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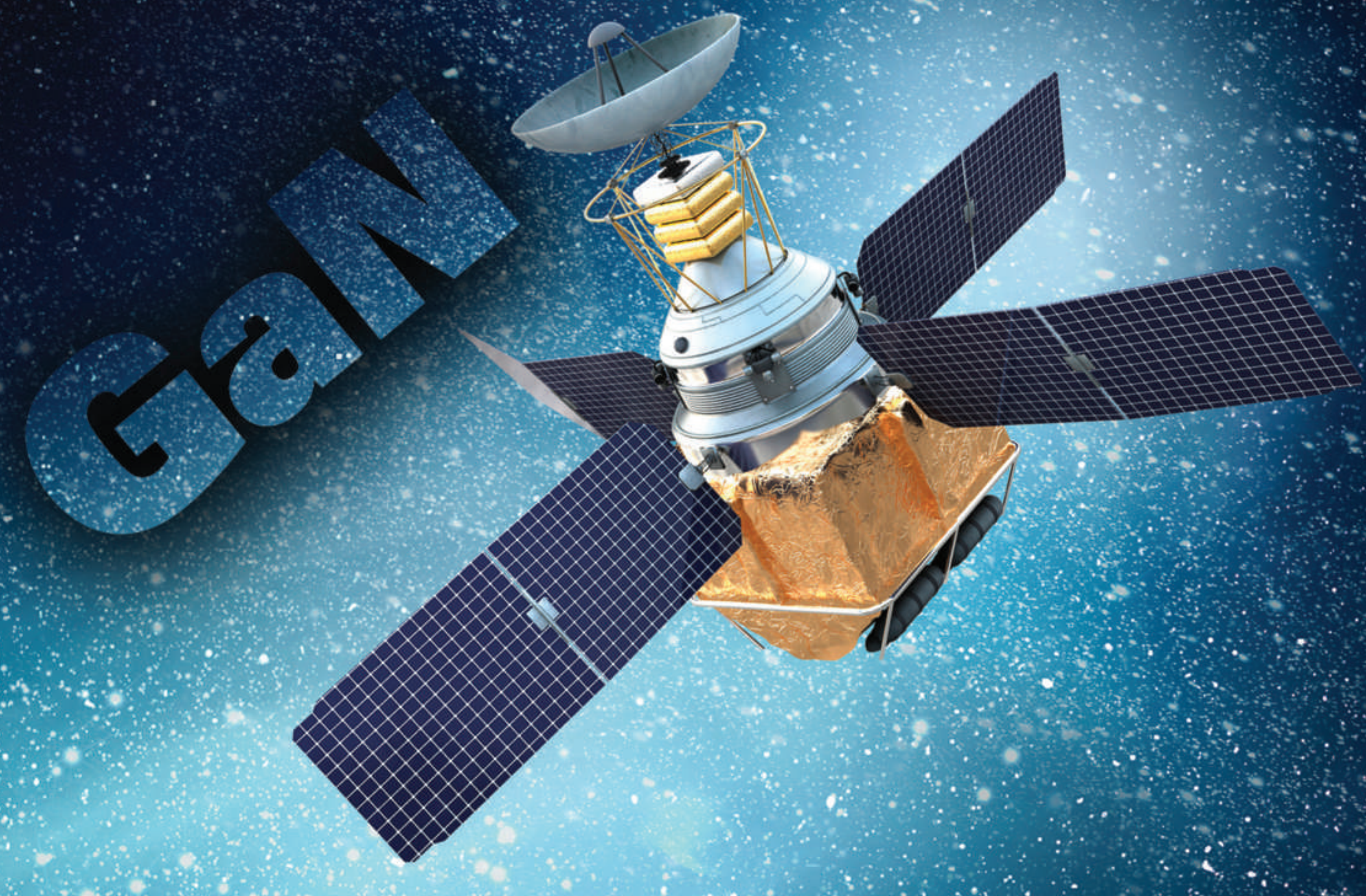

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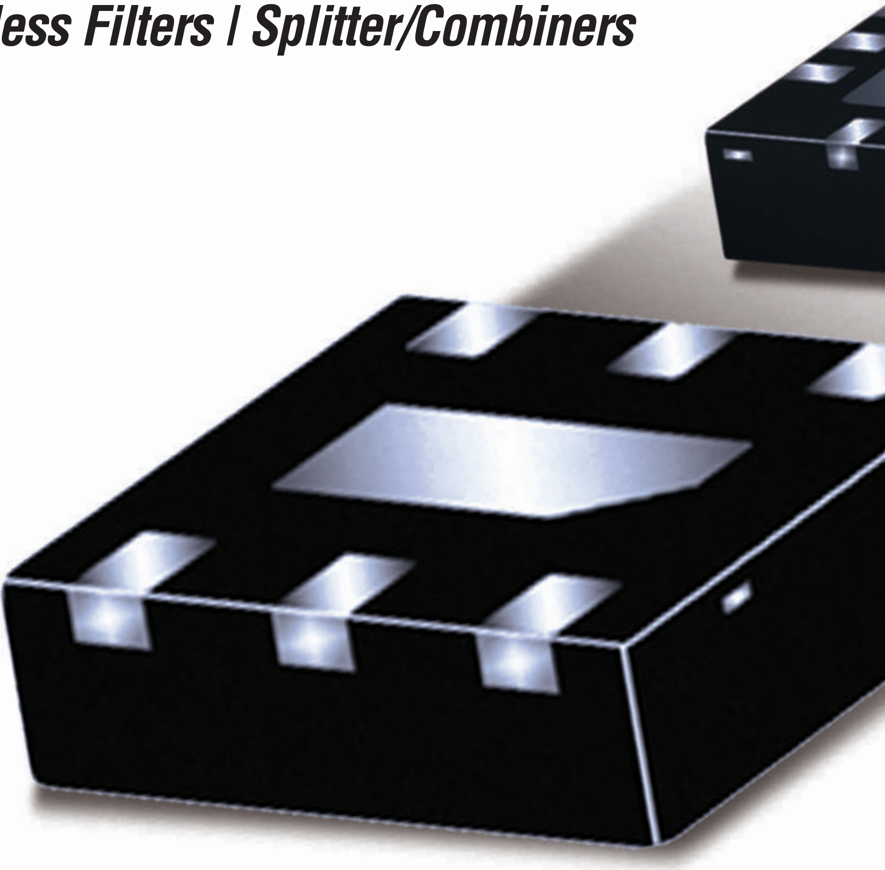

