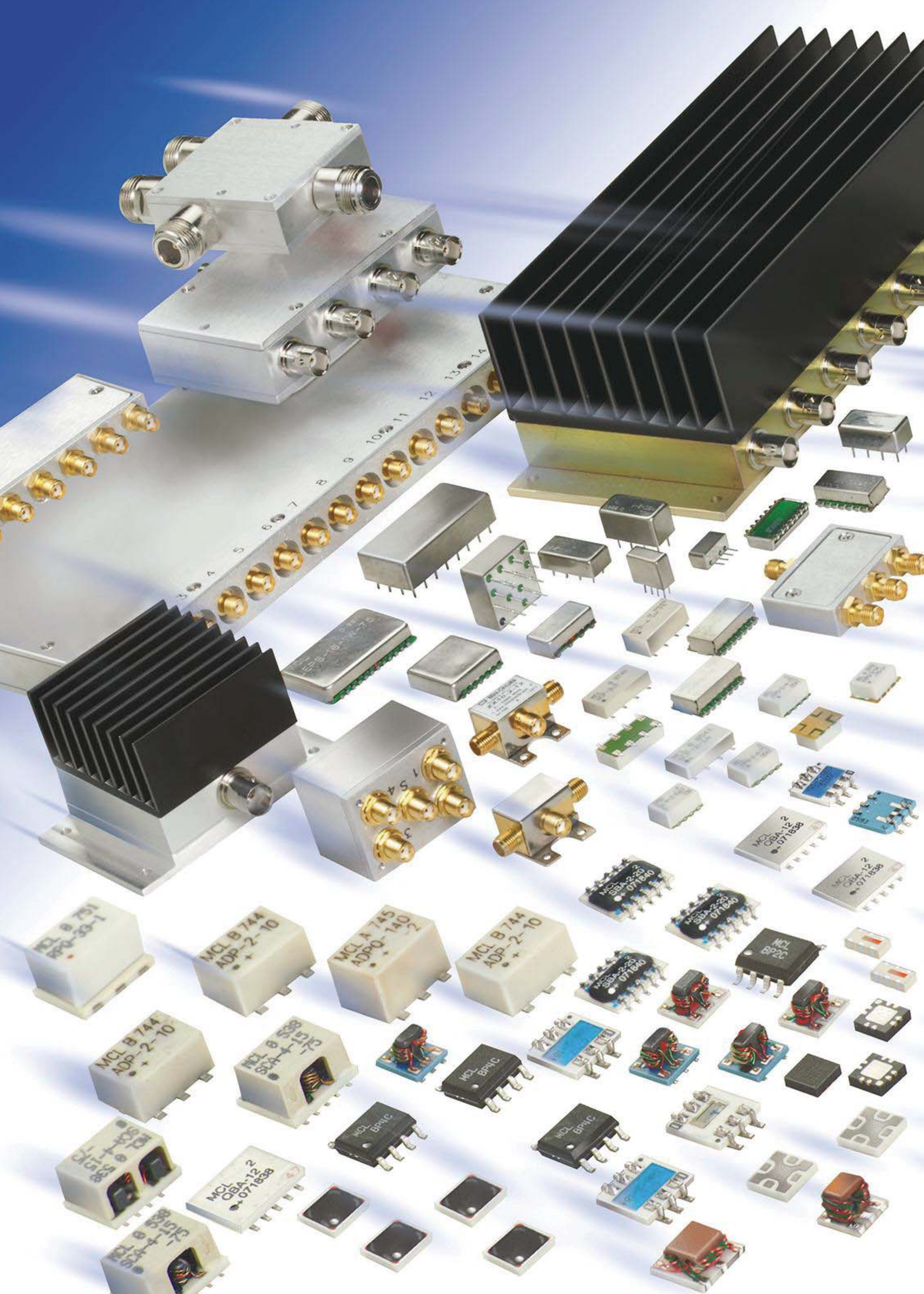
CD: What applications are utilizing SDR technology?
MU: At this point, SDR is the dominant industry standard. Everything from wearables to cellphones to base stations to microwave radios to test equipment use SDR technology in the modem chips. CR, on the other hand, is an emerging technology. For cost reasons, the highest volume SDR applications, such as wearables and cellphones, use band-specific RF front ends, rather than a wideband cognitive radio that can scan the spectrum and choose the most appropriate band for transmit and receive. However, as spectrum becomes more of a shared resource (i.e., the Citizen's Broadband Radio Service at 3.55 GHz in the U.S.), CR will become increasingly prevalent—even in consumer devices.

> **"At this point, SDR is the dominant industry standard. Everything from wearables to cellphones to base stations to microwave radios to test equipment use SDR technology in the modem chips."**

CD: Are there any examples of applications that SDRs have recently begun to exploit?
MU: SDR is literally everywhere. CR, on the other hand, is following a similar path as SDR in terms of market adoption. Today, CR is common in military applications, such as military radios, signals intelligence, surveillance, and electronic warfare (EW), which need maximum spectrum coverage and flexibility. Products from Ettus Research have been used for such applications. It is also common in some low-volume commercial markets, such as test and measurement and certain wireless infrastructure. For example, much of NI's test equipment is both SDRs and CRs. Cognitive radios from Ettus Research have even been used for wildlife tracking. However, it has not really penetrated high-volume commercial markets, as the cost has outweighed the potential benefits. This should change in the future, however, as 5G technologies and spectrum sharing become more prevalent, with CR being a key enabling technology for both. This will help to create the economies of scale necessary to drive the price down to a commercially acceptable point, so that the technology can bridge the gap between infrastructure and terminals/user equipment.

CD: What role do you see SDRs playing in regard to the Internet of Things (IoT)?
MU: Similar to my earlier statements, SDR is already a dominant technology for Internet of Things infrastructure and devices. As an example, most application processors used for IoT devices use modems that are at least partially software defined. The role of CR is less certain, though. The highest-volume sensors and devices are likely to be too cost-sensitive for CR for the foreseeable future. From a test perspective, however, it makes sense for the test equipment to be CRs and SDRs so that it can be used to test multiple devices using different protocols in multiple RF bands.

CD: What performance capabilities can we expect to see from SDR technology in the future?
MU: As processors continue to increase in capability and performance, software-defined radios will continue to reap the benefits in terms of flexibility (i.e., supporting more air-interface standards), lower power, and smaller form factors. As for cognitive radio, improvements in RFICs will enable CRs to support wider bandwidths (resulting in more data throughput) and cover more spectrum, also at lower power and smaller form factors. mw



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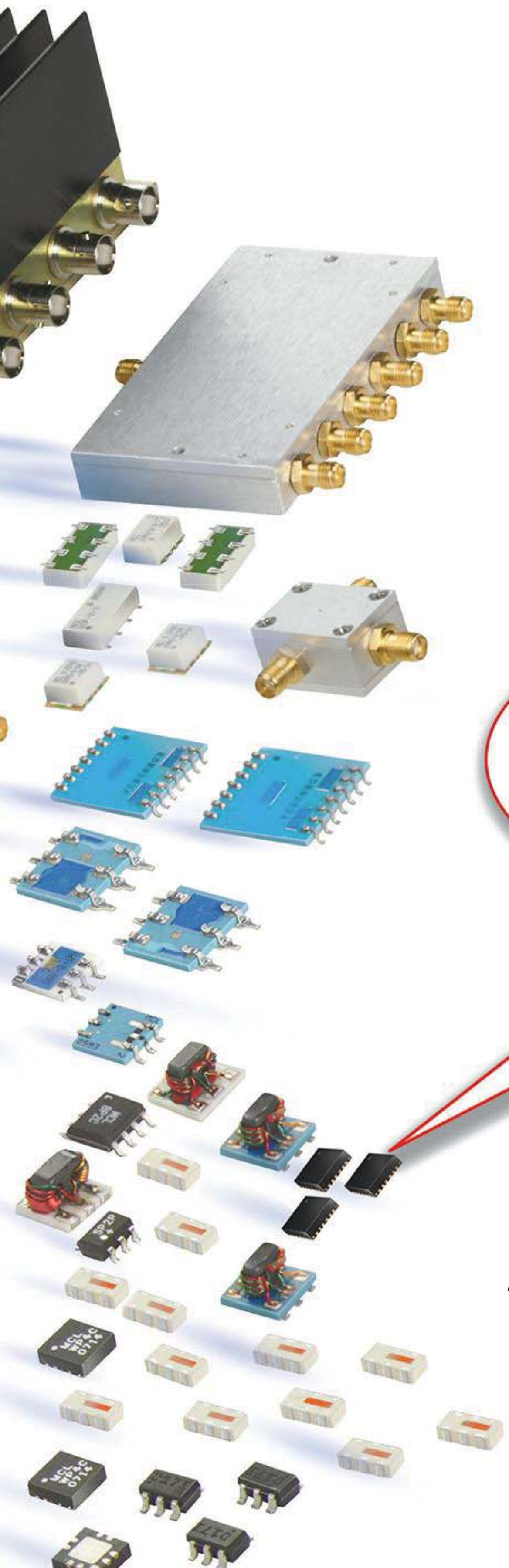

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SIW CAVITY ANTENNA RESONATES AT 340 GHz

TERAHERTZ FREQUENCIES (IN the 100-GHz range) offer great promise for detecting a wide range of objects, from cancer cells to concealed weapons. To make such high frequencies more practical, researchers at China's Nanjing University of Science and Technology and the Semiconductor Device Research Laboratory of the China Academy of Engineering Physics developed an on-chip antenna (OCA) capable of high gain and high radiation efficiency at 340 GHz. The terahertz antenna was designed with standard 0.13-μm silicon-germanium (SiGe) biCMOS semiconductor technology without post-processing. The antenna incorporates a rectangular slot loop etched into the upper wall of a substrate-integrated-waveguide (SIW) circuit to form a magnetic current loop radiator. The SIW structure creates a back cavity to suppress surface waves and ultimately separate the radiating aperture from the substrate.

The researchers created both single antenna elements and a 2 × 2 antenna array to demonstrate the concept. The SIW back cavity resonates at the dominant mode, with electromagnetic energy accumulating inside the cavity and the cavity preventing energy absorption by the substrate material. The result is an antenna element with high gain and frequency range of 335 to 348 GHz, and an antenna array with maximum gain of 7.9 dBi and efficiency of 48% at 340 GHz.

The SiGe BiCMOS process involves seven metal layers fabricated on a 300-μm-thick silicon substrate, with the two top metal layers isolated by a 10-μm-thick silicon-dioxide layer. The silicon substrate has a dielectric constant of 11.9 and resistivity of 10 Ω-cm. The chip size of the standalone antenna is 0.7 × 0.7 mm^2 and the antenna array chip measures 1.1 × 1.1 mm^2. The OCAs were characterized by means of a commercial vector network analyzer (VNA) and frequency extender for measurements from 220 to 347 GHz. See "340-GHz SIW Cavity-Backed Magnetic Rectangular Slot Loop Antennas and Arrays in Silicon Technology," *IEEE Transactions on Antennas and Propagation*, December 2015, p. 5,272.

ROBOTS EXECUTE NEAR-FIELD MM-WAVE MEASUREMENTS

ANTENNA PATTERN MEASUREMENTS require discipline and precise positioning of antenna measurement probes, especially at millimeter-wave frequencies and higher. In their configurable robotic millimeter-wave antenna (CROMMA) facility, members of the National Institute of Standards and Technology (NIST, Boulder, Colo.) developed a cost-effective antenna-pattern measurement system—one using robotic motion control to achieve antenna positioning within 25 μm RMS for precision near-field measurements. With the aid of a commercial VNA for measuring amplitude and phase, the robotic test system captured near-field and far-field data for a standard gain horn at 183 GHz.

Antenna pattern measurements can be quite challenging at millimeter-wave frequencies, because of the small wavelengths and the need to perform probe positioning with precision equal to a fraction of a wavelength for achieving pattern measurements with high fidelity. By combining six-axis robotics, optical spatial metrology, and a coordinated metrology approach, the NIST researchers created the CROMMA system for scanning antenna patterns in multiple configurations from 75 to 500 GHz. The positioning resolution goal for the system is better than 15 μm in support of antenna pattern measurements at 500 GHz. The system incorporates a six-axis industrial robotic arm and controller from MOTOMAN (www.motoman.com).

The system's motion is simulated by means of computer modeling, using a kinematic model to determine the Denavit and Hartenberg (DH) parameters. The robot controller uses these parameters to define the kinematic activity of the robot arm and its antenna measurement probe, allowing the antenna and arm to be positioned with six degrees of freedom and precise resolution. The motion of the robotic arm is refined through a form of "teaching process" that allows it to adapt to almost arbitrary probe shapes and sizes for precise positioning of the antenna measurement probe. This robotic arm is augmented by a second type of robot, a hexapod based on a parallel network of six prismatic actuators, as part of the CROMMA system. The hexapod actuators feature individual positioning accuracy of 500 nm for a combined positioning accuracy of 1 μm. In contrast to the larger robotic arm, this robotic positioner provides extremely high precision, but for a much smaller total volume.

Measurements were performed with a commercial four-port, 50-GHz VNA and frequency extenders for antenna pattern measurements at 183 GHz. The system covers a near-field radius of 100 mm and a far-field radius of 1000 mm. It is currently being evaluated through 300 GHz, with the expectation of being capable of performing robotic antenna pattern measurements through 500 GHz. See "Millimeter-Wave Near-Field Measurements Using Coordinated Robots," *IEEE Transactions on Antennas and Propagation*, December 2015, p. 5,351.

CHRIS DeMARTINO | Technology Editor

NEW HIGH-FREQUENCY DEVICES RUN THE TECHNOLOGY GAMUT

Suppliers of devices and integrated circuits remain busy, delivering cutting-edge products to enable new applications and boost existing brands.

High-frequency devices and integrated circuits (ICs) are hitting the market at a rapid-fire pace, reflecting how suppliers continue to push the envelope through technological innovation. Various device technologies are making an impact in many target applications, including one exciting new possibility: RF solid-state cooking.

Gallium-nitride (GaN) technology is undoubtedly all the rage today. But other semiconductor technologies, such as laterally diffused metal-oxide semiconductor (LDMOS), are still alive and well, judging by several recently unveiled high-power LDMOS devices. In addition, the industry has seen the arrival of myriad new amplifier products—both high-power and low-noise varieties—to satisfy today's diverse requirements.

HIGH-POWER LDMOS

Despite the attention being thrown at GaN technology regarding its use in enabling several applications, other semiconductor technologies still play a key role. LDMOS technology, for example, remains vital. In fact, a handful of new LDMOS-based products recently hit the market.

LDMOS devices are a staple product of NXP Semiconductors (www.nxp.com). The company's high-power LDMOS-based products can enable a range of applications, such as cellular infrastructure, radar, and mobile radio.

Two new LDMOS-based products developed by NXP are the A2I25H060N and A2T26H165-24S. The A2I25H060N is an asymmetrical Doherty power amplifier (PA) that spans 2300 to 2690 MHz. It is suitable for all typical cellular base-station modulation formats. The A2T26H165-24S is a 32-W

1. RF solid-state devices may soon find their way into the cooking appliances in our homes. *(Courtesy of Ampleon)* power transistor that covers 2496 to 2690 MHz. Like the A2I25H060N, the A2T26H165-24S will find homes in cellular base stations.

For its part, Ampleon (www.ampleon.com) expanded its line of LDMOS-based products by releasing a portfolio of new RF power transistors. The new BLP05H6xxxXR series aims for markets like TV broadcasting, as well as industrial, scientific, and medical (ISM) RF power generators. The transistors, which span a frequency range from HF to 600 MHz, provide anywhere from 35 to 700 W of continuous-wave (CW) power. Furthermore, the transistors all come in an SOT-1223 package.

LDMOS technology also is the driving force behind RF solid-state cooking *(Fig. 1)*. Both NXP and Ampleon, which are at the forefront of this emerging niche, believe that solid-state technology can potentially replace the venerable magnetron-based microwave ovens.

"Using RF power transistors for solid-state cooking applications is high on the list of exciting new application areas for RF energy usage," says Gerrit Huisman, marketing director at Ampleon. "Magnetrons have had a long life within our microwave ovens. We have all experienced the hot and cold spots they can create in our food. Thanks to recent technology developments, RF power transistors are now viewed as reliable and ideal candidates for microwave cooking applications."

He adds, "There is no doubt that the accurate power control of a solid-state device greatly helps to provide more control and stability in the cooking cycle. An oven's operation can now set the cooking profile depending on what it finds in the oven, instead of blindly working to a user set-time.

"The power output, frequency, and appliance power efficiency will vary depending on, for example, whether a bag of popcorn is being cooked or a frozen chicken," Huisman says. "Cooking times are reduced by about 30% and taste is improved. Most importantly, homogeneously cooking is achieved. This means that food will not be over- or undercooked. With added modern sensor technology, it is possible to constantly monitor, adapt, and optimize the cooking process."

HIGHER-POWER DEVICES AT HIGHER FREQUENCIES

Suppliers are meeting the demand for high-power devices at higher frequencies, such as Ka-band, which is now commonly used for satellite-communications (satcom). GaN technology also has extended into this frequency range.

New Ka-band PAs have recently been introduced to the marketplace. For example, Qorvo (www.qorvo.com) unveiled its TGA2636-SM, a Ka-band, 3-W GaN PA for commercial very-small-aperture-terminal (VSAT) satellite ground terminals. The TGA2636-SM, housed in a 5- × 5-mm, surface-mount-technology (SMT) package, provides 25 dB of linear gain while achieving 30% power-added efficiency (PAE). The PA is fabricated using Qorvo's 0.15-μm gallium-nitride on silicon-carbide (GaN on SiC) process. The company says this process delivers three times more power density than previous-generation gallium-arsenide (GaAs) pseudomorphic high-electron-mobility-transistor (pHEMT) solutions.

MACOM (www.macom.com) entered the fray by unleashing its MAAP-011246 and MAAP-011139 Ka-band PAs. Both devices are offered in 5- × 5-mm, SMT packages. The MAAP-011246, which covers 27.5 to 31.5 GHz, provides 2 W of output power. The MAAP-011139 is a 4-W PA that spans 28.5 to 31.0 GHz. Both PAs are well-suited for next-generation Ka-Band VSAT systems.

2. This LNA achieves a noise figure below 1 dB. *(Courtesy of Guerrilla RF)*

LOW-NOISE AMPLIFIERS IN THE NEWS

Though high-power devices seem to be dominating, several new low-noise amplifiers (LNAs) have opened some eyes, too. A common theme among the latest LNAs is that external components are minimized significantly, thus turning them into convenient, low-cost solutions.

Sparking interest on this front is Custom MMIC's (www.custommmic.com) new CMD223 LNA, which spans 9 to 18 GHz. It's targeted at electronic-warfare (EW) and communication systems that demand small size and low power consumption. At 13.5 GHz, the CMD223 delivers more than 22 dB of gain and achieves a 1.5-dB noise figure.

Two new LNAs from Skyworks (www.skyworksinc.com), the SKY65605-21 and SKY65611-11, are fabricated using advanced silicon-germanium (SiGe) biCMOS technology. Both LNAs operate from 1.559 to 1.606 GHz, and are intended for Global Navigation Satellite Systems (GLONASSs), BeiDou, Global Positioning System (GPS), and Galileo receiver applications. The SKY65606-21, for example, achieves a typical gain of 19 dB along with a noise figure of 0.6 dB.

Guerrilla RF (www.guerrilla-rf.com) recently launched its GRF4042 LNA *(Fig. 2)*. The device is well-suited for small-cell and cellular booster applications in the 700- to 3800-MHz frequency range. Offered in a 2- × 2-mm SMT package, the GRF4042 achieves a sub-1-dB noise figure.

Although not every new product could be mentioned in this report, it's clear that manufacturers are supporting a wide range of applications using several different technologies. Such innovation is nowhere more apparent than in the strides made with RF solid-state cooking. It will certainly be interesting to watch what devices, products, and technologies will make their impact on the industry in the coming year. mw

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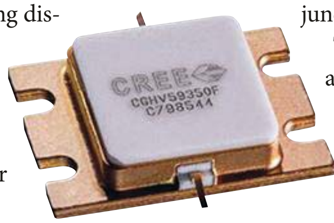
Brush Up on Transistor and Diode Basics

These two semiconductor building blocks have been fabricated in many forms, using many different semiconductor materials, in search of ideal, reliable performance at high frequencies.

MANY DIFFERENT ACTIVE circuits are based on two essential semiconductor function blocks—diodes and transistors. In analog, digital, and mixed-signal circuits, diodes and transistors both provide different types of switching functions, while transistors also supply signal amplification when needed.

Diodes and transistors of various types are used at RF and microwave frequencies, depending on required function and frequency range. Knowing how the different semiconductors behave can simplify the task of specifying disparate diodes and transistors for a wide range of RF/microwave applications.

Put simply, a diode is a two-terminal semiconductor device and a transistor is a three-terminal semiconductor device. A diode can allow the flow of current in one direction while blocking the flow of current in the other direction. The device works well as a switch, and is useful for limiting signal levels, frequency multiplication, tuning, and protecting circuitry from the flow of current in a given direction. In addition, diodes often function as rectifiers to convert alternating current (ac) to direct current (dc) in a circuit.



1. High-power microwave HEMTs are being made affordable and easier to handle in surface-mount housings. *(Courtesy of Wolfspeed, www.wolfspeed.com)*

Transistors are versatile semiconductor devices fabricated from many different chemical elements and compounds, such as silicon (Si), gallium arsenide (GaAs), and gallium nitride (GaN). They can be used as amplifiers or switches, with frequency dependent on device structure, dimensions, and material properties. With the three terminals, a voltage or current applied between one pair of terminals can affect the voltage or current between another pair of terminals to produce gain as needed for an amplifier or an oscillator. Depending on the application, a transistor may be operated at low power levels in its small-signal or linear region, or at higher power levels in its large-signal or nonlinear region.

AN ARRAY OF OPTIONS

Diodes and transistors have been developed and fabricated in many different forms. Diode types include Schottky-barrier, positive-intrinsic-negative (PIN), Gunn, Impatt, and varactor-tuning diodes. Transistor types essentially include field-effect transistors (FETs), such as metal-oxide-semiconductor FETs (MOSFETs) and metal-epitaxial-semiconductor FETs (MESFETs), and bipolar junction transistors (BJTs), such as heterojunction bipolar transistors (HBTs).

The two terminals of a diode are known as the anode and the cathode. The three FET terminals are called the gate, drain, and source, while the three bipolar transistor terminals are referred to as the emitter, collector, and base. In either type of transistor, charge is transferred in a controlled manner between two terminals: between the source and the drain in an FET and between the emitter and the collector in a bipolar transistor. Current flows laterally in an FET and vertically in a bipolar transistor.

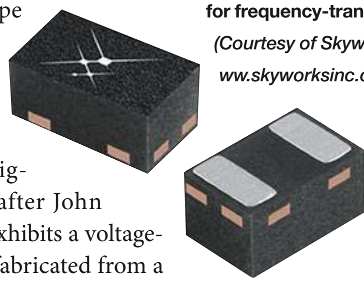
A bipolar transistor essentially consists of two junction diodes on semiconductor material having positive (p) and negative (n) polarities. A transistor with two positive layers surrounding a negative layer is known as a pnp transistor, and a device with two negative layers around a positive layer is an npn transistor.

Choosing a transistor for a high-frequency application generally hinges on frequency range and performance. For example, in receiver applications, signal sensitivity is critical and the noise figure of a receiver front-end transistor must be as low as possible. Thus, GaAs FETs might be the best option, thanks to their low (under 1 dB) noise figure at microwave frequencies.

Such transistors are characterized for use in their linear, small-signal regions, with the tradeoff of output power generally being less than 1 W. For higher power amplification, GaN is usually the material of choice for microwave frequencies, typically in the form of a flange-packaged power GaN HEMT device *(Fig. 1)*.

PINPOINTING THE RIGHT DIODE

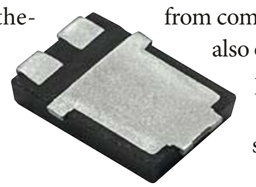
Selecting a diode for a particular RF/microwave application is more a matter of understanding which type of diode performs what type of function. For example, Gunn diodes, which are also known as transferred electron devices (TEDs), are typically employed to generate RF/microwave signals and/or detect signals, such as in radar detection. Named after John Battiscombe (JB) Gunn, this type of diode exhibits a voltage-controlled negative resistance. It is usually fabricated from a single piece of n-type semiconductor material, such as GaAs or indium phosphide (InP), and can produce oscillations well through the millimeter-wave frequency range.



2. Schottky diodes are also available in low-cost, surface-mount packaging for frequency-translation applications. ***(Courtesy of Skyworks Solutions, ww.skyworksinc.com)***

Schottky diodes, named after Walter H. Schottky, are often used for frequency translation in mixers or for signal detection *(Fig. 2)*. They feature low forward or turn-on voltage and fast recovery time. These rectifying diodes are often found in circuits with multiple power supplies, such as an ac source and a battery, to prevent one source of power from feeding into the other.

The high-power Impatt diode, short for "IMPact ionization Avalanche Transit-Time diode," is typically used to generate signals. The negative resistance possible in the device allows it to act as an oscillator, although for applications where phase noise is not critical compared to a frequency synthesizer. Impatt diodes also often act as local-oscillator (LO) sources in integrated receivers. As with many diodes, they can conduct current in the forward direction and block current in the reverse direction.



3. PIN diodes are among the most versatile of semiconductors, used for components ranging from switches to attenuators. ***(Courtesy of Fairchild Semiconductor Corp., www.fairchildsemi.com)***

Perhaps the workhorse of all RF/microwave diodes is the PIN diode, commonly used in high-frequency switches and attenuators *(Fig. 3)*. The name derives from its three layers of p-type, intrinsic, and n-type semiconductor materials. The p-type layer holds the anode while the n-type layer forms the diode's cathode. PIN diodes, which are fabricated from both silicon and GaAs semiconductor materials, act like current-controlled resistors. The more current that flows through the intrinsic region in turn decreases the device RF resistance. A PIN diode behaves like an open circuit, like a short circuit, and anywhere in between. It can be current-tuned to a required impedance, such as 50 Ω, for impedance-matching purposes.

A PIN diode acts like a rectifier at lower frequencies and as a variable resistor at RF/microwave frequencies. The frequency at which the diode changes from rectifier to variable resistor is a function of the intrinsic layer's thickness. Thicker devices can be used as switches to lower frequencies. Very low current levels are needed to control PIN diodes that can handle high amounts of RF/microwave signal power.

Varactor diodes are also widely used in high-frequency applications, for frequency multiplication as well as tuning purposes. Exhibiting a capacitance that varies as a function of applied reverse voltage, varactor diodes are commonly used to tune the frequency of oscillators like voltage-controlled oscillators (VCOs).

REACHING INTO THE PAST AND FUTURE

Finding older RF/microwave diodes and discrete transistors in the marketplace can at times be challenging, especially when they are needed for critical applications such as pulsed amplifiers in commercial or military radar systems. Unfortunately, over the past few decades, many RF/microwave transistor and diode suppliers have changed hands or ceased operating, exacerbating the challenge of finding older semiconductor part numbers for existing electronic circuit designs.

Fortunately, a number of distributors and semiconductor suppliers stock discontinued models and replacement parts for hard-to-find devices. ASI Semiconductor (www.advancedsemiconductor.com), for instance, manufactures many replacement high-power devices for radar applications that are unavailable from companies no longer in the market, such as Motorola. It also offers microwave diodes no longer supplied by companies such as Alpha Industries and Avago Technologies. High-power transistor types include older silicon MOSFET and silicon bipolar transistors.

In terms of recent advances, a great deal of interest has surrounded graphene as a semiconductor material for next-generation transistors. Described as a "zero-bandgap" material for its high electron mobility, graphene can achieve high current density. The material is formed of a one-atom-thick layer of carbon atoms arranged in a honeycomb lattice. It is suitable for high-frequency, high-speed transistors through millimeter-wave frequencies, and as the basis for photodetector diodes for use in optoelectronic circuits and systems.

Graphene FETs have been fabricated with cutoff frequencies beyond 30 GHz. They are of particular interest for flexible circuits, though, in wearable electronic devices. Such devices, which include different types of temperature and motion detectors, are being designed with wireless transceiver capabilities for use as Internet of Things (IoT) wireless devices. Researchers also continue to search for ways to scale semiconductor dimensions smaller in size. The goal is to develop practical transistors and diodes for short-range millimeter-wave, or even terahertz (THz) frequency, wireless communications in support of the expected higher wireless data rates needed for IoT applications. mw

JACK BROWNE | Technical Contributor

Sizing up Discrete Devices Against Integrated Circuits

Discrete transistors require more extensive design efforts than integrated circuits—albeit with much greater flexibility for realizing an amplifier or other component with special features.

INTEGRATED CIRCUITS (ICs) may best symbolize the electronic technology of the present day, at times packing the equivalent functions of a system into a single semiconductor chip or package. ICs have made our current world of portable computers and mobile communications devices possible at affordable prices.

But for many applications, discrete RF/microwave components are still to be preferred over ICs, even with their larger sizes and higher costs—and sometimes because of their larger sizes. While this industry may not use as many vacuum tubes as it did three decades ago, it still enjoys healthy demands for discrete RF/microwave components versus ICs.

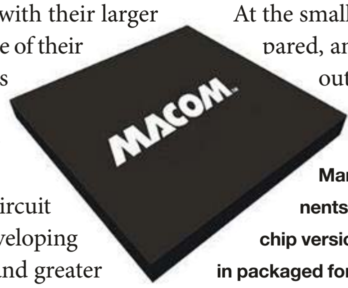
While it is possible to pack a great deal of circuit functionality within a small packaged IC, developing such a circuit typically requires longer time and greater expense than designing and assembling a circuit with similar functions using discrete active and passive components on a printed-circuit board (PCB). The small device geometries of the semiconductors and passive circuit elements in an IC enable the construction of extremely compact analog, digital, and mixed-signal circuits. That being said, those small device dimensions will also limit the amount of RF/microwave power that can be produced from any amplifiers within those ICs.

In solid-state circuitry, size equates to power. Larger semiconductor devices are capable of higher energy output levels, and will consume more power than smaller devices to achieve those levels. Still, there is no way to truly compare an RF/microwave transistor fabricated in a monolithic-microwave-integrated-circuit (MMIC) with a discrete transistor. This holds true even when both are based on the same semiconductor substrate—e.g., silicon, gallium arsenide (GaAs), or gallium nitride (GaN).

Even if a discrete transistor was fabricated with the same dimensions as the monolithic transistor, it would provide the potential for higher output-power levels for a given bias supply, since all of the power supply is being directed to the transistor. In the MMIC, energy is consumed by the surrounding circuitry.

Of course, the additional circuitry provides additional benefits compared to a discrete transistor, depending on the design of the MMIC. It may include power-supply circuitry and even electromagnetic-interference (EMI) filtering on chip, so as to avoid the chore of adding those circuits to an amplifier designed around a discrete device.

At the small-signal power levels at which they can be compared, an IC amplifier, for example, will have input and output ports matched to 50 Ω for ease of installation in a circuit or system layout. In contrast, a discrete-device amplifier can be constructed using a wide choice of PCB materials, selecting materials for optimum characteristics—such as permittivity and coefficient of thermal expansion (CTE)—to enable the highest amount of output power and greatest power-added efficiency from a discrete power transistor.



Many IC components are available in chip versions as well as in packaged form, such as this 4-W power amplifier IC, for flexibility in circuit design and layout. *(Photo courtesy of MACOM)*

In addition, while they add to the size of the discrete power amplifier, thermal-management materials and heat sinks can be included to vent heat away from the power transistors. This allows for continuous operation at higher power levels than is possible with a monolithic amplifier designed for small size and lacking thermal-management materials.

In spite of the multiple circuit functions available in IC form, many circuit designers still start with discrete transistors and diodes. According to Tim Boles, distinguished fellow of technology at MACOM (www.macom.com), there are many benefits to be realized from the use of discrete components: "Historically, RF discrete circuits have been displaced by MMIC solutions at low power levels because the required functionality increased in complexity, and the volume requirements of the marketplace applications ensured an adequate ROI despite the dramatic increase in associated developmental costs.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"This migration path was and continues to be true for the wide variety of technology platforms that are utilized for RF applications, including silicon, GaAs, and most recently GaN," Boles continues. "However, MMIC solutions do have limitations. The first is in the realm of very high power. MMIC power integration continues to increase, but discrete RF components have increased much further, yielding discrete RF devices capable of delivering over 1 kilowatt of RF energy in the microwave range.

"Second, as mentioned earlier, the development costs and complexity associated with MMICs are much higher than the costs and effort of expanding the performance of an RF discrete component. In order to economically justify this development effort and expense, the final market application must require a large enough unit volume to provide a reasonable ROI. Thus, for small-volume RF circuit requirements, discrete makes the most sense in terms of cost-effectiveness."