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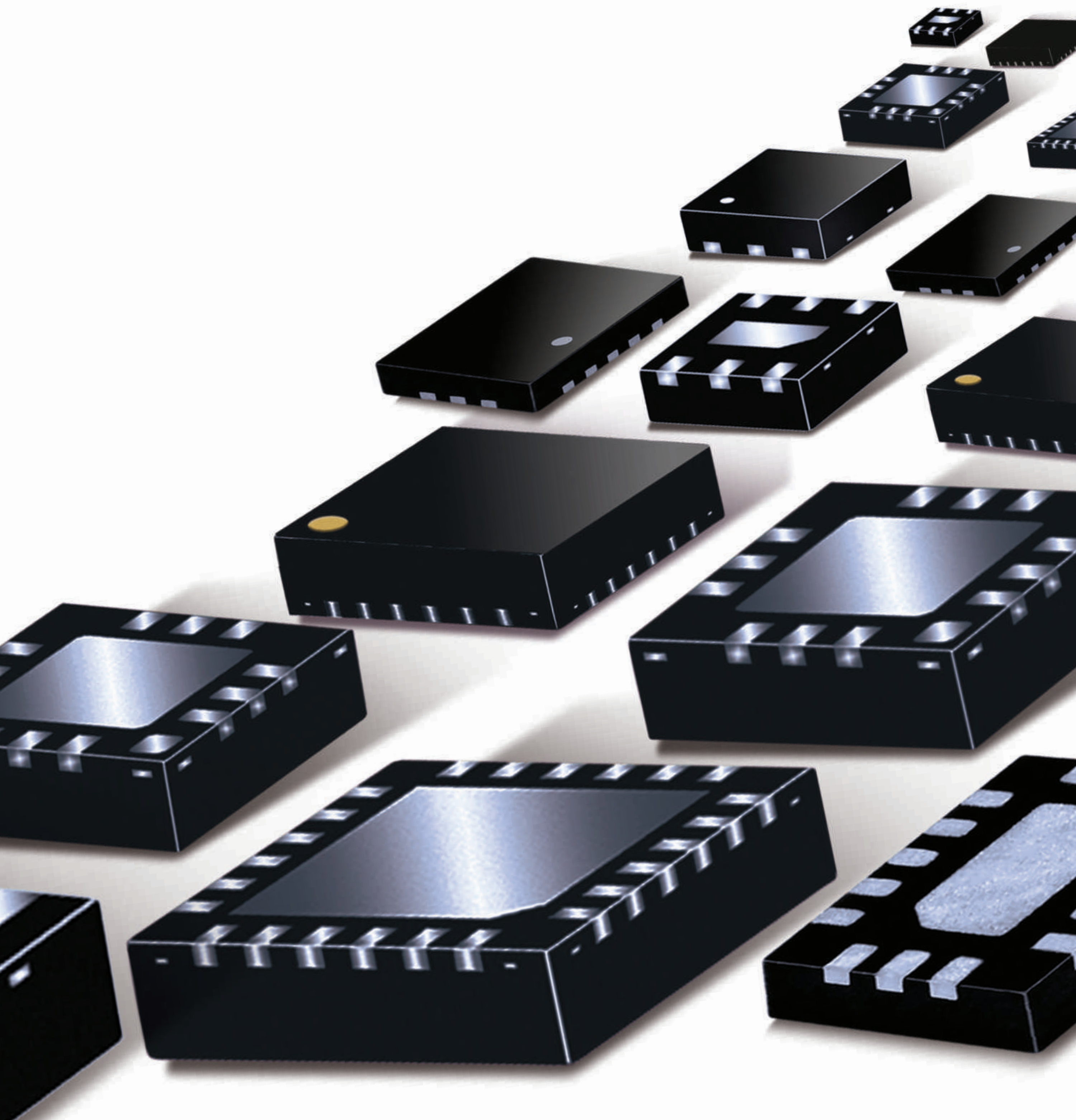

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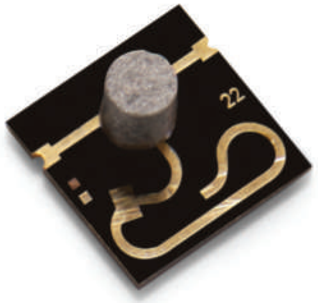

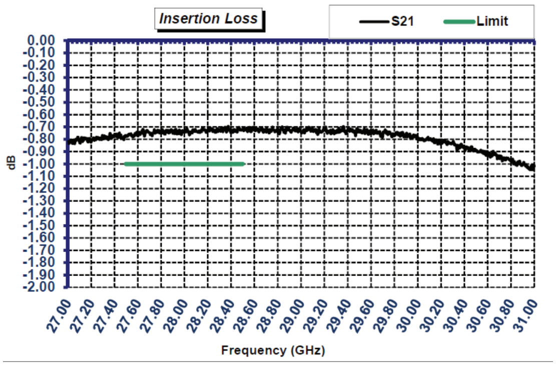

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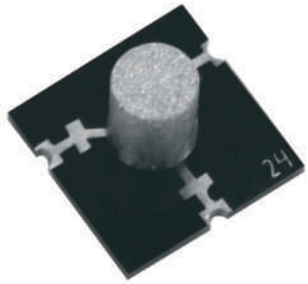

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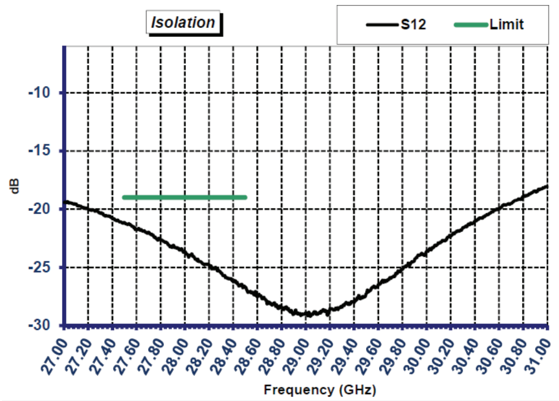