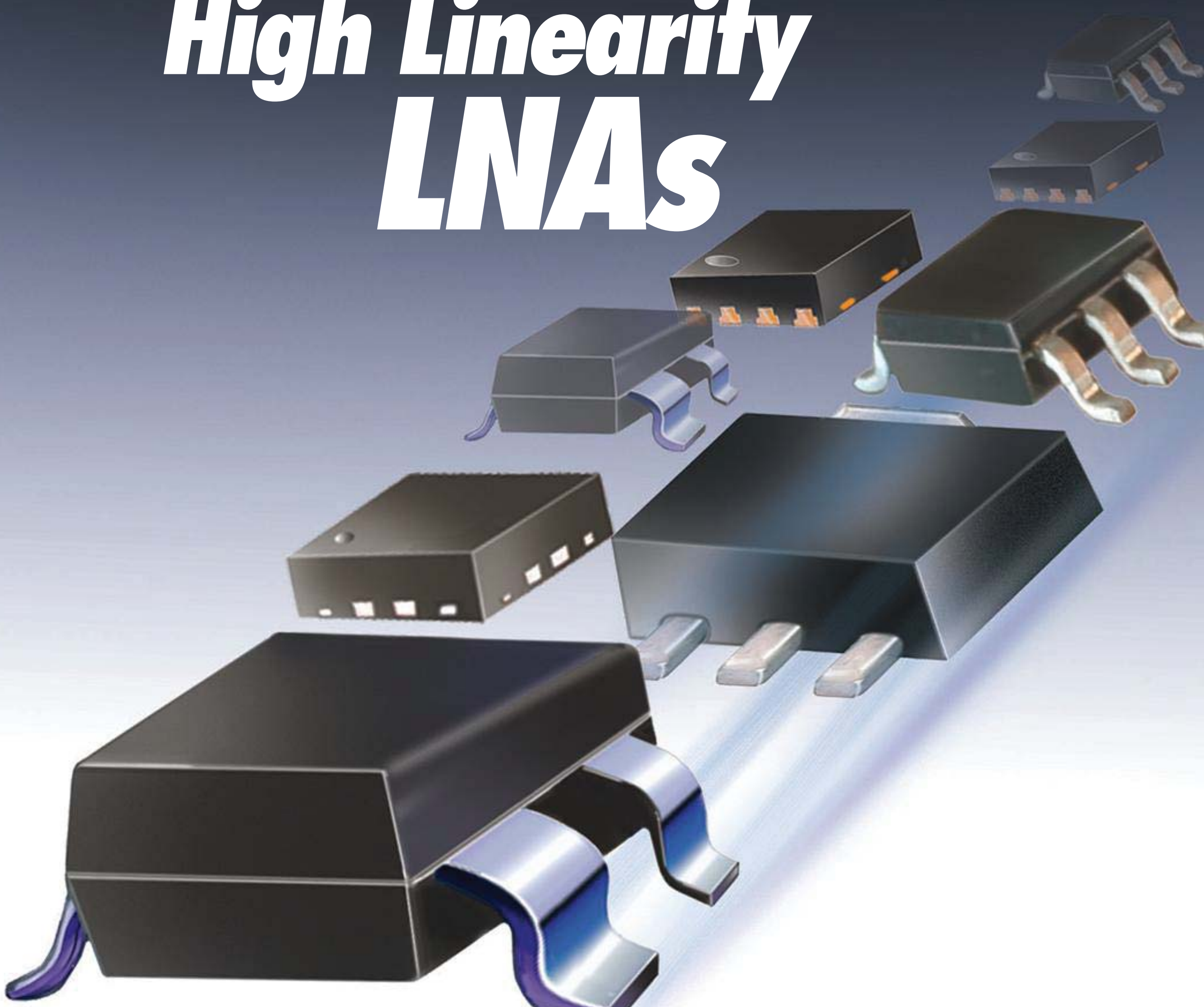
For any high-volume applications requiring excellent unit-to-unit repeatability, ICs can achieve levels of repeatability in amplitude and phase responses with frequency that can be challenging to achieve with discrete component designs. The repeatability possible with a semiconductor process and IC components requires a great deal of broadband testing and hand-tuning of a discrete component design, with the associated higher costs noted by Boles for discrete device designs.

Boles' firm, MACOM, supplies both ICs and discrete devices based on silicon GaAs and GaN substrate materials. As he notes, "MACOM has been a leader in providing high-performance RF discrete power components...we continue to advance our discrete RF offerings while using these building-block components to enhance MMIC performance in the areas of GaAs pHEMT power amplifiers, high-power PIN-diode MMIC switches, and GaN modular power integrated circuits."

IC-based components such as amplifiers are typically available in miniature packages, such as surface-mount-technology (SMT) housings, as well as in die form for designers to directly mount the IC onto a PCB without the package. As an example, the model MAAP-011139-DIE is a 4-W IC bare die amplifier for use from 29 to 31 GHz for very-small-aperture-terminal (VSAT) applications. It can also be supplied in an SMT package *(see figure)*.

Based on GaAs pseudomorphic-high-electron-mobility-transistor (pHEMT) semiconductor technology, this device provides reasonable output power for its small size, although higher power levels are possible using discrete transistors and associated amplifier circuitry, with the tradeoff being larger size. mw

High Linearity LNAs



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Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
New! PMA3-83LN+	500 – 8000	21.0	**1.3**	**35**	23.2	80	11.95
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)	2.58
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**	17	41 (3V) 57 (4V)	2.87
PMA-545G3+	700-1000	31.3	**0.9**	**34**	22	158	4.95
PMA-5454+	50-6000	13.5	**0.9**	**28**	15	20	1.49

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
New! PMA2-43LN+	1100 – 4000	19	**0.46**	**33**	19.9	51	3.99
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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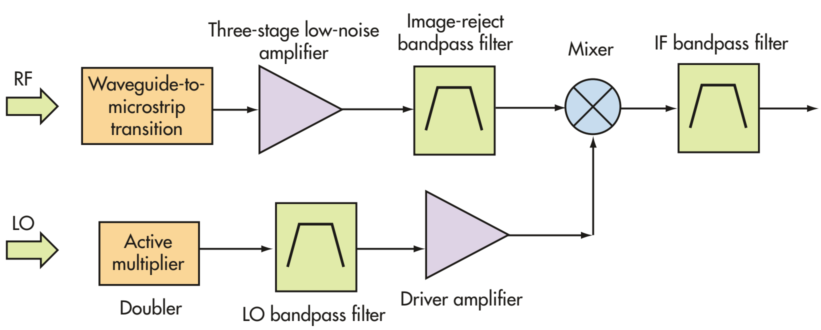
Integrated Front End Serves Satcom Receivers

This integrated Ku-band front-end system employs a modular design approach, achieving a great deal of functionality in compact packaging for satellite communications receiver applications.



1. The block diagram shows the components that comprise the satcom integrated front end module.

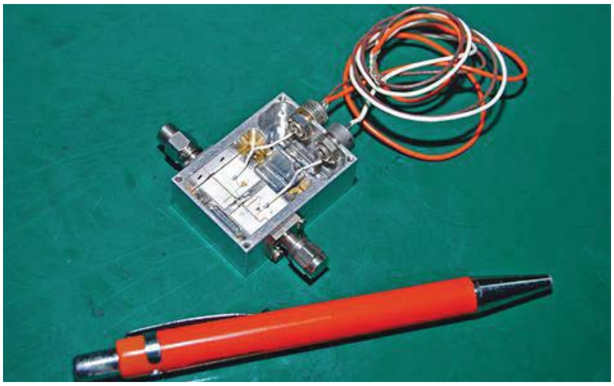
2. This plot shows the frequency response of the amplifier stages.

Microwave front ends are a critical part of any high-frequency receiver architecture. They downconvert incoming signals from an antenna and pass along lower-frequency intermediate-frequency (IF) signals for further processing, typically to an analog-to-digital converter (ADC). By adopting a modular approach, an integrated front end was developed for satellite-communications (satcom) applications from 12.75 to 13.25 GHz. This front end is compact in size while also achieving outstanding electrical performance.

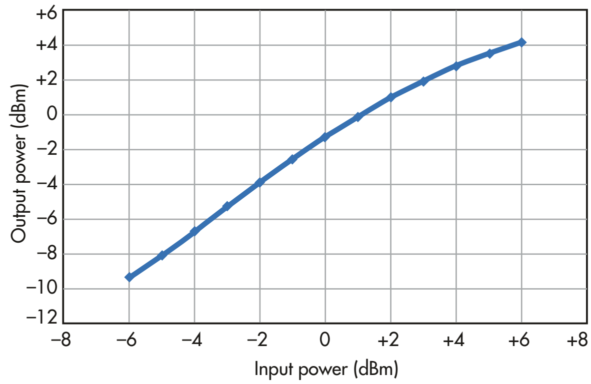
An effective front-end receiver design should provide good low-noise performance, as characterized by low receiver noise figure, and high gain at the frequencies of interest. For Ku-band satcom applications, a receiver front end was designed for use from 12.75 to 13.25 GHz. This consists of three independent function modules: a low-noise block downconverter (LNB) module, a local oscillator (LO) driver module, and a frequency downconversion module.

The LNB module includes a waveguide-to-microstrip transition, three stages of low-noise and high-gain amplifiers, and an image-reject filter. The LO driver module consists of an active frequency multiplier, a bandpass filter, and a driver amplifier. The frequency downconverter module incorporates a single-balanced frequency mixer (based on a low-barrier Schottky diode) and an intermediate-frequency (IF) bandpass filter to achieve the desired bandwidth and out-of-band rejection of unwanted signals. Active circuits in these modules are biased by means of a common sequential bias circuit.

The individual modules were fully characterized before being assembled into the satcom system housing. The active circuits were designed with the aid



3. **This photograph shows the fabricated multiplier circuit for the integrated front end.**



4. **This is the response of the frequency multiplier circuit as a function of input power.**

of an in-house nonlinear model for a commercial high-electron-mobility-transistor (HEMT) device,[2] a model CFY67-08 transistor from Infineon Technologies (www.infineon.com). This is a high-reliability (hi-rel) gallium arsenide (GaAs) transistor usable from 500 MHz to beyond 20 GHz with typical noise figure of 0.7 dB at 12 GHz.

The front end incorporates novel and compact filters to achieve small size and low insertion loss. The design of the front-end modules reduces the total parts count by using a single GaAs HEMT as the active device for all of the active circuits. The circuits are implemented using microwave-integrated-circuit (MIC) technology on alumina substrates. The modules are integrated into aluminium housings with a robust mechanical design to avoid undesired coupling and cavity oscillations. *Figure 1* shows a block diagram of the different function blocks in the integrated front-end design.

ACTIVE CIRCUITRY

The LNB module includes three amplifier stages *(Fig. 2)*: a low-noise-amplifier (LNA) stage followed by two gain stages. These amplifier stages are conjugately matched and constructed with GaAs HEMT active devices. The operating frequency range of the LNA is 12.75 to 13.25 GHz. The devices are biased at 2.0 V dc and 15 mA. Since low noise figure is a critical parameter for the LNA, in-house-extracted S-parameters are used for the GaAs HEMT device (rather than supplied by the manufacturer), along with noise data for the device to determine the actual device phase response for Γ_{opt} for optimum impedance matching for low noise figure.

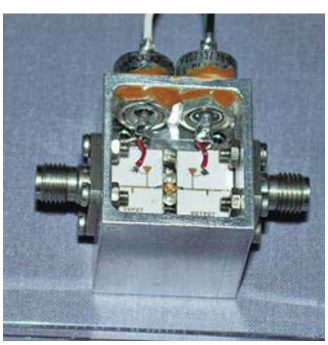
This is done since high-frequency package parasitic impedances may change the phase response of the device. By employing this design approach, it was possible to obtain a noise figure of 2.3 dB with gain of 26 dB for the LNB, with measured results closely matched to the computer simulated performance.

A frequency doubler, part of the LO driver module, was designed to produce the required frequency range for the front-end design. The doubler *(Fig. 3)* accepts input signals across a C-band frequency range and provides output signals at Ku-band frequencies. The multiplier operates across an output frequency range of 6.225 to 6.500 GHz. The design is based on reflector network topology to achieve low conversion loss in order to provide usable output-power levels when operating with input signals at minimum input power levels.

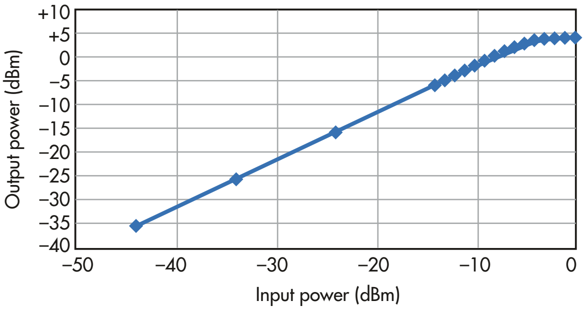
The design was simulated and developed by means of nonlinear analysis using harmonic-balance computer-aided-engineering (CAE) simulation software *(Fig. 4)*. The GaAs HEMT active device in this doubler is operating in its pinchoff region to help achieve the aforementioned low conversion loss. This loss is 3 dB from C-band to Ku-band when operating with optimum input power of +2 dBm.

The driver amplifier *(Fig. 5)*, which is also part of the LO driver module, was designed to provide small-signal gain to the output of the frequency doubler output in order to feed the frequency mixer's LO port at an optimum power level. The operating frequency of the driver amplifier is 12.45 GHz with a 5% bandwidth. The driver amplifier is operated at its 1-dB compression point (P1dB) to provide constant power at the mixer's LO port. Nonlinear analysis by means of harmonic-balance CAE simulation was also performed on the driver amplifier to help optimize the design *(Fig. 6)*.

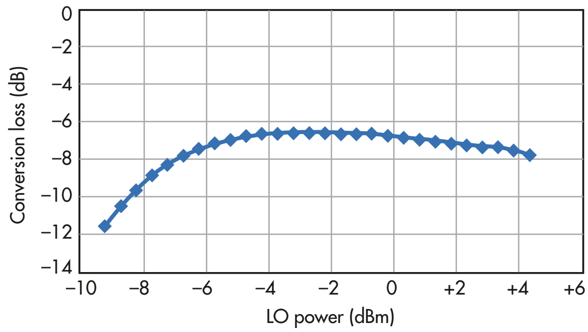
5. **This photograph shows the driver amplifier circuit used in the integrated front end.**



To achieve P1dB at low input power, the output load analysis of the driver amplifier was based on optimizing the small-signal gain, where the output load is maintained at a high value (based on load line analysis of the active device). This approach makes it possible to obtain higher gain compression at lower input signal level. The driver ampli-



6. This is the driver amplifier's output power at 1-dB compression as a function of input power.



7. This simple circuit was used for the frequency mixer in the integrated front end.

fier is biased at +2 V dc and 15 mA. It delivers 9-dB gain and provides +4.0 dBm output power (P1dB).

A single-balanced diode-based frequency mixer, which is part of the frequency downconversion module, was designed for operation from 12.2 to 13.2 GHz. The mixer incorporates low-barrier Schottky diodes operating at Ku-band frequencies at low LO drive levels. The mixer is designed with a 180-deg. hybrid for high RF-to-LO isolation and suppression of even-order harmonics generated by the LO. Quarter-wavelength traps were incorporated at the IF port to suppress undesired RF and LO harmonics. As with the frequency doubler and driver amplifier, nonlinear analysis was also performed using harmonic-balance CAE simulation software. The computer simulations helped to achieve conversion loss of 7 dB with a drive level of 0 dBm. *Figure 7* shows the assembled mixer, with simulated response in *Fig. 8*.

8. This plot shows the response of the mixer when driven by the LO.

9. The photo shows the basic structure of a resonator-type filter.

10. The photograph shows the fabricated IF filter.

The image-reject filter, which is part of the amplifier module, was implemented as a resonator-type filter *(Fig. 9)*. The function of the filter is to reject noise and signals at image frequencies. The filter, which measures 10 × 5 mm, has a bandwidth of 200 MHz with insertion loss of 2.5 dB, with better than 45-dB image rejection.

The LO bandpass filter, with a structure and design similar to those of the image-reject filter, is a part of the LO driver module. It selects the desired second harmonic from the doubler and eliminates fundamental-frequency signals and unwanted harmonics produced by the multiplier. The compact LO bandpass filter was designed for a bandwidth of 200 MHz at a center frequency of 12.45 GHz. It exhibits insertion loss of 3.0 dB across the passband, with better than 40-dB rejection of unwanted, out-of-band signals.

TABLE 1: A SUMMARY OF AMPLIFIER MODULE PERFORMANCE			
Module	Frequency (GHz)	Gain (dB)	Noise figure (dB)
1	12.75	26.5	2.0
2	13.0	26.0	2.2
3	13.25	26.0	2.2

TABLE 2: A SUMMARY OF LO DRIVER MODULE PERFORMANCE				
Module	Input frequency (GHz)	Input RF power (dBm)	Output frequency (GHz)	Output RF power (dBm)
1	6.225	+2.0	12.45	3.8
2	6.355	+2.0	12.71	4.0
3	6.536	+2.0	13.072	4.2

TABLE 3: A SUMMARY OF DOWNCONVERSION MODULE PERFORMANCE				
Module	Input RF frequency (GHz)	Input LO frequency (GHz)	Input RF power (dBm)	Output RF power (dBm)
1	12.75	12.201	–30	–40.5
2	13.00	12.451	–30	–40.0
3	13.25	12.701	–30	–40.0

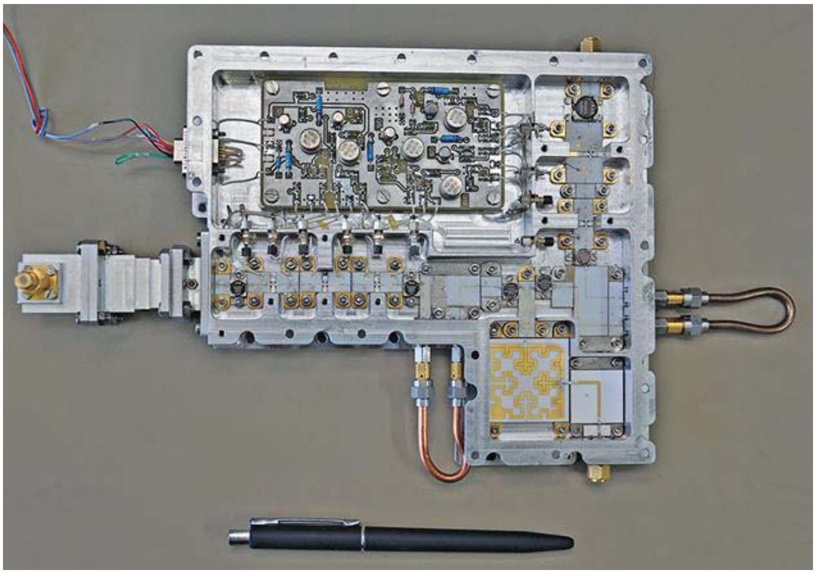
TABLE 4: A SUMMARY OF THE INTEGRATED FRONT-END PERFORMANCE				
Module	Input RF frequency (GHz)	Input LO frequency (GHz)	Gain (dB)	Noise figure (dB)
1	12.75	12.201	12	2.8
2	13.00	12.451	12	2.8
3	13.25	12.701	12	2.8

The IF filter, which is part of the frequency downconversion module, is based on microstrip transmission-line technology using a compact open-loop resonator.[3-7] The filter is designed for a center frequency of 549 MHz and a bandwidth of 20 MHz with insertion loss of 4.0 dB across the passband. It provides maximum notch rejection of 40 dB and second-IF rejection of better than 25 dB.

The filter measures 30 × 30 mm, which is compact for a component operating at UHF. *Figure 10* shows a photograph of the fabricated IF filter. All three filters were designed with the aid of the LINMIC simulation software, now available from Computer Simulation Technology (www.cst.com).

The three modules were assembled into a front-end housing. The modules were characterized independently to determine performance levels prior to integration in the front-end housing. They were characterized over wide temperature extremes to ensure that minimum performance levels would be met even at operating temperature extremes. The various tables provide summaries of key performance parameters. *Table 1* provides details on the amplifier module while *Table 2* offers information on the performance of the LO driver module.

Table 3 presents details on the performance of the frequency downconversion module. It was characterized for a constant IF of 549 MHz and LO power of +4 dBm. *Table 4* shows the performance attributes of the integrated microwave front-end



11. The modular front end measures 150 × 180 × 20 mm and weighs 750 g.

assembly. The front-end subsystem is designed to operate with + 5 and −15 V dc supplies with DC power consumption of 0.7 W. The performance of the front-end system has been verified over an operating temperature range of −30 to +60°C. Variations in gain and noise figure as a function of temperature are controlled to better than ±1.0 and ±0.5 dB, respectively.

All three modules were integrated into a common modular package *(Fig. 11)*. The circuits within these modules were implemented using MIC technology on alumina substrates, mounted on Kovar plates, and interconnected via of ribbon bond wires. The length and width of the ribbon bonds were optimized to less than 15 mils for an impedance match to 50 Ω[6] Tuning stubs near the ribbon bond wires were used to fine-tune any impedance mismatches in the interconnections.

Great care was taken in routing dc wire connections from the active stages, such as the amplifier module and the LO driver module, to the integrated bias card to avoid undesired low-frequency oscillations. Ferrite beads were incorporated with feedthrough capacitors to form a lowpass filter, further rejecting spurious energy and avoiding in-band oscillations within the active circuits.

The housing was fabricated from 6061 aluminium alloy. It is designed to avoid mutual coupling between the gain stages and also avoid direct coupling between the LO drive module and the three-stage amplifier module. The modular front-end subsystem measures 150 × 180 × 20 mm and weighs 750 g. The compact front end was designed for integration into a command and ranging receiver for future spacecraft applications. mw

ACKNOWLEDGMENT

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JACK BROWNE | Technical Contributor

What are the Filtering Differences Between SAWs and BAWs?

Components based on SAW and BAW technology both employ acoustic waves but in different ways and with different performance levels, especially at higher frequencies.

Acoustic waves may seem out of the useful range of RF/microwave designs, but such low-frequency waves are quite effective in higher-frequency systems. They form the foundation for surface-acoustic-wave (SAW) and bulk-acoustic-wave (BAW) resonators, filters, oscillators, and delay lines. Components based on these technologies have found their ways into many applications, from automotive navigation systems and smartphones to military radar systems.

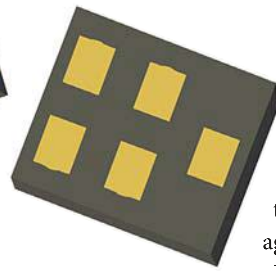
Both SAW and BAW components employ interdigital transducers (IDTs) to convert electrical energy to mechanical acoustic waves and then back to electrical energy, enabling signal processing in the acoustic realm. Given how RF/microwave frequencies can be translated into shorter-wavelength acoustic signals, it's possible to create extremely small filters and resonators for SAW structures that process higher-frequency electromagnetic (EM) signals.

These small structural features, however, limit the high-end frequency for which a SAW filter or resonator can be practically manufactured. Power-handling capabilities also become limited due to the high current densities in small structures.

DIFFERENT BUT COMPLEMENTARY

In a SAW component, acoustic waves travel across the surface of an elastic, piezoelectric material, with wave amplitude that typically decays exponentially with depth into the substrate material. This acoustic-wave phenomenon is sometimes referred to as Rayleigh waves (named after Lord Rayleigh, who made the discovery in 1885). In contrast, the acoustic waves in a BAW component travel through and are stored in the piezoelectric material.

If anything, SAW and BAW can be seen as complementary technologies. SAW components such as filters can be manufactured to about 2.0 or 2.5 GHz before the dimensions of the SAW transducers become unmanageably small.



1. Model 885128, a BAW bandpass filter with a center frequency at 2.4 GHz, is supplied in a miniature surface-mount package. *(Courtesy of Qorvo/RFMW)*

BAW components, on the other hand, are sometimes known as "high-frequency SAWs" and can be used to 2.7 GHz and beyond for filtering, delay lines, and other functions. For some applications, such as Long Term Evolution (LTE) wireless systems, SAW and BAW filters will both have roles to play. In this case, SAW filters handle the lower-frequency bands and BAW filters take on the higher-frequency bands.

Since SAW filters are known to drift in frequency more with temperature than BAW filters, some designers opt for BAW filters in circuits or systems that must be used over wide operating-temperature ranges. In recent years, though, a number of SAW manufacturers have developed either temperature-compensated or more temperature-insensitive SAW filters that provide stable frequency operation even over wide operating-temperature ranges.

PIEZO IS PRIMARY MATERIAL

SAW and BAW components rely on piezoelectric materials to transfer or store acoustic energy, and the choice of material can have a great impact on filter or resonator performance. In either type of component, the piezoelectric material layer is usually produced with top and bottom metal layers and mounted to a substrate material for stability.

Piezoelectric materials for SAW components must exhibit optimum mechanical and electrical properties.

Movement of the surface waves can vary with the type of substrate material, such as lithium niobate ($LiNbO_3$) or lithium tantalite ($LiTaO_3$). One piezoelectric material that has gained widespread acceptance for its manufacturability and performance levels is aluminum nitride (AlN). In addition to SAW and BAW devices, piezoelectric materials are also used in the fabrication of microelectromechanical-systems (MEMS) components.

2. Model 857271 is a SAW bandpass filter with a 39-dB passband centered at 456 MHz and supplied in a miniature surface-mount package. *(Courtesy of Qorvo/RFMW)*

Piezoelectric material can also support different bandwidths for SAW filters, depending on the type. Basic quartz materials have been found to be adequate for low-bandwidth filters, while lithium tantalite has served well for medium-bandwidth varieties. Lithium niobate is typically employed for SAW filters with wide bandwidths. As with most high-frequency components, however, these materials yield other tradeoffs in exchange for such performance characteristics. In particular, lithium niobate is known for high temperature dependency and higher loss than some of the other piezoelectric materials.

To form a SAW or BAW filter or resonator, different types of metal films are deposited on the top and bottom of the piezoelectric materials. These include aluminum (Al) and tungsten (W) for lower and higher power levels, respectively. In such acoustic components, the resonant frequency is inverse proportional to film thickness, with both the metal and dielectric layers helping to determine the resonant frequency. Removing some of the top layer metal thickness, for example, can boost the frequency.

Storing acoustic-wave energy within the piezoelectric material has its advantages. At their higher frequencies, BAW resonators are capable of achieving high quality factors (Qs) that translate into highly selective filters. For bandpass filters, for example, low passband insertion loss is possible with very sharp filter skirts. This enables high rejection of signals closely located to a desired passband, as has become the case for many of the wireless communications standards. BAW filters tend to be better suited for higher-power-level signals than SAW filters with their fine circuit features that can suffer the performance-degrading effects of electromigration at higher power levels.

As delay lines, both technologies are effective within their frequency ranges, with SAW delay lines somewhat smaller and less expensive than BAW delay lines. SAW delay lines operate at lower frequencies than BAW delay lines, and are somewhat limited in terms of the amount of delay time that they can introduce to a circuit or system compared to their BAW counterparts.

WHAT'S AVAILABLE?

As frequency resonators or oscillators, SAWs have demonstrated extremely low-noise performance, with outstanding phase noise. Synergy Microwave Corp. (www.synergymwave.com), for example, known for its crystal and phase-locked oscillators, also supplies a line of SAW oscillators through about 2 GHz. The firm's HFSO800-5H voltage-controlled SAW oscillator provides a stable output at 800 MHz when running on 20 mA from +0.5 to +5.0 V dc. It exhibits single-sideband (SSB) phase noise of –150 dBc/Hz offset only 10 kHz from the carrier. The oscillator comes in a compact surface-mount-device (SMD) package.

For higher frequencies, the model VS-401 voltage-controlled SAW oscillator from Vectron International (www.vectron.com) is available from 1.3 to 2.5 GHz for optical receivers and data converters. For a frequency of 1.75 GHz, SSB phase noise is –119 dBc/Hz offset 10 kHz from the carrier. It comes in a 13- × 20-mm SMD package, although surface-mount, through-hole, and connector-equipped packages are available, too.

One unmistakable trend is toward the design and production of both smaller SAW and BAW components to reduce a circuit's footprint and weight as much as possible. As electronic end products continue to be made smaller, lighter, and more portable, component designers feel greater pressure to develop correspondingly smaller and lighter signal-processing components, such as filters. Qorvo's (www.qorvo.com) recent unveiling of SAW and BAW filters proves this point.

In another example, Qorvo and RFMW Ltd. (www.rfmw.com) announced the availability of the model 885128 BAW filter from TriQuint (www.triquint.com) for 2.4-GHz coexistence of multiple wireless standards, notably WLAN, Wi-Fi, and Bluetooth systems. The BAW filter allows the wireless technologies to coexist in the presence of Fourth-Generation (4G) Long-Term-Evolution (LTE) wireless communications systems.

The 885128 employs the firm's LowDrift and NoDrift temperature-stabilization technologies to minimize frequency drift with temperature over an operating-temperature range of –40 to +95°C. It handles as much as 4 W (+36 dBm) input power in a SMD housing measuring just 1.1 × 0.9 × 0.5 mm *(Fig. 1)*.

At the same time, Qorvo and RFMW introduced the higher-frequency 857271 456-MHz SAW filter. It provides a 39.6-MHz, 1.4-dB bandwidth at a center frequency of 456 MHz for use with WCDMA/LTE applications. It is housed in a ceramic surface-mount package measuring 7.01 × 5.51 × 1.70 mm *(Fig. 2)*.

DESIGN PROCESS OF CAVITY-BASED, HELICAL RESONATOR FILTERS ENTERS HIGHER GROUND

THE PERFORMANCE OF a cavity-based filter is determined by its geometry. Although these filter structures can be tuned, it can be a challenge to obtain the proper geometric dimensions that allow the tuning elements to attain the desired synthesized response. Simulation software is a valuable tool that can assist with the design of such filters. In the application note, "Cavity-Based Helical Resonator Bandpass Filters Designed With Parameterized Project Template in NI AWR Software," National Instruments describes the design process for a cavity-based, helical resonator bandpass filter at UHF frequencies. The design of this filter type can be aided with the NI AWR Design Environment, which includes the Analyst three-dimensional (3D) electromagnetic (EM) simulator.

The design process began by using ideal elements and traditional filter theory. Optimization techniques were utilized to achieve the required response. The Analyst software platform was used to perform EM simulations, thereby streamlining the task of creating models. An ideal prototype model was constructed in a linear schematic to show that the derived coupling coefficients were correct.

Starting-point dimensions were determined for the helical resonator and cavity. These dimensions were then fine-tuned with a 3D model that also included a variable-length tuning screw and a coil-support structure. Simulation results are presented for a 380-MHz filter with the tuning screw inserted at both minimum and maximum depths. Another 3D model was created that was comprised of two cavities and a coupling slot, enabling inter-resonator coupling bandwidths to be characterized for various dimensions of the coupling slot. Finally, the entire filter model was created, demonstrating that it could achieve the desired Chebychev response.

The fabrication files needed to build the filter were generated by using the hierarchal parameterization elements. A 215-, 380-, and 540-MHz bandpass filter were each assembled. The helical resonator coils were wound on 3D-printed plastic that was formed from a solid-conductor household wire. The application note concludes by presenting the measured results of the 380-MHz filter, which correlated with the simulation results.

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UNDERSTAND THE DOMINION OF ADCs AND DACs IN MODERN TEST EQUIPMENT

MODERN TEST INSTRUMENTS utilize digital technology in place of the analog circuitry that was used in years past. Typically, high-performance analog-to-digital converters (ADCs) and digital-to-analog-converters (DACs) are used in today's test equipment. This has enabled waveforms to be analyzed and generated with better fidelity at higher frequencies and with increased dynamic range in comparison to previous-generation test instruments. In the application note, "Demystifying the Impact of ADCs and DACs on Test Instrument Specifications," Keysight Technologies discusses common converter characteristics and their effect on test instrumentation performance.

The application note begins with an explanation of the characteristics of ADCs and DACs. Integral nonlinearity (INL) and differential nonlinearity (DNL), which are important indicators of a converter's accuracy, are both described. The performance tradeoffs between bit resolution and sampling rates are also explained in the document. Furthermore, readers are provided with a description of how dynamic range is directly related to bit resolution, as well as a description of sampling rates in relation to bandwidth.

Several performance-enhancing techniques that can be applied to ADCs and DACs are explained. The interleaving technique is analyzed, as it offers a means to improve sampling rates without sacrificing bit resolution. Dithering, which is the process of adding a small amount of random noise to a signal before it enters a converter, is also discussed. By implementing the dithering technique, spurious-free dynamic range (SFDR) can be improved. Additional performance-enhancing techniques include oversampling, interpolation, and decimation, which are all explained in the document. A short overview of the undersampling technique is presented as well as a brief analysis of the Hilbert transform.

The application note continues with an explanation of how converter specifications are related to instrument performance. Dynamic specifications, such as signal-to-noise and distortion (SINAD), effective number of bits (ENOB), and spurious-free dynamic range (SFDR), are important to understand when analyzing system performance. Lastly, an overview is presented of ADC and DAC implementations in specific test instruments, including signal analyzers, oscilloscopes, digitizers, arbitrary waveform generators (AWGs), and vector signal generators (VSGs).

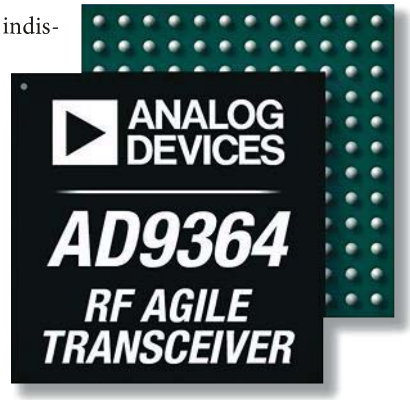
Keysight Technologies Inc., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663; www.keysight.com

CHRIS DeMARTINO | Technology Editor

Prepare Winning Design Recipes with SoCs

Suppliers of systems-on-a-chip—highly integrated solutions that deliver an assortment of benefits—are feeling the IoT-driven push to reach new performance heights.

SYSTEMS-ON-A-CHIP (SOCs) have become indispensable in today's designs, powering applications ranging from cellular infrastructure and radar to test-and-measurement equipment, among many others. SoC types include highly integrated RF transceivers that combine RF, mixed-signal, and digital sections in a single device. Such devices, in some instances, can slash the amount of required external components and ultimately reduce costs.



1. These transceivers integrate RF, mixed-signal, and digital circuitry in a single device. *(Courtesy of Analog Devices)*

Currently, the Internet of Things (IoT) is prompting chipmakers to develop SoC-based products to support a vast amount of requirements. SoCs will also need to satisfy more difficult requirements in the future, such as the challenges associated with upcoming 5G networks.

"5G and massive multiple-input, multiple-output (MIMO) are driving the need for denser, lighter, smaller, and more power-efficient base stations," says Nitin Sharma, senior director of marketing and applications at Analog Devices (www.analog.com). "SoC solutions need to address this by means of higher levels of integration, wider bandwidths, and lower power consumption."