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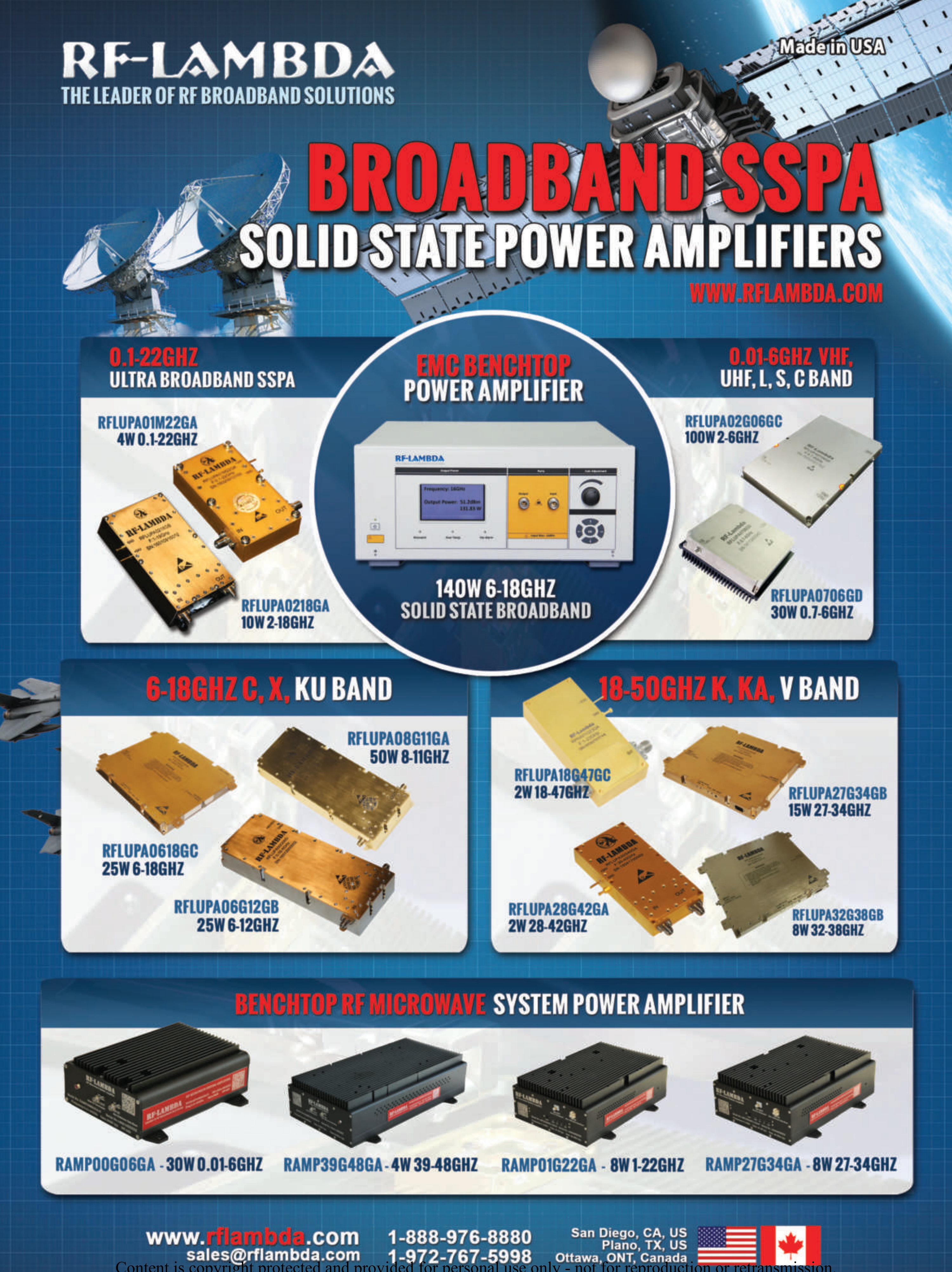
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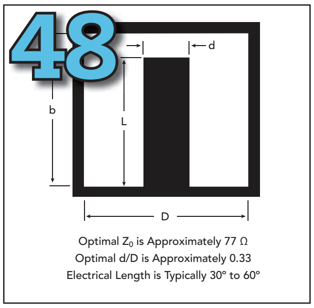

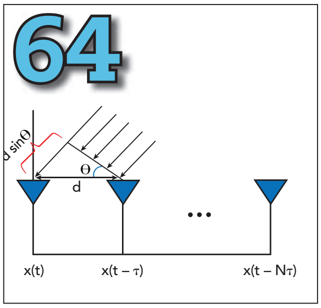

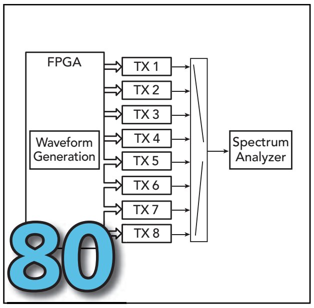

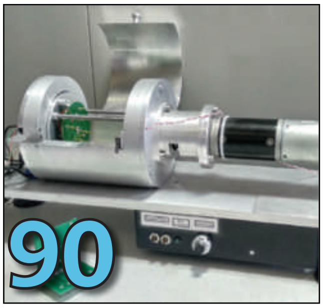

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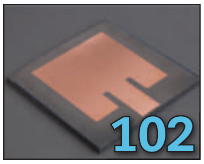

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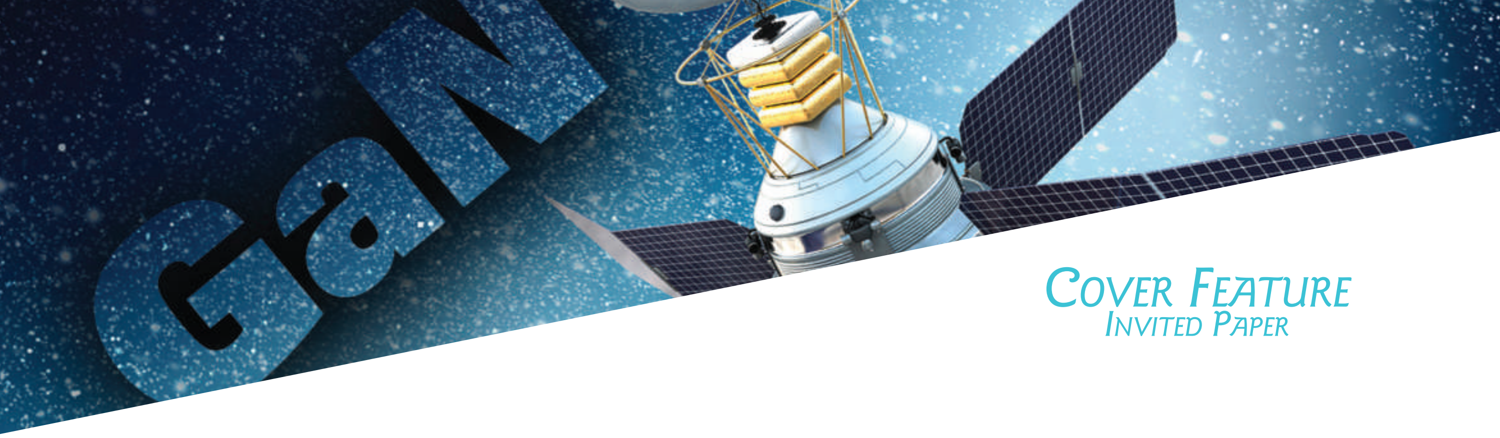

GaN SSPA Technology for Space-Based Applications

Mario LaMarche
Mercury Systems, San Jose, Calif.

Few technology applications are positioned to benefit from high-power RF GaN device insertion to the extent as space payloads. Costing roughly $10,000 per pound of payload to launch a satellite into space, the benefit of small, lightweight hardware is obvious. The trend toward low Earth orbit (LEO) satellite constellations is increasing the pressure to develop cost-saving technologies. While GaN is well-positioned to deliver these benefits, its use is not without challenges. To maximize the mean time between failures (MTBF), the thermal conduction path away from the device must be carefully designed. As an added challenge, the lack of industry heritage using GaN in space requires thorough analysis and additional qualification testing.

GaN is a III-V direct bandgap semiconductor. Similar to GaAs, its high electron mobility makes it well-suited for RF/microwave applications. Compared to GaAs, the wider bandgap of GaN—3.4 vs. 1.4 eV for GaAs—enables operation at very high-power densities. Instead of using bulky combining networks to sum the power of many GaAs devices, a small number of GaN devices will efficiently produce high output power. As GaN technology continues to mature (see ***Figure 1***), it is replacing some traveling wave tube (TWT) amplifiers, which have been the primary technology for satellite power amplifiers for years.

SATELLITE AMPLIFIER TECHNOLOGY

As with nearly all communications systems, satellite transponders include transmit and receive modules. In the traditional architecture, the uplink signal is passed through a low noise amplifier to a frequency converter, then to the transmit module. Amplifying the signal to the required output level is typically the role of a TWT amplifier. While tube amplifiers produce high-power at Ka-Band, their large size and high-cost are challenging, especially evident with the new generation of LEO satellites. Since these satellites must be smaller and less expensive than traditional satellites, relying on expensive and large TWT amplifiers is problematic.

TWTs amplify RF signals through the interaction between an electron beam and the RF signal. While this is an efficient method for generating high output power, TWT amplifiers are inherently complex assemblies, requiring the mechanical integration of multiple, high-precision components. This complexity drives the high price of TWTs and increases the risk of failure. TWT amplifiers also require very high bias voltage—usually thousands of volts—generated by a high voltage supply, which is also large and expensive. As a rough order-of-magnitude, the size of a Ka-Band TWT amplifier with 500 W output power is about 18 in. × 3 in. × 3 in., with

▲ **Fig. 1** **Increasingly used in radar, EW and communications application, GaN power amplifiers offer size, weight and power benefits for satellites.**

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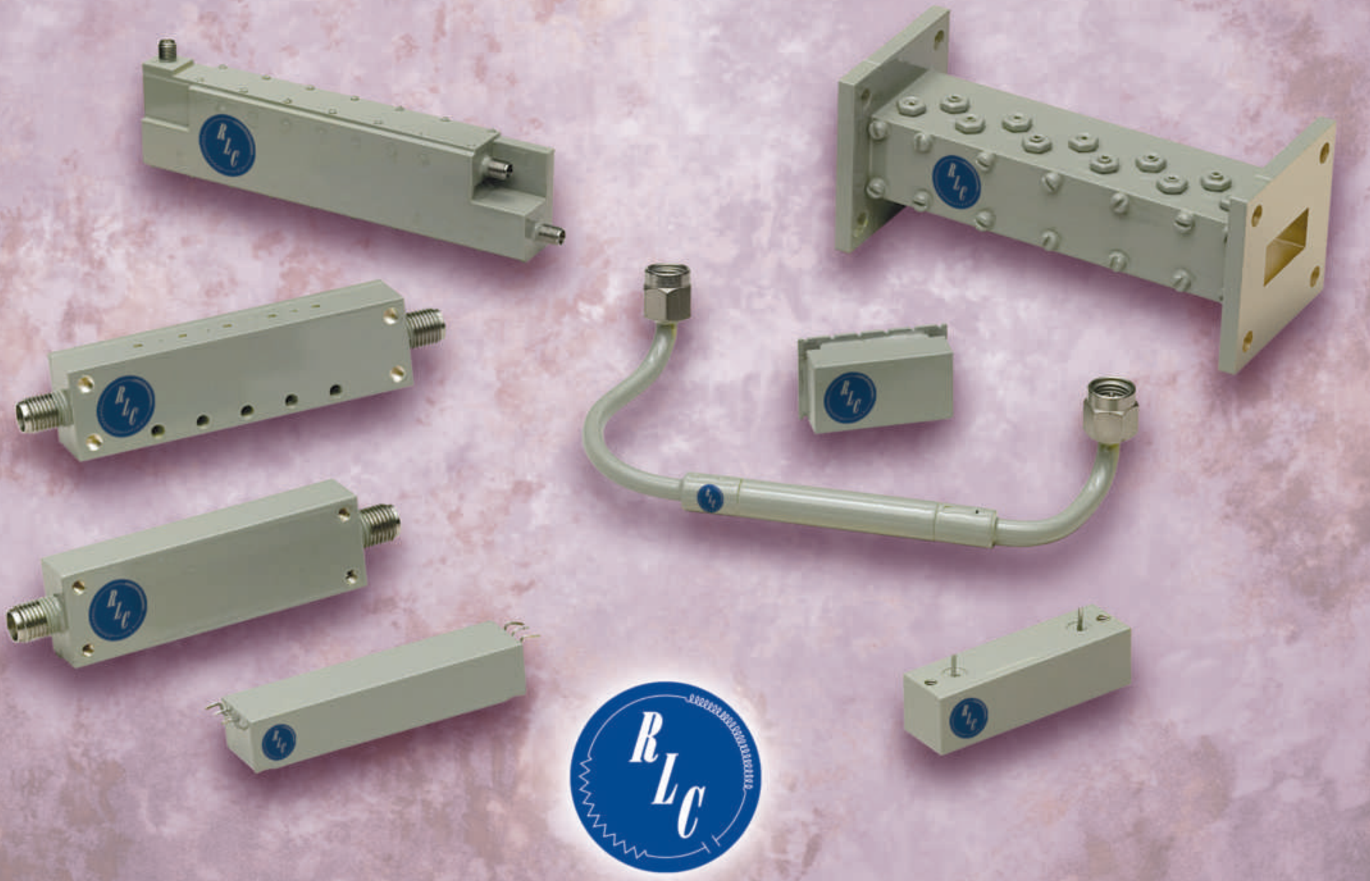

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an equally large power supply. Not only does the large size of the TWT amplifier restrict its use in LEO satellites, even traditional satellites have strict size and weight limits on their payload systems and will benefit from smaller components.