SoC CHALLENGES AND CAPABILITIES

Designing SoCs does not come without its challenges. For example, sensitive RF/analog circuitry must be protected from noisy digital circuitry to ensure acceptable spurious performance.

"Jointly locating sensitive RF/analog circuitry and large digital blocks is certainly one of the most challenging tasks," says Sharma. "As the RF performance requirements increase to meet market demands, focus needs to be on spurious performance. With multiple power supplies, attention is required to ensure that sensitive analog circuits are protected from digital blocks that are large and noisy. In addition, with the inclusion of multiple high-performing phase-locked loops (PLLs), isolation between the voltage-controlled oscillators (VCOs) becomes critical. Without proper design techniques, these issues could generate undesired spurs that could severely limit the performance and flexibility of the end product."

Engineers at Analog Devices utilize various techniques to develop RF transceiver SoCs that can achieve wideband, spurious-free performance while maintaining isolation requirements. For example, the company's AD9361 and AD9364 RF transceivers *(Fig. 1)*, which are well-suited for a broad range of applications, operate from 70 MHz to 6 GHz.

Many other companies produce SoCs to support multiple applications. Nordic Semiconductor (www.nordicsemi.com), for instance, offers low-power wireless chips, as well as reference designs. Its nRF51822 and nRF52832 multi-protocol SoCs enable applications like Bluetooth Smart, among others *(Fig. 2)*. Another device, the nRF9E5 SoC, is a multi-band, sub-1-GHz solution. The company stretches beyond SoCs by providing several development kits as well.

Broadcom (www.broadcom.com) also delivers chips that have found homes in a wide range of applications. The company, which was recently acquired by Avago Technologies (www.avagotech.com), just introduced the BCM43012 Wi-Fi/Bluetooth combo chip for mobile platforms and accessories. The chip integrates power amplifiers (PAs), low-noise amplifiers (LNAs), and power management, enabling bill-of-materials (BOM) cost reductions and small system footprints. On top of that, battery life of the BCM43012 is as much as three times longer than previous Broadcom combo chips.

THE INTERNET OF THINGS

The IoT is spurring chip makers to develop integrated solutions to support different facets of the burgeoning network. In

fact, a large number of SoCs have recently emerged to enable IoT applications.

"We believe that the next big thing will be a trillion wireless things connected to form the IoT," says Svenn-Tore Larsen, CEO at Nordic Semiconductor. "To meet the technological needs of the IoT, we launched an IPv6 over Bluetooth Smart solution that enables end-to-end Internet communications, thus easing the development of IoT applications.

"Our sales increase in 2015 was driven heavily by early IoT-related applications, such as sports and fitness, consumer health, connected toys, location beacons, smart watches, and wearables," he continues. "But we still feel that this is only the start of the IoT revolution. There is enormous potential in many sectors, such as the smart home, industrial automation, automotive, asset tracking and management, and retail/ point-of-sale systems."

2. This single-chip 2.4-GHz device will find homes in Bluetooth Smart types of applications. *(Courtesy of Nordic Semiconductor)*

NEW PRODUCTS FOR THE IoT

Several new IoT-based products have surfaced of late. Qualcomm (www.qualcomm.com) just launched its new CSR102x brand, which is a Bluetooth Smart SoC product line. The CSR102x series is optimized for IoT-specific applications, including wireless remote controls, simple smart watches, and home-automation solutions and beacons. This line of SoCs is intended to simplify integration into each target application, thereby eliminating expensive interface components. A development kit, expected to arrive later this year, is comprised of a programmer base board and pluggable CSR102x SoC module.

For its part, MediaTek (www.mediatek.com) is fresh off its announcement of the MT7697 SoC, which enables Wi-Fi and Bluetooth connections for smart gadgets and wearables. The MT7697 incorporates a PA with transmit power as high as +10 dBm. A dual-band Wi-Fi version of the chipset, the MT7697D, supports both 2.4- and 5-GHz applications. The MT7697 is expected to be available in the first half of this year.

In other recent news, Telink Semiconductor (www.telink-semi.com) launched the TLSR8269, which is an all-in-one SoC for the IoT. The TLSR8269 combines the functionality of all 2.4-GHz IoT standards in a single SoC. The company believes that the TLSR8269 can be a single-chip solution for devices ranging from smart-home applications to wireless toys. In addition, the TLSR8269 integrates hardware acceleration to support complicated security operations.

A large number of companies offer SoCs today, and this article provides some examples of recent activity in this arena. Other companies are providing their own innovative solutions, too. With the emergence of the IoT, expect chipmakers to push the performance envelope even further to enable the required connectivity. Simply put, cutting-edge SoCs will be at the very heart of it all. mw

CHRIS DeMARTINO | Technology Editor

Public-Safety DAS Serves to Protect the People

This high-reliability distributed antenna system is tasked with providing public-safety communications at all times.

NO DOUBT, WIRELESS communication has had a major impact on all of our lives. However, one critical sector—one that often gets overlooked—requires reliable wireless communications: public-safety communication. These systems rely on wireless signals to ensure the safety of people in the event of an emergency situation. First responders and emergency personnel depend on these systems to communicate without interruption.

One company that's made public-safety solutions a priority is Dali Wireless (www.daliwireless.com). Its t-Series PS all-digital distributed antenna system (DAS) provides reliable public-safety coverage and access in all types of environments. In fact, the t-Series PS system was selected to provide the Dallas Fort Worth Airport with in-building public safety coverage throughout all airport terminals.

The t-Series PS system is comprised of the headend as well as medium- and high-power radio remote units. It supports FM, VHF, UHF, and 700/800-MHz frequency bands along with a wide variety of air interfaces, including P25 phase I and II, TETRA, and Tetrapol. The company says the system is LTE-ready as well.

The headend of the tSeries PS network is the tHost-ps—an all-digital and programmable software platform *(see figure)*. The tHost-ps accepts the input from public-safety base stations or off-air repeaters, then RF signals are converted to digital data packets. Multiple tHost-ps units can be cascaded, allowing signals to be digitally processed and combined. The aggregated digital data stream is subsequently distributed via fiber-optic links at a data rate of 6 Gb/s to the remote units.

As a quad-band unit, the tHost-ps bidirectionally transfers four separate public-safety bands to the remote transceivers. It can support as many as six independent optical fibers and more than 36 remotes in a star or daisy-chained configuration. Ethernet backhaul at 1 Gb/s is available for additional devices like security cameras.

The core of the t-Series PS system is its tHost-ps headend, which provides a great amount of functionality.

GOING REMOTE

The t37-ps remote unit is Dali Wireless' medium-power, dual-band remote transceiver. It offers 5 W of output power per frequency band. As a dual-band unit, the t37-ps can bidirectionally transmit and receive two public-safety bands over a single optical fiber at 6 Gb/s. In addition, it will accommodate Ethernet backhaul at 1 Gb/s. By integrating digital equalization and linearization circuits, the t37-ps is able to achieve superior error-vector-magnitude (EVM) performance. It also boasts very low additive system noise. Maximum gain is 30 dB in the uplink bands, and 40 dB in the downlink bands.

On top of that, Dali Wireless' t43-ps high-power, dual-band remote unit delivers 20 W of output power per band. It can even be combined with a second unit to create a compact, integrated quad-band transceiver. Each high-power RF port utilizes high-rejection filters to minimize interference. The unit's RF power amplifiers (PAs), which are implemented in a Doherty configuration, take advantage of patented adaptive equalization, digital predistortion (DPD) algorithms. As a result, the t43-ps is able to attain a high level of EVM and efficiency performance. Like the t37-ps, it maintains very low additive system noise as well.

All remote units feature DSP and network switching capabilities. They also accommodate network management, channelization, Wi-Fi and camera integration, and customer-specific applications. Monitoring and control can be performed locally via the Ethernet craft port or remotely through the tHost-ps unit. mw

CHRIS DeMARTINO | Technology Editor

Simulation Software Solvers Tackle Multiple Problems

The FEKO simulation software tool encompasses several different electromagnetic solution methods, making it suitable for a large number of applications.

COMPUTER-AIDED ENGINEERING (CAE) software plays a critical role in today's design process. Electromagnetic (EM) analysis is extremely valuable—so much so that it can even replace expensive measurements on full-scale structures. Designs can therefore be analyzed efficiently, lowering cost and significantly decreasing development cycles.

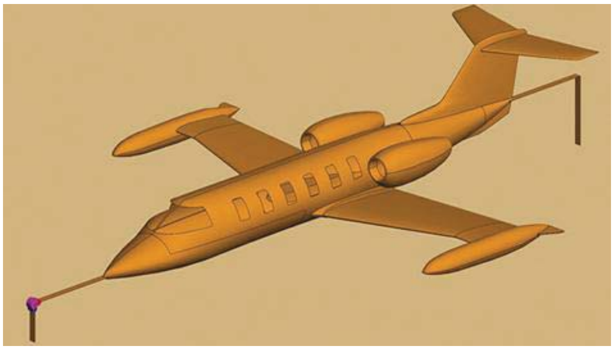
FEKO, which is integrated into the HyperWorks simulation software platform from Altair Engineering (www.altair.com), is a software tool used to perform EM field analysis of three-dimensional (3D) structures. It includes several solvers in all versions, thus enabling users to tackle a wide range of EM problems.

FEKO is well-suited for the analysis of antennas, as well as RF/microwave components like filters, couplers, isolators, and circulators. Antenna-placement analysis is another capability, as the software can simulate an antenna's interaction with electrically large environments *(see figure)*. FEKO is also used extensively to perform electromagnetic-compatibility (EMC) analysis.

EM simulation requirements vary in terms of geometrical complexity and electrical size. No single numerical method can efficiently handle the entire range of potential EM problems on its own. Thus, all versions of FEKO include multiple solvers, which are also hybridized. The strengths of the most suitable techniques are combined, resulting in hybrid solutions.

To solve geometrically complex problems, the software offers method of moments (MoM), finite-element method (FEM), and finite-difference-time-domain (FDTD) solvers. The FDTD solver, which was incorporated into the suite 7.0 release, is a good fit for modeling inhomogeneous materials. The multilevel fast multipole method (MLFMM), physical optics (PO), ray-launching geometrical optics (RL-GO), and uniform theory-of-diffraction (UTD) solvers are ideal for electrically large problems.

FEKO has many features that enhance its performance capability. The adaptive-frequency-sampling (AFS) technique, for example, automatically selects frequency sample points, enabling fast and accurate simulations. Responses are sampled more densely when needed—at resonances, for instance.



FEKO can analyze the placement of antennas on a wide range of platforms, such as aircraft and ships.

Users can achieve optimal designs by means of the various optimization methods available in FEKO. A number of optimization goals can be specified. In addition, several goals can be combined to accommodate multiple optimization requirements.

A standard FEKO workflow begins with the CADFEKO graphical-user-interface (GUI). Users can create their own computer-aided-design (CAD) geometry models. CAD models can also be imported from various formats, such as Parasolid, AutoCAD DXF, Gerber, and ODB++. Another feature is the advanced CAD healing functionality, which enables inconsistencies, gashes, slivers, and spikes to be fixed.

The media library includes pre- and user-defined materials. CADFEKO also has a scripting interface based on the Lua programming language to create advanced user-specified models.

The POSTFEKO GUI is where a standard FEKO workflow ends. This GUI allows users to visualize and compare simulation results. Users can also generate reports by exporting an active POSTFEKO session to a PowerPoint, Word, or PDF file. Various image, animation, and data export options are available.

Finally, POSTFEKO utilizes the Lua programming language to allow scripting for advanced user-specified post-processing. For example, users can create non-standard output types and plot them in the POSTFEKO interface. mw

JACK BROWNE | Technical Contributor

GaN Amplifiers Power 30 MHz to 7.5 GHz

This GaN power-amplifier family serves applications ranging from radar to video data links, with broad operating bandwidths as wide as 100 MHz to 6 GHz.

GALLIUM NITRIDE (GaN) has become the semiconductor material of choice for high-frequency discrete and integrated-circuit (IC) power devices. In fact, its transition from the laboratory to commercial products has been quicker than the push toward gallium arsenide (GaAs) in the 1980s. Fueled by funding to private industry by the U.S. Defense Advanced Research Projects Administration (DARPA), GaN devices made their first large-scale appearance during the mid-2000s in IED jammers. Less than a decade later, GaN devices can be found in commercial, industrial, military, and even medical electronic applications.

Many suppliers now offer GaN devices, but few provide short delivery times. One exception is Pasternack Enterprises, with its line of GaN high-electron-mobility-transistor (HEMT) power amplifiers (PAs) that cover frequencies ranging from 30 MHz to 7.5 GHz. All are available from stock, and they meet MIL-STD-810 environmental test conditions.

Model PE15A5032 delivers 10 W (+40 dBm) at 3-dB compression from 0.5 to 7.0 GHz, with 60-dB small-signal gain and –70-dBc spurious suppression.

The PA line targets multiple applications from commercial and military communications to satellite communications (satcom), L-band radar, data links, air traffic control (ATC), and medical systems. The most broadband models cover 0.1 to 6.0 GHz. Output power at 3-dB compression (P3dB) ranges from 10 to 100 W. All amplifiers are designed to meet military requirements for shock and vibration under high humidity and wide operating-temperature ranges. Units come with hermetic seals and can be used at altitudes to 30,000 ft.

Small-signal gain ranges from 43 to 60 dB, with power-added efficiency (PAE) from 20% to 35%. Active GaN devices are mounted on silicon-carbide substrates for effective thermal management. The amplifiers, which operate with supplies from +28 to +36 V dc, feature integral voltage regulation, bias sequencing, and over-current/over-temperature monitoring and protection. They come in rugged coaxial packages with female SMA input and output connectors *(a listing of these devices can be seen in the online version of this article at www.mwrf.com)*.

One PA from the Pasternack line, model PE15A5032 *(see figure)*, delivers 10-W (+40 dBm) P3dB output power from 0.5 to 7.0 GHz. It exhibits 60-dB small-signal gain with ±1.25-dB gain flatness. PAE is 20% and the noise figure measures 10 dB. Spurious suppression is –70 dBc at the rated output-power level. The GaN amplifier runs on 2.2 A at +28 V dc complete with voltage regulation, bias sequencing, and transistor-transistor-logic (TTL) control. The MIL-STD-202 amplifier handles operating temperatures from –40 to +85°C.

Another PA from the line, model PE15A5019, is a narrowband GaN amplifier for use from 7.2 to 7.5 GHz, such as in coded orthogonal frequency-division-multiplexing (COFDM) video and unmanned aerial and ground (UAV/UGV) data links. It provides 20-W output power with P3dB of 15 W (+41.75 dBm) and 5 W (+37 dBm) typical linear COFDM output power. Typical small-signal gain is 58 dB, flat within ±2 dB. The amplifier incorporates protection for VSWR mismatch, thermal overload, over- and under-voltage conditions, and reverse bias. mw

PASTERNACK ENTERPRISES INC., 17802 Fitch, Irvine, CA 92614, (866) 727-8376, (949) 261-1920, fax: (949) 261-7451, e-mail: sales@pasternack.com, *www.pasternack.com.*

JACK BROWNE | Technical Contributor

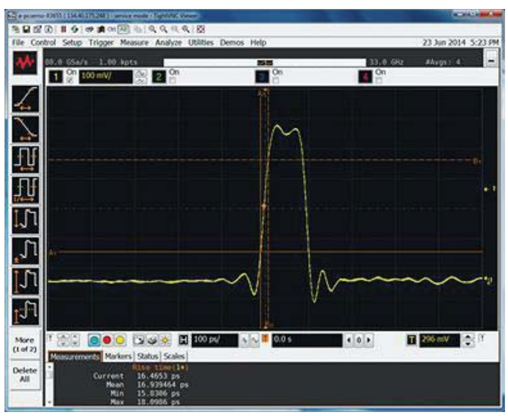
Waveform Generator Makes the Jump to 25 GHz

An already-powerful arbitrary waveform generator now adds real-time signal processing, a new long sequencer, and frequency generation to 25 GHz.

WAVEFORM GENERATION plays a critical part in testing analog and digital circuits and systems, whether for commercial or military applications. The M8195A arbitrary waveform generator from Keysight Technologies is a popular RF/microwave signal generator that featured impressive capabilities when first introduced *(see Microwaves & RF, December 2014, p. 98)*, including signal generation to 20 GHz. But that wasn't good enough for the restless engineers at Keysight, who upgraded the performance of this versatile signal source with several new features and frequency-generation capability to 25 GHz.

1. The M8195A arbitrary waveform generator's bandwidth now extends to 25 GHz with 8-b vertical resolution.

The latest generation of the M8195A arbitrary waveform generator (AWG) offers up to 65 Gsamples/s on as many as four synchronized channels, all from a one-slot AXIe module *(Fig. 1)*. The AXIe modular format allows for flexibility, adding channels and memory as needed. Each AXIe module can be configured with one, two, or four differential channels; more modules can be added to a chassis when the need arises for more test channels (the number of channels is software-upgradeable). As many as 16 signal channels can be generated from four M8195A AWG modules tucked into a five-slot AXIe chassis.