A solid-state solution offers a more robust, compact option. A GaN power amplifier uses standard IC manufacturing processes, producing small devices only a few millimeters on each side. Instead of using artisan-style manufacturing, GaN devices are produced using automated semiconductor processes at low-cost. While a single GaN device is unable to deliver the same output power as a TWT amplifier, multiple GaN devices can be combined in a small package. As an added benefit, GaN amplifiers only require bias voltages of 28 to 50 V.

Given the differences between GaN and TWT amplifiers, GaN is particularly attractive for applications sensitive to size, weight and cost, as well as those that require less transmit power. This precisely describes LEO satellites.

CHALLENGES OF GaN IN SPACE

While GaN amplifiers offer compelling benefits for satellite applications, specific challenges must be overcome to successfully use GaN in space-qualified hardware. The first and most obvious challenge arises from the high power density of the device. While TWT amplifiers also require a complex cooling system, a GaN IC generates significant heat in a very small space. For example, a 30 W solid-state GaN amplifier can easily draw 2.5 A biased at 28 V, resulting in 40 W power dissipation in an area not much larger than 10 mm^2. If the thermal transfer is inadequate to cool the device, the elevated junction temperature will lower output power and reduce MTBF—possibly even causing catastrophic failure.

This raises the second challenge: reliability. The high-power dissipation common with GaN devices results in a significant temperature rise in the active region; as the temperature in the device increases, the reliability of the amplifier degrades. The temperature rise depends on the power dissipation in the GaN and the thermal resistance between the device and the case—both difficult to model and control. Power dissipation depends on multiple factors such as RF drive and load impedance, and the thermal resistance is highly dependent on minor variations in the assembly process.

Even under ideal circumstances, where the temperature is carefully controlled, high RF drive levels can cause permanent damage to the GaN lattice, resulting in degraded output power. Compared to GaAs, GaN is a much newer technology, and the lack of heritage raises reliability concerns. While this applies to all applications using GaN, operating in a space environment requires an extra focus to assure reliability. Since repair is generally not an option, a single device failure can be extremely expensive.

The design of the GaN ICs and amplifier modules is also a challenge, especially for space-based applications requiring custom de-

signs for specific programs, rather than using standard, off-the-shelf products. One critical element to first-pass design success is accurate device modeling. Since even class A amplifier design requires nonlinear models, modeling a GaN amplifier is considerably more complex than simply using an S-parameter file.

This discussion highlights several key challenges to implement GaN technology in space-qualified power amplifiers. Addressing these requires multi-disciplinary expertise including, RF design, mechanical design, manufacturing and quality. The following sections discuss possible approaches to managing these challenges.

GaN AMPLIFIER THERMAL MANAGEMENT

The high power density in GaN semiconductors presents a major thermal management challenge. Pulling the heat away from the active region of the device is critical to maximizing the output power and reliability. Starting with the bare die, proper thermal management requires an optimal die attach process. Since even a small increase in thermal resistance results in a significant temperature rise, use of a high thermal conductivity material for die attach is critical. For example, using a gold-tin eutectic die attach process provides much better thermal conductivity than silver epoxy. However, achieving good die attach with high thermal conductivity requires more than simply choosing the correct material. The process must be carefully controlled. Since even small air voids under the die can greatly increase thermal resistance, they must be minimized, which requires experience, careful process control and techniques such as performing die attach in a vacuum. Validating die attach is also critical to ensuring proper heat transfer. This can be accomplished using scanning acoustic microscopy (C-SAM), which identifies voids between the die and the thermal spreader or baseplate.

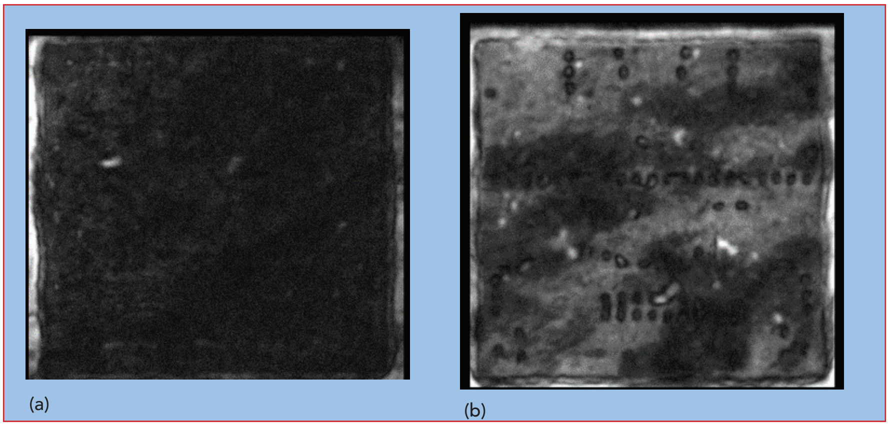

Fig. 2 C-SAM images showing GaN die attach with largely void-free solder coverage (a) and excessive voiding (b).

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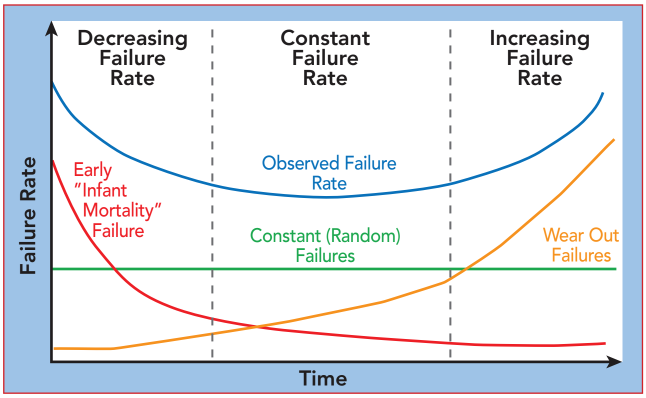

Fig. 3 Reliability bathtub curve. Source: Wikimedia.