2. The rise/fall time of the M8195A is specified at 18 ps without predistortion.

Programming of the AWG is handled by an AXIe embedded controller or software on an external personal computer (PC). The AWG provides 8-b vertical resolution across an analog bandwidth of 25 GHz, and packs as much as 16 Gsamples of waveform memory per AXIe module. At the fastest sampling rate, this translates into a running time of 250 ms, allowing operators to create long and/or complex signal patterns with the AWG's sequencer option.

SPECS AND OTHER FEATURES

These are high-quality signals, with as much as 1-V peak-to-peak, single-ended amplitude and 2-V peak-to-peak differential amplitude, within a voltage window of –1.0 to +3.3 V. They're suited for digital as well as analog testing, with an 80%/20% rise/fall time of typically 18 ps with no predistortion and typically 12 ps with predistortion applied *(Fig. 2)*. The intrinsic jitter is less than 200 fs. The M8195A incorporates frequency- and phase-response calibration to maintain the best possible signal quality. Each AWG includes a 16-tap finite-impulse-response (FIR) filter in hardware to execute frequency-response corrections as needed.

Software is modular with the AWG—waveform generation can be modified by adding software tools, such as the M8085A software plug-in. It works with the AWG to create a multiple-lane MIPI C-PHY and D-PHY receiver test-application. In addition, 81195A optical modulation generator software provides test signal patterns needed for high-speed optical testing.

P&A: $95,000. mw

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1. The APG-79 AESA radar system, which employs numerous COTS components, uses an agile scanned radar beam for air-to-air and air-to-surface detection of targets. *(Photo courtesy of Raytheon Co.)*

CHANGES ARE COMING in Defense Procurement

Tightened defense budgets signal changes for RF/microwave companies supplying components for these systems, along with a greater need for the use of an open architecture.

LORNE GRAVES | Chief Technologist
Mercury Systems, 201 Riverneck Rd., Chelmsford, MA 01824-2820; (978) 256-1300, www.mrcy.com

CHANGES ARE coming for companies that work with defense and aerospace customers. Wide-ranging initiatives put in place by the United States Department of Defense (DoD) are fueling those changes. These initiatives are intended to ensure that the different branches of the military are equipped with the latest high-frequency technologies—but also to maintain competitive bidding among contractors and suppliers and to eliminate the custom "one-off" systems of the past, while generally achieving more of a shrinking defense budget.

Changes such as these will significantly impact the microwave industry for years to come. They will change the way microwave subsystems are designed, constructed, and tested; the technology that they employ; and who will pay for the development of these subsystems.

Granted, the microwave industry is not the only industrial sector that will be impacted by these changes. But in addition to being one of the most technically challenging and specialized portions of a defense-electronics system, RF/microwave technology is crucial to next-generation military systems. The result will be the most dramatic (some would say draconian) change faced by the microwave community in decades. To understand why, it's necessary to examine some of these initiatives, one by one.

The RF/microwave industry has long been motivated to do business with the U.S. DoD due to cost-plus-fixed-fee (CPFF) contracts and reimbursement for

(continued on p. 76)

NEWS SHORTS

RAYTHEON Begins to Define MOKV Concept

RAYTHEON COMPANY (www.raytheon.com) completed its first Program Planning Review with the United States Missile Defense Agency (MDA) on its Multi-Object Kill Vehicle (MOKV). The MOKV program is part of a $9,775,608 contract awarded in August 2015 to develop a weapons system capable of destroying several objects by using advanced sensor, divert, and attitude control, as well as communication technologies.

Working within the concept development phase of the contract, Raytheon must work closely with the MDA's expectations for the system. In addition to the Standard Missile-3 and Exoatmospheric Kill Vehicle programs, Raytheon has achieved more than 30 intercepts in space to this point. ■

(continued on p. 72)

Don't Forget Those "Auxiliary" Technologies

Jack Browne, Technical Contributor

TECHNOLOGY has long provided an edge for most military forces, whether on land, at sea, or in the air. Advanced electronic technologies have often begun inside secure laboratories at facilities such as the Army Research Laboratory (ARL) or the Naval Research Laboratory (NRL), and much of the early work in high-frequency electronics can be traced back to vacuum tubes.

Anyone who has carried a chassis containing those large vacuum tubes and their even larger power supplies knows that technology often moves in the direction of smaller and lighter. Current advances in solid-state RF/microwave power—including discrete devices and amplifiers based on gallium-nitride (GaN) semiconductors—have received a great deal of attention and funding from such defense-driven organizations such as the U.S. Defense Advanced Research Projects Agency (DARPA) and the U.S. Department of Defense (DoD).

GaN certainly must be considered a "major" technology for future defense systems, since it can be used to boost signal strength from RF through millimeter-wave frequencies. Lasers and laser-based weapons are another area of interest, in what might be considered another major area.

The power densities of GaN devices are quite impressive, enabling high-power RF/microwave amplifiers to be constructed in a fraction of the size of those old vacuum-tube amplifiers. Of course, engineering of any kind involves tradeoffs, and achieving higher solid-state output power from smaller footprints requires dependable performance from what are often overlooked or "auxiliary" technologies, such as packaging and thermal-management materials.

Certainly, such materials and packaging are not considered auxiliary by the companies that develop and manufacture them. But they are essential to the success of truly high-power GaN amplifiers—not to

mention, any possible semiconductor technologies that may follow GaN in the ongoing quest to replace tubes for generating high-power RF/microwave signal levels.

Such auxiliary technologies make it possible to pack many high-power GaN transistors into a single compact amplifier housing without causing overheating and meltdown. Unfortunately, any transistor wastes a great deal of supplied energy as heat, leaving suitable packaging and thermal-management materials to conduct heat away from the source.

GaN certainly must be considered a "major" technology for future defense systems, since it can be used to boost signal strength.

In military applications, they must do so continuously, and under a wide range of temperatures, humidity, and other environmental conditions around the world (and sometimes in outer space). For a high-power semiconductor technology such as GaN to deliver high performance under such rigorous conditions, it is the packaging and the thermal-management materials that help to protect the GaN devices and contribute to a long operating lifetime.

Admittedly, GaN gets a great deal of attention for its high power densities in military and commercial applications. The semiconductor technology is widespread, found in everything from cell phones to automotive radar systems. But for it to endure for the long term in the harshest operating conditions, in aerospace and defense electronic systems, GaN must be protected by those "auxiliary" technologies. Therefore, important components such as packaging and thermal-management materials should not be overlooked. de

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498 rev.E

Digital Moving Map
Aids Avionics Operators

WORKING WITH FliteScene Digital Moving Map software from Harris Corp. (www.harris.com), the Defense Solutions division of Curtiss-Wright Corp. (www.curtiss-wright.com) has developed a system-ready application (SRA) for use with embedded avionics systems. The firm's LiteScene Digital Mapping Solution combines the software with a single-board computer (SBC) and graphics-processing-unit (GPU) -based display graphics controller board, creating an open-architecture, commercial-off-the-shelf (COTS) digital moving map solution for embedded avionics systems.

Applicable to both commercial and military avionics systems, the solution enhances the integration of situational awareness and mapping functions in a field-qualified system. The Harris software provides scalable, configurable two- and three-dimensional terrain images for aerospace, defense, firefighting, and law-enforcement requirements. ■

COTS and IoT Advances Will Benefit DoD Markets

UNITED STATES Department of Defense (DoD) command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) markets are projected to remain flat through 2020. However, they will improve technologically, thanks to advances and growth in commercial-off-the-shelf (COTS) computing and Internet of Things (IoT) wireless and sensor markets. These predictions come from market research firm Frost & Sullivan (www.frost.com), which foresees that the DoD's appetite for advances in communications and computing technologies will draw from the technological evolution of wireless and COTS IT hardware and software for commercial uses (e.g., smartphones, smart homes, and sensor-driven automobiles).

The research and analysis firm finds that a total of $39.54 billion has been earmarked for 2016 DoD programs for C4ISR, EW, and information operations, as well as multipurpose technologies, or an increase of 8.8% from 2015. C4ISR spending is expected to grow at a compound annual growth rate of 1.4% during 2014 through 2020. ■

EW Spending Expected to be Strong

GLOBAL SPENDING on electronic warfare (EW) is expected to grow to almost $19 billion in 2024, according to a market forecast performed by Strategy Analytics Advanced Defense Systems (ADS). The forecast, "Global Electronic Warfare Market Forecast: 2014-2024," details spending on frequency-agile radar systems and other EW platforms, with the growth representing a compound annual growth rate (CAGR) of 3.7%. The forecast report covers the total EW sector, comprising electronic-attack (EA) and electronic-warfare-support (EWS) systems, in addition to electronic protection (EP) support services.

North America is projected to be the largest part of that total market, with rapid spending growth occurring in the Asia-Pacific region. Airborne EW systems will be the largest portion of the total market. ■

Navigation Software Meets FACE Standard

A RECENT DEMONSTRATION at the Redstone Arsenal (Huntsville, Ala.) showed the capabilities of Rockwell Collins' Required Navigation Performance Area Navigation (RNP RNAV) flight-management system. The system, which was evaluated in terms of its compatibility with the Future Airborne Capability Environment (FACE) standard, was used with only FACE edition 2.1 aligned interfaces to a third-party-supplied FACE transport services segment and the LynxOS-178 FACE operating-system segment. FACE aligned interfac-

es are designed for portability across different hardware platforms in a navigation system.

According to Troy Brunk, vice president and general manager of Airborne Solutions for Rockwell Collins (www.rockwellcollins.com), "This demonstration represents a significant milestone because it is the first software application submitted for FACE verification testing. It also reflects our company's commitment to build modular and reusable software applications that fully meet the latest open standards and civil airspace requirements." The FACE technical standard is NAVAIR's Open Architecture Backbone and the Army's Common Operating Environment. Rockwell Collins is a founding member of the FACE consortium. ■

CERDEC to Meet With Industry

TECHNOLOGY REPRESENTS a large part of the advantages held by U.S. troops, and the Army is no exception to this rule. The U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) plays a key role in pursuing and maintaining a technological edge for the Army, relying, of course, on guidance from the electronics industry. To foster communications between CERDEC and the industry, the organization scheduled a two-day technical interchange meeting (TIM) with the industry from March 31 to April 1 to help identify mutually beneficial research-and-development investments.

These sessions are intended to enhance government-and-industry communication and enable industry to quickly respond to emerging defense-related requirements with innovative technology solutions and partnerships. Breakout sessions will deconstruct Army requirements into specific research-and-development activities in CERDEC mission areas. Those mission areas include mission command; tactical and deployed power; tactical and strategic networks; tactical cyberspace operations; electronic warfare; countermine/counter-IED; intelligence, surveillance, reconnaissance and targeting; and intelligence analysis, exploitation, and dissemination.

As Henry Muller, CERDEC's technical director, explains: "If we want to leverage creativity and innovation to its fullest, Army R&D must work more closely with industry in the earliest stages of the product lifecycle before requirements are firm and design concepts are determined. The sooner industry knows of our interest in a specific capability, the sooner they can begin to explore or invest in applicable technologies and formulate ideas for Army consideration." Registration for the sessions will run from February 1 through February 28, with more details available on the CERDEC website at www.cerdec.army.mil. ■

METAMATERIALS Form Radar Antenna Array

METAMATERIALS, or materials formed of various compounds, offer great promise for electronic applications. Echodyne (www.echodyne.com) has realized some of that promise in the design and manufacture of a metamaterials electronically scanning array (MESA) for radar applications. The use of metamaterials enables a reduction in size and cost compared to conventional materials, without loss of performance.

This model MESA-X-EVU X-band antenna array is available for partners and integrators interested in exploring the capabilities of this technology.

As noted by Eben Frankenberg, founder and CEO of Echodyne, "We are very pleased with the early reception of MESA-X-EVU by key partners and are excited to be able to offer more units to qualified partners and integrators.

"Metamaterials-based radar has the opportunity to not only change how traditional, heavy, expensive radar systems are deployed," adds Frankenberg, "but can open up new markets for advanced radar that were never before thought possible because of the cost, size, and weight of traditional electronically scanned arrays."

Unlike conventional mechanical apertures that steer a radar beam using motorized gimbals, Echodyne's MESA employs electronically scanning and requires no moving parts to steer its radar beam. Most impressively, it can achieve submicrosecond speeds in the process.

MESA-X-EVU is suitable for integration with existing or new radar systems and meets cost, size, weight, and power (SWaP) requirements. As an added bonus, it is considerably less complicated and expensive than traditional active electronically scanned array (AESA) radar solutions; the latter employ phase shifters, amplifiers, and other various components for electronic scanning.

The MESA-X-EVU subsystem includes the metamaterial array, the array control driver circuitry, and the beam-steering computer. Input signals can be fed to the antenna array through a single coaxial SMA port. The antenna array can scan ±0 deg. in azimuth and ±45 deg. in elevation and is controlled through a USB 2.0 interface. It operates from a single +12-V dc source and measures 50 × 18 × 2.5 cm. ■

2. During a visit to Stanford University, U.S. Defense Secretary Ashton Carter explored the needs of the DoD with executives of local high-technology companies. *(Photo courtesy of the Associated Press*

(continued from p. 67)

non-recurring-engineering (NRE) costs. It can be argued that without CPFF and NRE incentives, some of the most advanced RF/microwave technology developed since World War II might never have found its way into deployed platforms.

Now that these incentives are fading from the lexicon as the DoD clamps down on rising costs, the onus is on manufacturers supplying to the DoD to devote their own R&D resources to meet the stringent specifications required by defense systems. This also means that the most financially sound, technologically innovative companies will fare best in this new defense environment, while less well-endowed firms may struggle without those incentives.

COMMERCIAL SOLUTIONS?

Recent world events have awakened the DoD to the fact that the U.S. is no longer the only country in the world with the engineering and financial wherewithal to advance the state of the art in radar, electronic warfare (EW), signal intelligence (SIGINT), electronic intelligence (ELINT), and communications technologies. Commercial technology—ranging from microprocessors and field-programmable gate arrays (FPGAs) to high-performance analog-to-digital converters (ADCs) and digital-to-analog converters (DACs)—are now almost universally available.

Furthermore, their capabilities are often equal to those being deployed now and proposed for next-generation military systems, and decades beyond those of legacy systems. Simply stated, active electronically scanned array (AESA) radar, cognitive EW, and other technologies are no longer the exclusive property of the West, a reality being demonstrated by adversaries across the globe *(Fig. 1)*.

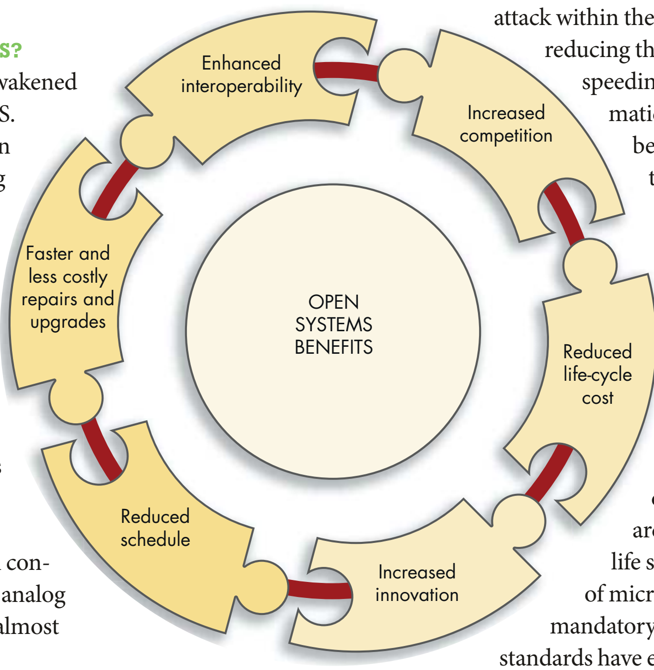
Military systems can benefit from the technologies and technological advances employed in the commercial sector, since many of these advances represent the leading edge of performance and technology in a range of different functions required by military platforms. Technology developed for the DoD in many cases no longer represents the state of the art.

Armed with this knowledge, U.S. Secretary of Defense Ashton Carter has been on the campaign trail in a serious attempt to persuade this country's electronics and information technology goliaths to join the DoD. Carter is pushing for these firms to integrate the latest technology into defense systems now—not in the 8 to 10 years typically required for defense procurement of advanced technology *(Fig. 2)*.

Concerns have also been raised about releasing intellectual property (IP), even if that IP is "protected" by the DoD. Regardless, without what the commercial sector can bring to defense systems, it will be difficult (if not impossible) to keep pace with the tech advances being achieved by the adversaries of the U.S.

The DoD's infamous approach to system development—in which radar, EW, and other systems are designed by a single contractor using its proprietary technology to create a design dedicated to, and only usable by, a single platform—is deeply ingrained after 70 years of "refinement." It's now under attack within the Pentagon in the interest of reducing the number of "one-off" systems, speeding technology refresh, and dramatically reducing the sheer number of incompatible systems and their cost.

One of the key tenets of DoD's plan to change this scenario is adoption of "open" architectures for hardware, the technologies that interconnect them, and the software that controls and orchestrates their functionality. In the domain of digital embedded systems, open architectures have been a fact of life since the 1980s. But in the case of microwave subsystems, no such mandatory form factors or other common standards have existed.