Figure 2 shows typical C-SAM images of die attachment, comparing with good solder coverage and excessive voids.

The thermal conductivity of the baseplate material holding the die must also be maximized. For lower power applications, die is often installed on a Kovar™ baseplate, chosen because of its matched coefficient of thermal expansion (CTE). However, when thermal conduction is critical, a material such as copper molybdenum (CuMo) is a better choice. The process of choosing materials to optimize the thermal conductivity of each interface continues through the entire design, from device to system packaging.

While this thermal design approach is used for GaN amplifier designs regardless of application, it is particularly important for space-qualified hardware. The size and weight constraints common to space programs increase power density by limiting the volume, while the reliability requirements for space operation require maximum cooling of the active devices.

GaN RELIABILITY

Reliability is often characterized by the failure rate versus time, which often looks like a "bathtub" and has been called the "bathtub curve" (see ***Figure 3***). Typically, the majority of failures occur early in the product's life or after considerable use. Early failures are usually caused by a manufacturing defect, either during device fabrication or subsequent assembly. On the other side of the graph, the uptick in failures represents the device wearing out near the end of its lifetime. To optimize and assure reliability, each of these failure types must be considered.

In the case of GaN, early failures are reduced through manufacturing process control, wafer screening and burn-in. Process control includes repeatable die attach, discussed above, and control of all aspects of the manufacturing process. Clear documentation and operator training are critical, as well as environmental controls, such as reducing the risk for damage caused by electrostatic discharge (ESD). With minimal performance variation across a GaN wafer, sample testing

can be used to qualify a wafer, improving confidence in the device's reliability before committing the devices from a wafer to assembly. Depending on the program, wafer screening may require accelerated life testing and destructive physical analysis. The risk of early failure can be reduced further through 100 percent burn-in screening. Using burn-in, amplifiers are biased and placed in an oven at elevated temperature for a specified time to stress the active devices. Burn-in screening will weed out the early failures, reducing the probability of failure in the field.

To quantify the length of operational time before wear-out failures occur, the MTBF of the amplifier is calculated. This calculation uses multiple factors such as device temperature, bias and environmental conditions and is based on empirical data from accelerated life testing. To maximize the MTBF, the device cooling must be optimized, as described earlier.

While the radiation encountered in space creates another reliability risk, the high molecular bond strength of GaN results in a higher radiation tolerance than GaAs and silicon.

CUSTOM GaN AMPLIFIER DESIGN

Since space missions usually require amplifiers with unique frequencies, bandwidths, output power and reliability, they usually require custom designs rather than off-the-shelf products. Since the production volumes are typically low, the cost of the development must be minimized as well as the unit cost, to keep the total program cost low. One of the best ways to reduce design time and cost is to improve first-pass success, which requires accurate device modeling.

Nonlinear device modeling for power amplifier design is always a challenge; since GaN is a newer technology, its models are less mature. To address this lack of accurate models, the design engineer has several options:

- Rely on measured load-pull data to determine the ideal output impedance match to optimize the RF power.
- Through experience, adjust the simulation models to improve the accuracy for the specific design conditions.
- Substitute a measured, small-signal S-parameter file for the nonlinear model to confirm similar results for linear operation.

SUMMARY

Satellite applications will clearly benefit from space-qualified GaN power amplifiers, which offer size, weight and thermal benefits over TWT amplifiers. However, producing GaN power amplifiers is challenging, particularly with the lack of space heritage. Successful insertion requires experience with both the electrical and mechanical aspects of GaN amplifier design, complementing space quality levels and requirements such as MIL-PRF-38534 class K. For organizations with both competencies, space-qualified GaN technology offers exciting new market opportunities.■

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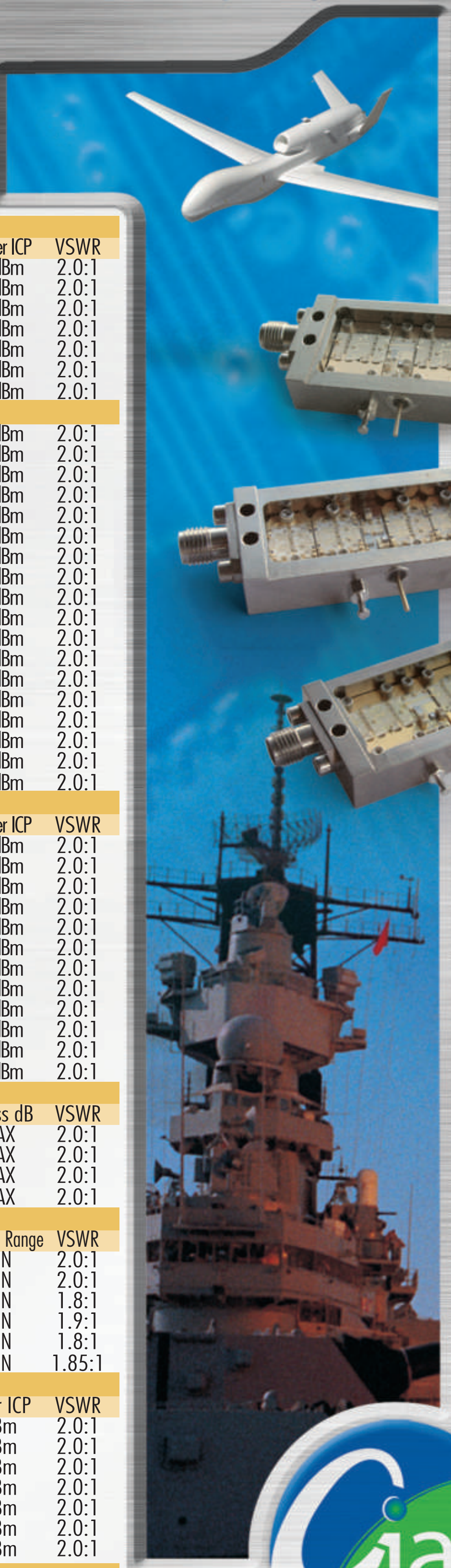

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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DefenseNews

Cliff Drubin, Associate Technical Editor

The MoD and Thales Create New Eyes for the Royal Netherlands Army

Together with operational specialists of the Royal Netherlands Army (RNLA), Thales has developed the Multi Mission Radar (MMR) for artillery, 4D air surveillance, air defence and security applications. Years of studies and testing have led to a contract between Thales and Defence Materiel Organisation (DMO), in which nine radar systems will be delivered to the RNLA.

Every second is critical during a mission. Therefore, extremely fast and flexible radar deployment, for observing all kind of hostile activities and actions, are of vital importance. The MMR, meeting all today's requirements for modern warfare, will be the new eyes of the Dutch armed forces. The MMR sees and records everything from RAM, UAV/UAS, aircraft, helicopters and cruise missiles easily and in real-time. Because of its simplicity and high degree of automation, the MMR is a time saver, from its first introduction during training, to installation on any type of vehicle as well as during its operational deployment and use. The MMR is deployable and ready for use within minutes, which makes it one of the most advanced systems in the market. It is the latest version of the Thales 4D AESA radar family.

The MMR is internationally marketed as GM200 MM/Compact, as a part of the Ground Master 200 family. The MMR makes a wide range of operational missions possible, ranging from air surveillance to weapon locating. In the role of "counter battery" the MMR can distinguish the individual tracks in a salvo firing. It is a "software defined" system, advanced and future-proof, keeping pace with changes in missions and threats.

According to Lieutenant General L.J.A. (Leo) Beulen, Commander of the Royal Netherlands Army, "Due to its unique true multi mission capability, the MMR will not only set the conditions for winning battles at long range through accurate target acquisition, it will also enhance the RNLA Air Defence capability by addressing the evolving air threat, including rocket, artillery and mortar and unmanned air systems."

MMR (Source: Thales)

MBDA Unveils the SPIMM: Self-Protection Module for Surface Ships

At Navdex 2019, MBDA introduced the SPIMM (Self-Protection Integrated Mistral Module), an all-in-one air defence module based on the SIMBAD-RC system and designed to equip ships of all types, particularly those without a combat system, such as supply ships.

The SPIMM module consists of a SIMBAD-RC automated naval turret equipped with two ready-to-fire Mistral missiles and a 360-degree infrared panoramic system to detect and track air and surface threats. The system is entirely controlled by two operators located in a shelter inside the module, which is also used to store four additional missiles. This ISO standard "all-in-one" module, 10 feet long and weighing some seven tons, can be easily positioned on the deck of a ship using a crane and requires just a standard electrical connection.

Designed to protect surface vessels against most conventional airborne threats—anti-ship missiles, combat aircraft, helicopters and UAVs—the SIMBAD-RC and Mistral demonstrated, at the end of last year, its ability to neutralize asymmetric threats such as Fast Inshore Attack Craft (FIAC) by day and by night.

"The SPIMM enables the urgent and rapid adaptation of supply vessels or landing platform docks to cope with new threats, or for using them in contested areas," says Naval Defence Systems Product Executive Christophe Leduc. "This system illustrates MBDA's ability to understand its customers' needs and to quickly come up with effective and functional solutions."

SPIMM (Source: MBDA)

Top 15 Small Satellite Companies Dominate Global Small Satellite Market

Satellites are typically classified on the basis of function, type of orbit, cost, size and so forth. The mass of these satellites generally refers to in-orbit fully-fuelled wet mass. The term "small satel-

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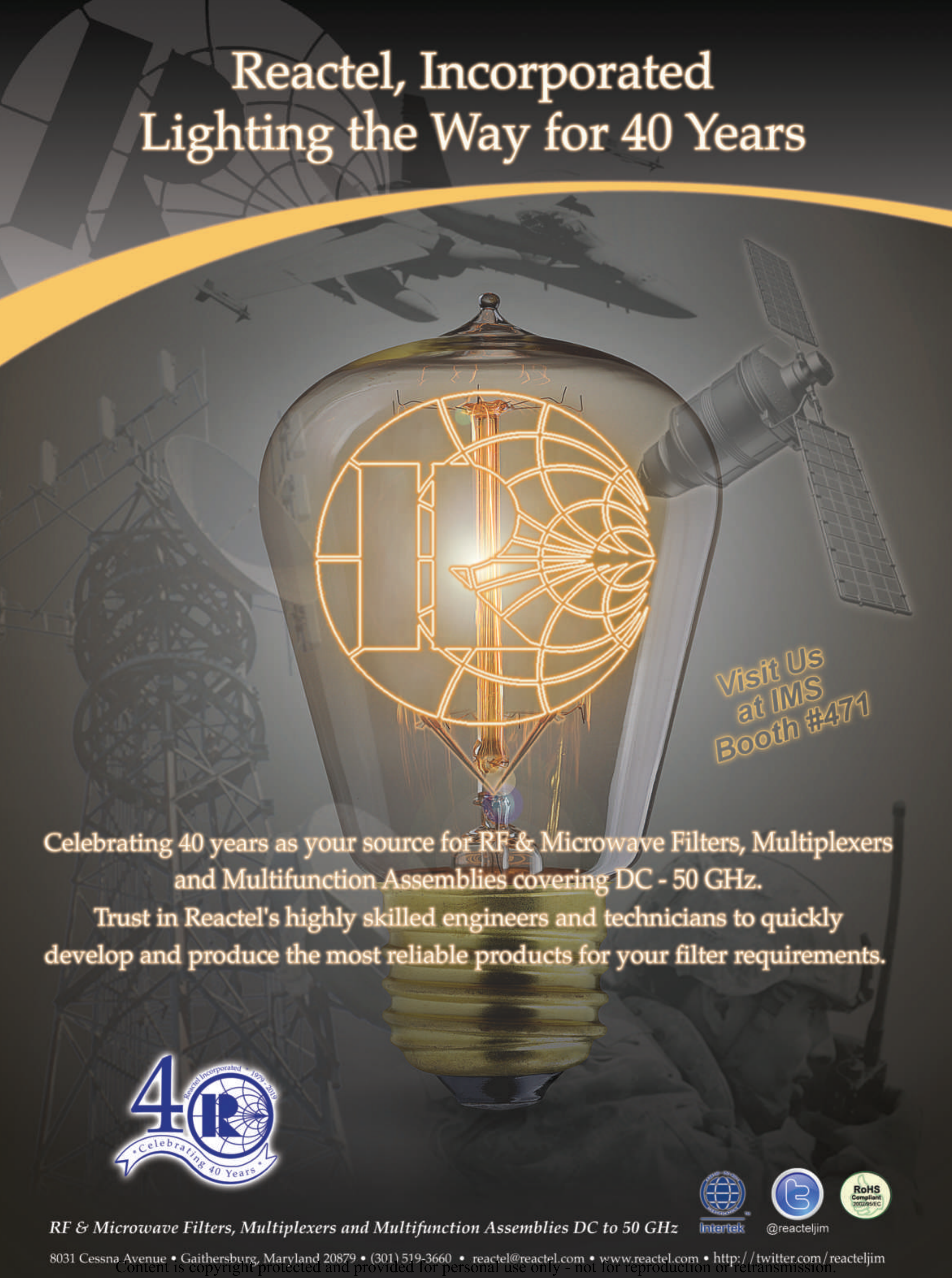
lite" is used for spacecraft with in-orbit masses of less than 500 kg. These satellites may be called by different names, such as nanosats and lightsats, by various government agencies and organisations. Nanosatellites typically weigh between 1 to 10 kg, microsatellites 10 to 100 kg, mini satellites 100 to 500 kg, picosatellites 0.1 to 1 kg and femto satellites less than 100 g. The International Academy of Astronautics (IAA) also defines small satellites as those whose mission should fill a clear gap and the program must have a short lead time.