3. This diagram shows the benefits of an open-system approach to developing defense systems. *(Diagram courtesy of the Government Accountability Office)*

That is not to say that the microwave industry has no standards to meet for military design and development. In fact, the military (MIL) specifications related to RF/microwave systems are possibly more demanding than standards applied to most other technologies. The difference is the lack of a set of rules to which all subsystems, principally integrated microwave assemblies (IMAs), must adhere. This is hardly surprising, since the DoD has typically been content just to find engineers capable of meeting its "bleeding-edge" requirements for performance under severe environmental and operating conditions.

However, if the DoD is to succeed in making radar, EW, and other systems transferable with minimal (or no) redesign from one platform to another, the custom design scenario must change. Or at least, it must change for those IMAs serving either receive or low-power-transmit applications that can accommodate the confines of a standard form factor, like OpenVPX.

The sincerity with which DoD is pushing open architectures is evident in documents, presentations, and other activities within the Army, Air Force, Navy, and Marine Corps. The Armed Forces are working with industry and standards bodies such as the VMEbus International Trade Association (VITA) and the VITA Standards Organization (VSO; www.vita.com) to craft open standards, including those for microwave subsystems. The OpenRFM architecture defined by Mercury Systems (www.mrcy.com) was the first and remains the only such industry-sponsored initiative, and the company has been delivering OpenRFM-compliant products for over a year.

Without a documented approach and common form factor and language, creating integrated RF subsystems at Mercury would be greatly hindered in the future. Having already initiated the now-standard OpenVPX architecture for processing systems, it was essentially the next step toward implementing the approach throughout all of the company's business units.

In addition, if widely adopted like OpenVPX, the OpenRFM standard could help the industry as a whole to create similar efficiencies in the RF domain. Among other benefits, OpenRFM allows IMAs to be created using a building-block approach. This allows subsystems to be rapidly configured with minimal software changes and with the capability to reuse of IMA across many systems and for a host of different applications *(Fig. 3)*.

This is not the first time the Department of Defense has thrown down the gauntlet to industry. But these new efforts carry great weight. Wholesale changes to procurement have been a long time in coming. Now they have finally arrived. de

HEMANT MISTRY | President, Jayco mmi Inc.

Designing Clear, Reliable Military/Aerospace HMIs

The design of human-machine interfaces is a highly complex undertaking—one that can be simplified by consulting an interface specialist before proceeding with design work.

THE SUCCESS of most military operations depends on the effective operation of different systems and tools in the field, and human-machine interfaces (HMIs) can significantly impact the performance of those military and aerospace systems. Effectively designed HMIs have made a vital contribution to the success of countless products across the spectrum of industries, ranging from the most sought-after consumer products to the most advanced military and aerospace equipment. But for military applications, the effectiveness and efficiency of an HMI is often a matter of life or death.

Aerospace applications range from cockpit controls and displays to cabin environment controls to in-flight entertainment systems. HMIs are used throughout defense and aerospace industries *(Fig. 1)*, whether for shipboard, airborne, or ground-based mobile applications. These include handheld computers, man-pack radios, high-resolution monitors, and secure voice/data communications devices. Because such hardware must withstand rough handling and extreme environmental conditions, such devices often require a ruggedized HMI for maximum performance.

HMIs for defense and aerospace applications must be designed to improve cognition and comprehension to enable rapid decision-making. Thus, it is essential not only that information is clearly presented, but that inputs can be provided to a system without error—even under stressful conditions and situations.

Although an HMI may be viewed as an integral part of a military system, the

1. This intuitive yet rugged HMI was developed for effective operation of ground vehicles under harsh conditions.

2. This tablet electronic-flight-bag (EFB) interface provides a clear control panel that provides high reliability at high attitudes.

design and manufacture of the interface is often a separate, specialized process that involves the highest levels of complexity (both human and technological). At the same time, build-to-print HMI designs created without the collaboration of an interface specialist is almost always fraught with problems.

Developing a successful machine interface involves design subtleties such as ergonomics, psychology, and other "user-centric" considerations *(Fig. 2)*. Plus, there is a host of available materials and interface technologies to choose from, the need to perform in harsh environments and, increasingly, the need to fit the most effective HMI within extremely limited space on smaller products.

Whether the interface is displaying information, collecting data, or controlling operations, it may require special design consideration such as ruggedized features or the integration of multiple elements into one. These are indicative of the many design challenges at the higher levels of complexity shared by HMIs.

AVOIDING DESIGN PITFALLS

Design engineers experienced in the development of HMI solutions often provide complete documentation for their designs. While a system may be well designed and documented, opportunities may be lost for reducing costs or gaining other benefits possible by consulting with HMI manufacturers prior to the completion of a system design.

As Keith Heinzig, vice president of engineering at Secure Communications Systems (www.securecommunications.com) observes, "There are serious challenges involved when customers build-to-print their own interface designs. Those include possible errors requiring redesign and additional time and money. Also, depending on the application, reliability is always a key constraint."

Heinzig reports that engineers at Secure Communications Systems are not open to compromises that may impact reliability. The company provides customized rugged computer solutions and custom contract manufacturing solutions for defense, aerospace, and industrial applications that involve cold weather and other extreme operating conditions. Secure Communications Systems specializes in the integration of commercial-off-the-shelf (COTS) equipment into rugged, reliable, and cost-effective solutions.

"Our systems can be found in the hands of troops and on vehicles all around the world," notes Heinzig. "Our commitment to providing high levels of service and quality has made us a long-

term partner to many manufacturers in the defense industry."

Early involvement during the design phase, and integrating all of the various components of an HMI into a complete subassembly—including enclosures, displays, switches, and electronics—ensures that all parts work in harmony to meet the required performance levels. The end result is a higher-performing HMI that is easier for the end user to manage and integrate into their system.

Ensuring that interface devices are ruggedized for environmental conditions is a major concern in military and aerospace applications. This includes protection against corrosive environments, providing for ultra-rugged applications that require military-grade shielding, protection against shock or vibration, contaminate sealing, sunlight readability, night-vision lighting, and extended-life grade products.

Teaming with a firm that has extensive expertise in the design and development of HMIs, such as Jayco mmi Inc. (www.jaycopanels.com), can be instrumental in achieving system designs with the performance and ease of use required to operate under severe conditions.

"We have worked successfully with Jayco for a number of years, and their preliminary design consultation has been very helpful in keeping us on the right track as far as planning and implementing the HMIs for our products," says Heinzig. "Some of our more recent projects include very small controls, such as wrist displays for the military."

As an example of its many different HMI solutions, Jayco has developed an automatic weapon targeting interface for Soldier Enhanced Rigid Engagement and Vision in Ambient Lighting (SERVAL) systems. This is a weapon-mounted interface that enables a soldier to quickly change imaging modes. The HMI must function under the most demanding environmental conditions, including at 40,000 ft. altitude and under 12 ft. of water.

The HMI switch assembly features MIL-I-46058C seal protection, with secondary conformal coating to MIL-I-46058 requirements around connectors for additional protection. The HMI is intelligently designed for ease and efficiency of use, and constructed to operate when needed, no matter how harsh the operating conditions. de

JAYCO MMI, INC., 1351 Pico St., Corona, CA 92881-3373; (951) 738-2000, (877) 529-2648, FAX: (951) 738-2010, e-mail: hemant@jaycopanels.com, *www.jaycopanels.com*

JACK BROWNE | Technical Contributor

Signal-Analysis Software
Helps Radar Development

The latest version of X-COM's signal-analysis software teams with the company's signal recorders to provide close study of signals of interest within a wide capture range.

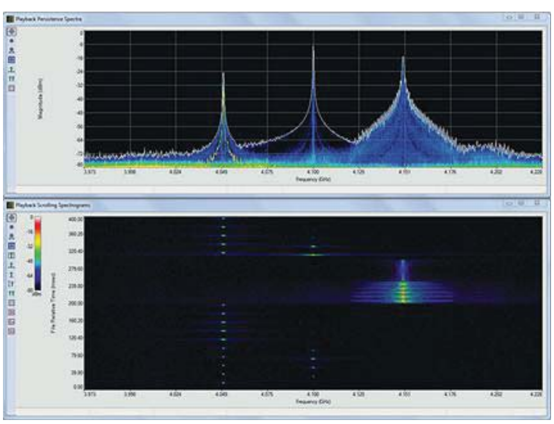
SIGNAL ANALYSIS is a grueling but necessary part of the design of many defense electronic systems, including radar, electronic-intelligence (ELINT), and signal-intelligence (SIGINT) systems. Fortunately, the latest version of Spectro-X signal-analysis software from X-COM Systems LLC removes a great deal of the tedium in finding and identifying signals across wide instantaneous bandwidths.

The Windows-based software works with signal data files from the firm's high-performance signal record/playback systems or other signal-capture sources. Users can quickly find and dissect signals of interest—precisely identifying them in frequency and time—as needed.

Spectro-X software features improved pulse analysis and waveform search capabilities along with advanced filtering functions that help screen signal data files for particular signal characteristics. For example, the software can simultaneously analyze as many as four captured-signal data files for specific signals from among thousands of emitters, with precision of ±1 sample.

Spectro-X works with signal data files saved by wideband instruments, such as X-COM's IQC5000B series or model IQC91000A signal record and playback systems. It can also scrutinize modeled or simulated data from commercial simulation software, such as MATLAB from MathWorks (www.mathworks.com), to identify signal events.

The software's toolkit contains signal search engines for carrier, arbitrary waveform, and pulse search functions. Signals can be searched relative to time, frequency, or both, with results displayed graphically *(see figure)*. The software provides the functionality to search and locate signals without need of additional programming; it can save portions of large files into formats usable by commercial measurement equipment for further demodulation and study.



The Spectro-X signal-analysis toolkit provides flexible graphical capabilities to show a signal of interest in frequency and time for close-in study.

When using the pulse search functions in Spectro-X, pulse waveforms can be characterized by carrier frequency—as well as by key pulse-specific parameters, such as pulse width, pulse repetition frequency (PRF), rise/fall time, and peak/average power. This latest version of Spectro-X software uses the 3-dB points (from peak amplitude) to define a pulse location and provide consistent, industry-accepted characterization of a pulse. It also performs computation of pulse frequencies at five points within each pulse to determine the pulse type or whether it is a modulated signal. To help with pulse/modulated-signal definitions, phase transitions are included in the pulse-signal results.

When four different signal files are being analyzed, they can be aligned in time to facilitate comparisons, or else offset in time and labeled with markers to study (for example, the performance of a radar system design under a number of different operating conditions or environments). As an aid to working with multiple signal files, X-COM also offers graphical RF Signal Editor software when it is necessary to edit or make modifications to modeled or captured signal files.

The improved signal-analysis software includes advanced functions to search for a waveform of interest within a single file, or within all files in a directory. The software can step in frequency to locate matches over a range of frequencies, and exclude unwanted frequencies from a signal data file. A highly selective filter is also part of the software.

The software boasts versatile windowing and zooming functions to provide closer looks at signals of interest. In addition, an arbitrary waveform search function provides a search through multiple waveforms based on a particular waveform characteristic or relative to a reference waveform. Similarly, certain known reference waveforms, such as commercial wireless signals, can be disregarded during a search when looking for particular signal traits.

Together with the company's signal/spectrum recording and playback instruments, which permit capture of broadband over-the-air signals, the signal-analysis software helps to speed and simplify a task that can be quite time-consuming and nerve-wracking. The firm is offering a 30-day trial version of the Spectro-X software on its website. de

X-COM SYSTEMS LLC (a subsidiary of Bird Technologies), 12345-B Sunrise Valley Dr., Reston, VA 20191; (703) 390-1087, *www.xcomsystems.com*

HEMT Amplifier Boosts DC to 7 GHz

MODEL CMA-84+ is a broadband InGaP high-electron-mobility-transistor (HEMT) 50-Ω amplifier suitable for commercial and military applications from dc to 7 GHz. Supplied in a compact low-temperature-cofired-ceramic (LTCC) surface-mount-technology (SMT) package, the amplifier achieves 24-dB typical gain at 100 MHz and better than 10-dB gain at 7 GHz. It offers +21 dBm output power at 1-dB compression at 100 MHz with a third-order-intercept point (IP3) of typically +38 dBm at 100 MHz. Equipped with patented transient protection, the amplifier has better than 16-dB input return loss across the full frequency range. It features an operating temperature range of –45 to +85ºC.

MINI-CIRCUITS

P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500, *www.minicircuits.com*

Reliable DRAM Handles the Heat

SUITABLE FOR USE in automotive, avionic, aerospace, and military applications, a line of memory components is designed to operate reliably at temperatures as high as +125°C. These dynamic-random-access-memory (DRAM) components avoid the memory loss due to energy leakage at higher temperatures that can plague conventional memory components. The DRAM components draw upon error-correction code to minimize the number of refresh-rate cycles and minimize power consumption. They are rated for operating temperatures from –40 to +125°C. Components include DDR1, DDR2, and DDR3 DRAMs with as much as 1 GB memory.

INTELLIGENT MEMORY

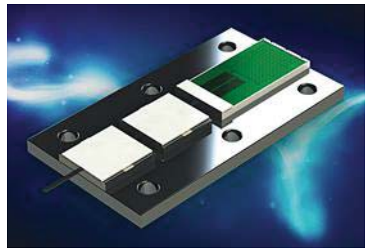
(852) 2422-0422, e-mail: info@intelligentmemory.com, *www.intelligentmemory.com*

Handheld Unit Performs Flightline Testing

PACKED INTO A PORTABLE "beer-can"-shaped housing, the model MTS-3060 SmartCan flightline tester simulates major electronic functions (like audio and video) of bombs, rockets, and missiles, including the latest "smart" weapons systems. The tester can evaluate alternate mission equipment (AME), including pylons, launchers, bomb racks, and pods. It provides stimulus and analysis functions with multiple measurement channels, dedicated and continuous squib circuit monitoring, multiple load channels, audio and video simulation, and support for testing MIL-STD-1760 smart weapons systems. It includes high-voltage ac and dc voltage testing channels and can analyze levels to 400 V. The SmartCan features an innovative power-management system to operate for 24 hours or more on standard AA batteries.

MARVIN TEST SYSTEMS INC.

1770 Kettering, Irvine, CA 92614; (888) 837-8297, (949) 263-2222, *www.marvintest.com*



Termination Tackles 1750 W to 1 GHz

DESIGNED FOR high-power signal management in radar and broadcast applications, model T50R0-1750-1X is a RoHS-compliant termination capable of handling power levels to 1750 W across a bandwidth of dc to 1 GHz. Fabricated from thick film on beryllium oxide (BeO) substrate material, the termination is rated for operating temperatures from –55 to +150ºC. The rugged termination achieves 20 dB or better typical return loss across the full bandwidth. It has a footprint of 2.25 × 1.25 in (57.15 × 31.75 mm).

BARRY INDUSTRIES

60 Walton St., Attleboro, MA 02703; (508) 226-3350, e-mail: sales@barryind.com, *www.barryind.com*

Wideband Amplifier Boosts GPS Systems

MODEL ML1590/BGA, a wideband amplifier suitable for navigation instrumentation and Global Positioning System (GPS) applications, continues to be available as National Stock Number (NSN) 5962-01-280-2203. Originally designed and built by Motorola/Freescale Semiconductor, the amplifier is supplied in eight-lead metal cans to Standard Microcircuit Drawing (SMD) 5962-876570. It is designed for use from –55 to +125ºC.

LANSDALE SEMICONDUCTOR INC.

5245 South 39th St., Phoenix, AZ 85040-9008; (480) 773-6844, *www.lansdale.com*

TTL Phase Shifters Tune 360 Deg. to 37 GHz

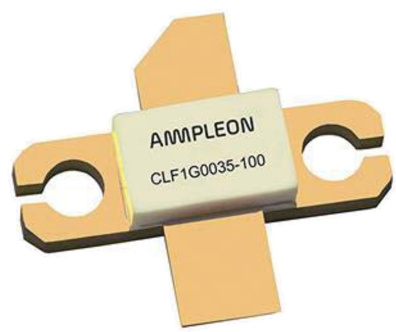
A SERIES OF 8-b digital phase shifters are programmable over a full 360-deg. range with 255 total steps in 1.4-deg. increments. Available for frequency coverage from 0.5 to 37.0 GHz, the phase shifters feature a transistor-transistor-logic (TTL) interface. Ideal for defense and electronic-warfare (EW) applications, the phase shifters can handle CW power levels to +30 dBm (1 W). They exhibit phase-shift errors ranging from ±0.9 to ±5.0 deg. They are equipped with field-replaceable SMA or 2.92-mm coaxial connectors, depending on frequency range. All models are designed to meet MIL-STD-202F conditions for temperature cycle, humidity, shock, altitude, and vibration.

PASTERNACK ENTERPRISES INC.

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

GaN Power Transistors Deliver Levels to 100 W

A LINE OF GALLIUM-NITRIDE (GaN) power transistors has been expanded to include discrete devices capable of output levels of 10, 30, 50, and 100 W for use through S-band frequencies. Based on a 0.5-µm high-electron-mobility-transistor (HEMT) process, the power transistors are supplied in push-pull thermally stable ceramic packages for ease of circuit installation. They are designed for broadband performance, meeting specific requirements of size, weight, and power (SWaP) in aerospace, defense, and radar applications. For example, model CLF1G0035S-50 provides 50-W output power from dc to 3.5 GHz when operating from a +50-V dc supply.



AMPLEON

Building BY 3.088, Gerstweg 2, 6534 AE Nijmegen, the Netherlands; (31) 6 208 14 771, e-mail: natascha.jellema@ampleon.com, *www.ampleon.com*

Power Divider Splits Clock Signals

THE WMPD08-0.01-X SERIES power divider/combiner is a laboratory-grade component capable of producing multiple synchronized clock signals from a single 10-MHz clock oscillator for use with test equipment. The divider/combiner features low insertion loss of 0.6 dB and high isolation of at least 22 dB, reaching as high as 35 dB between ports. It achieves amplitude balance of better than 0.1 dB for all ports and phase balance within 1 deg. or better for all ports. The maximum VSWR is 1.25:1. The power divider/combiner can be customized with a choice of BNC, Type-N, or SMA female coaxial connectors.

WERBEL MICROWAVE LLC

51 Chestnut Street, Livingston NJ 07039; (973) 900-2480, *www.werbelmicrowave.com*

DAU Developed for Flight Testing

A NEXT-GENERATION DATA-ACQUISITION unit (DAU) has been developed for flight test applications. Optimized for size, weight, and power (SWaP), the modular Axon DAU works with the firm's Acra KAM-500 DAU chassis while reducing volume by 55% and weight by 70% compared to traditional data-acquisition systems. Suitable for flight-test instruments, airborne telemetry, and flight-data monitoring, the DAU features a serial backplane with 1 Gb/s per module acquisition speed. The housings for the modules, which can be placed as far as 20 m from the chassis, are less than 8 cubic inches in volume. The Axon DAU is configured using the company's DAS Studio setup software.

CURTISS-WRIGHT CORP.

13925 Ballantyne Corporate Pl., Ste. 400, Charlotte, NC 28277; (707) 869-4600, e-mail: info@curtisswright.com, *www.curtisswright.com*

Connectors, Cables Simplify Mating

A LINE OF anti-torque stainless-steel SMA connectors and cable assemblies allow a user to hold the connector body with one wrench while simultaneously tightening a coupling nut to its mating connector with another. The connectors are compatible with 0.085- and 0.141-in.-diameter coaxial cables and can be supplied as part of cable assemblies with standard lengths of 6 through 36 in., as well as in custom lengths. The anti-torque stainless-steel connectors exhibit low loss from dc to 18 GHz for a wide range of broadband applications.

AMPHENOL RF

4 Old Newtown Rd., Danbury, CT 06810; (203) 796-2165, *www.amphenolrf.com*

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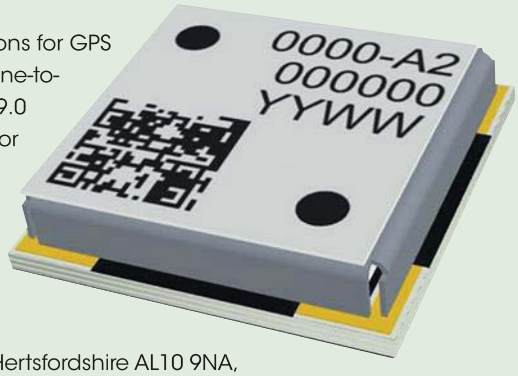
Antenna Modules Grab GPS and GNSS

A PAIR OF ANTENNA/RECEIVER MODULES serves as drop-in solutions for GPS and GNSS receiver functions in Internet of Things (IoT) and machine-to-machine (M2M) wireless applications. The SMT devices measure 9.0 × 9.0 × 1.8 mm with low current consumption. Model M10578-A2 for GPS applications operates on supplies from 2.8 to 4.2 V dc with out-of-band rejection of unwanted signals ranging from 43 to 54 dB. Model M10578-A3 for GPS, GLONASS, BEIDOU, and Galileo applications is housed in a similar package with the same compact footprint, including an LNA and temperature-compensated crystal oscillator (TCXO).



ANTENOVA LTD., 2nd Floor, Titan Court, 3 Bishop Square, Hatfield, Hertfordshire AL10 9NA, United Kingdom; +44 (0) 1223 810600; e-mail: sales@antenova-m2m.com; *www.antenova-m2m.com*

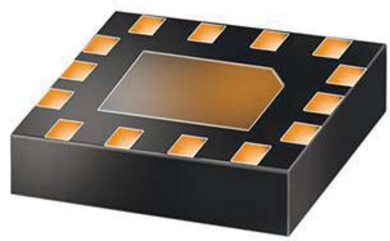
Power Amp Module Pushes 50 W to 18 GHz

BROADBAND POWER AMPLIFIER MODULE model BME69189-50 boasts 50 W or more of output power from 6 to 18 GHz. The Class-AB linear amplifier module has an RF input overdrive level of +10 dBm and typical gain of 47 dB. The gain flatness is ±4 dB at 40-W output power with output load VSWR of 2.0:1 at full power. The linear-amplifier module exhibits low noise, with better than –60-dBc spurious content, better than –15-dBc second harmonics, and better than –25-dBc third harmonics. The noise power output is –105 dBm/Hz. The amplifier module achieves dc-to-RF efficiency of typically 14% or more from a +28-V dc supply, with less than 15-W power consumption in standby mode. It requires less than 1 μs under TTL control to switch on from standby mode. The compact amplifier module is equipped with a 7-pin Combo D dc/control connector and field-replaceable female SMA input and output connectors. It measures 6.56 × 3.50 × 0.84 in., weighs 1.5 lb., and handles operating temperatures from –40 to +55°C.

COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900; *www.comtechpst.com*

Switch Controls 5 to 2,000 MHz

MODEL JSW4-23DR-75+ is a compact 75-Ω single-pole, four-throw switch with built-in CMOS driver well-suited



for cable-television (CATV) and test-system applications from 5 to 2,000 MHz. It handles 3 W power at 0.1-dB compression with low insertion loss of typically 0.7 dB at 1 GHz. The switch measures 2 × 2 × 0.55 mm in a 14-lead package with only 40-μA typical current consumption from a single supply of +2.5 to +4.8 V dc. The tiny SP4T switch achieves 38-dB typical isolation at 1 GHz and maintains a typical third-order intercept point of +59 dBm at 1 GHz.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500; *www.minicircuits.com*

Wilkinson Dividers Run 6 to 40 GHz

A LINE OF WILKINSON POWER DIVIDERS includes models with 2.92-mm connectors for use in bands from 6 to 40 GHz. Capable of handling 30-W power, these two-way power dividers are suitable for applications in telecommunications, aerospace, and test systems. The firm also offers resistive two-way power dividers with 2.92-mm connectors for use from dc to 26.5 GHz.

MECA ELECTRONICS INC., 459 E. Main St., Denville, NJ 07834; (973) 625-0733; *www.e-MECA.com*

Wideband Splitter Runs 350 to 6,200 MHz

WIDEBAND TWO-WAY, 0-DEG., POWER DIVIDER/COMBINER model Z2PD-622SMP+ handles power levels to 10 W from 350 to 6,200 MHz with low phase and amplitude unbalance. It features low 0.9-dB insertion loss across the frequency range with amplitude unbalance held to only 0.1 dB and phase unbalance with 2 deg. The two-way, 50-Ω power splitter/combiner is housed in an aluminum alloy case measuring 1.98 × 4.41 × 0.43 in. with SMP blind-mate snap-on coaxial connectors. It is designed for operating temperatures from –55 to +100°C. **MINI-CIRCUITS**, P.O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500, FAX: (718) 332-4661, *www.minicircuits.com*

Duplexer Divides 1,710 to 1,880 MHz

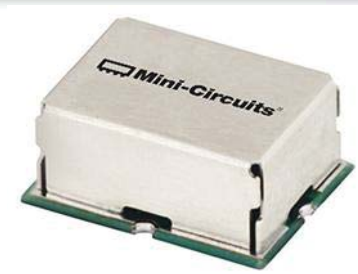
MODEL AD1747-1842D335 is a cavity duplexer designed for mobile communications infrastructure equipment, such as GSM systems. It screens receive signals from 1,710 to 1,785 and transmit signals from 1,805 to 1,880 MHz. The duplexer achieves better than 17-dB return loss and less than 1.2-dB insertion loss in both passbands. It is designed for a characteristic impedance of 50 Ω and achieves better than 50-dB isolation from out-of-band signals. Passband amplitude ripple is controlled to 0.8 dB or less. The robust device can handle 50-W CW power. The compact duplexer, which measures 97 × 74 × 40 mm, is supplied with female SMA connectors. **ANATECH ELECTRONICS INC.**, 70 Outwater Ln., Garfield, NJ 07026; (973) 772-4242; *www.anatechelectronics.com*

Coupler Directs 2.6 to 7.0 GHz

COAXIAL DIRECTIONAL COUPLER model ZADC-13-73+ offers 13-dB coupling with flat coupling characteristics (±1.2 dB) from 2.6 to 7.0 GHz. It handles as much as 4-W CW input power with low mainline insertion loss of 0.8 dB and low VSWR of 1.20:1. Typical directivity is 18 dB. The rugged directional coupler is housed in an aluminum-alloy case measuring just 2.0 × 2.0 × 0.75 in. with SMA connectors. The RoHS-compliant coupler can pass as much as 1 A of dc current and is designed for operating temperatures from –55 to +100°C. **MINI-CIRCUITS**, P. O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500; *www.minicircuits.com*

Flexible Waveguide Connects Up to 40 GHz

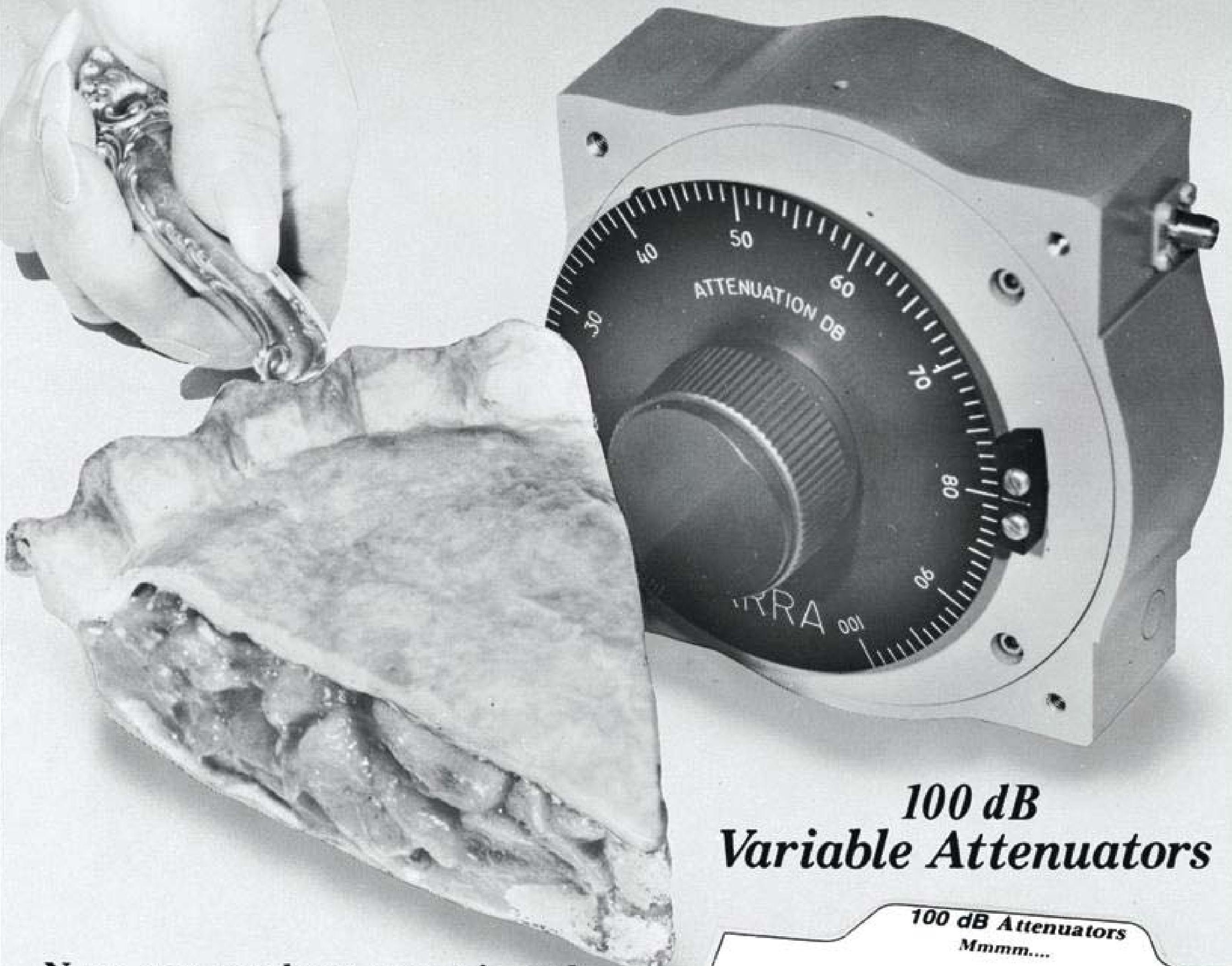
FLEXIBLE/TWISTABLE WAVEGUIDE SECTIONS are available in rectangular waveguide (WR) sizes from WR-137 to WR-28 for use through 40 GHz. These "flexguide" transmission lines employ helically wound, silver-coated brass strips surrounded by a flexible, durable neoprene sleeve and terminated with brass flanges. Insertion loss is as low as 0.07 dB while typical VSWR ranges from 1.05:1 to 1.35:1. The waveguides are available in standard lengths, including 12, 24, and 36 in. **PASTERNACK ENTERPRISES INC.**, 17802 Fitch, Irvine, CA 92614; (866) 727-8376, (949) 261-1920; *www.pasternack.com*



Surface-Mount Mixer Translates 10 to 2,500 MHz

BUILT FOR HARSH OPERATING ENVIRONMENTS, model SYM-R352HW+ is a surface-mount-technology (SMT) frequency mixer capable of broadband frequency translation with low loss. It operates with RF and local-oscillator (LO) frequencies from 10 to 2,500 MHz and provides an intermediate-frequency range of 10 to 500 MHz. With 6.5-dB typical conversion loss, the Schottky-diode-based triple-balanced mixer is designed for +17-dBm LO power. The RoHS-compliant mixer achieves typical third-order intercept point (IP3) of +23 dBm and exhibits 40-dB isolation between ports. The hermetic ceramic quad mixer measures 0.38 × 0.50 × 0.23 in. and is well-suited for cellular infrastructure applications where printed-circuit-board (PCB) real estate is scarce. It handles operating temperatures from –40 to +85°C. **MINI-CIRCUITS**, P. O. Box 350166, Brooklyn, NY 11235-003; (718) 934-4500; *www.minicircuits.com*

Get a piece of the ARRA pie...



100 dB Variable Attenuators

100 dB Attenuators
Mmmm....

Freq Range	Atten vs Freq ·dB	Model #
500 - 1000 MHz	1.5	2952 - 100
900 - 1300 MHz	0.75	2-3952 - 100
1000 - 2000 MHz	1.5	3952 - 100X
2000 - 4000 MHz	1.5	4952 - 100 X
4000 - 8000 MHz	1.5	5952 - 100X

Insertion loss - 6 dB

VSWR - 1.5

Power - 15 cw

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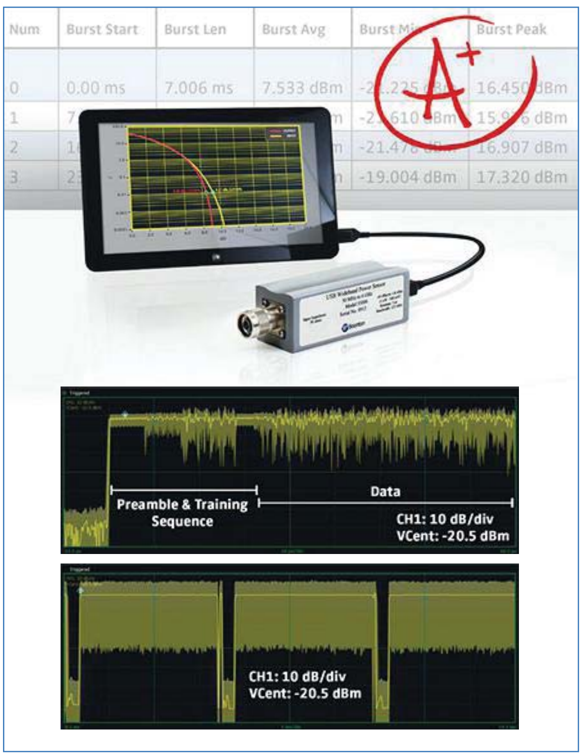

The 55 Series USB Peak Power Sensor

Real-Time Power Measurements for Complex Communications Signals

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