Small satellites are being used for various defense, commercial and research related applications. The optical, microwave and infrared payloads mounted on small satellites are being used for weather forecasting and meteorology. The use of electronic intelligence (ELINT) and imaging payloads enables their application for security/surveillance, which includes situational awareness, Earth observation and communications. Additionally, synthetic aperture radars (SAR) also enable small satellites to capture images and carry out terrain observation, thereby making them suitable for earthquake/seismic monitoring. They are also being used for other applications, particularly in the area of scientific research being conducted by universities, owing to their ability to provide low-cost access to space.

The leading 15 small satellite companies consist of a wide range of defense and security-focused and commercially-focused providers, both in the hardware and software sub-markets. Several of the 15 companies described in a recent ASD market research report achieve a significant share of their business through their contractual relationships with the U.S. government as foreign military sales (FMS) contractors. Most of them have embarked in a consistent international move to gain profit from opportunities in new markets and diversify risks connected to their dependence on North American and European customers.

> Growth is in international emerging markets.

Leading companies featured in the report are Space Systems Loral, Airbus Defense and Space and SST Ltd., Lockheed Martin Corp., Orbital ATK, Boeing, Thales Alenia Space, Mitsubishi Electric, Harris Corp., Spire Global Inc., Planet Labs Inc., Sierra Nevada Corp., China Aerospace Science and Technology Corp., Dauria Aerospace Ltd. and ISS Reshetnevn.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Cliff Drubin, Associate Technical Editor

Mobile Ticketing: The Critical Stepping Stone Toward Mobility-as-a-Service

The number of public transit tickets delivered to a mobile device will grow from just over 4.5 billion in 2018 to 7.9 billion in 2023, forecasted ABI Research. This growth will be driven by both increasing consumer use and an increasing understanding by Public Transport Authorities (PTA) that mobile will play a critical role in future-proofing business models as well as be the launchpad from which to diversify and place themselves in a central role in order to take advantage of the Mobility-as-a-Service (MaaS) opportunity.

Multi-modal transportation, MaaS and Mobility on Demand (MoD) are now considered more critical in order to offer a seamless commuter experience alongside the rise of use cases including ride-hailing, e-scooters and bike sharing. This is clearly where the public transit market needs to head, embracing the convergence between publicly and privately-owned transportation modes.

PTAs are perfectly positioned to leverage and recycle vast data mines related to their commuter bases, encompassing location, preference data and payment information. Through these analytics, this information becomes a monetizable asset to which PTAs could allow other transportation vendors to plug into as part of a wider MaaS solution.

PTAs now need to embrace this paradigm shift, in order to place themselves at the center of the MaaS opportunity via the creation of centralized mobility platforms/applications, where multiple transportation services, whether PTA or privately managed and owned, can be consumed from a singular mobile device. Mobile ticketing enablement is the PTAs first step toward realizing this emerging opportunity.

"Today, OEMs including Samsung, Apple and Google are leading the early mobile ticketing charge, leveraging open-loop payment platforms and reapplying to offer closed-loop ticketing support," commented Phil Sealy, principal analyst, ABI Research. "These OEMs all have established mobile payment applications and PTAs are able to leverage these to take advantage of their already existing scale." ABI Research believes that partnerships between PTAs and OEMs should be encouraged to not only ensure new levels of scalability, but also to ultimately serve as a platform for PTAs to launch new services and eventually enter the MaaS market.

"It's now 'Do or Die' for the PTAs; they need to embrace the paradigm shift toward MaaS. The first stepping stone is to launch a dedicated mobile ticketing platform/application. However, if PTAs do not begin to strategize and move toward MaaS, through platforms offering access to open APIs to MaaS aggregators like MaaS Global, others will come over the top and sweep the opportunity from beneath their feet. PTAs' closed mindset will inevitably widen the door to those vendors already leading the charge toward public transit displacement, such as Uber, which already has had a massive impact in London by taking control of previously profitable Transport for London routes, and Lime from a scooter perspective," concluded Sealy.

Mission Critical Applications to Drive Adoption of 5G sUAVs

Public safety agencies in big markets have started to deploy mobile broadband communication networks to replace their existing narrowband technology, such as FirstNet in the U.S. and the Emergency Services Network in the U.K. The adoption of LTE will lead to 5G New Radio (NR) and unlock a myriad of civil use cases for small UAVs (sUAV), according to a report by ABI Research.

As compared to a few years ago, sUAVs have been widely deployed in various public safety applications. This includes asset surveillance and monitoring, traffic management, crowd surveillance and control, as well as search and rescue. However, all these applications are performed using remote control and within visual line-of-sight. Existing communication technologies, such as LTE, Wi-Fi, Bluetooth and unlicensed spectrum, all have their limitations and restrictions.

"The biggest strengths of 5G are high throughput and low latency," said Lian Jye Su, principal analyst, ABI Research. "The high throughput enables the seamless transmission of high-resolution images and videos that are critical for search and rescue missions. Low latency, on the other hand, allows sUAVs to be controlled by a centralized command and control in beyond visual line-of-sight (BVLOS) flight. Path and route information, sensor information, geospatial and telemetry data can be exchanged with the command and control almost instantaneously."

With the increasing number of sUAVs sharing the airspace, public safety agencies will need UAV Traffic Management (UTM) system to control and manage national airspace. Each sUAV that is connected to the network will have a unique identifier which allows tracking and tracing across all kinds of terrains and environments. This will help public safety agencies track down rogue sUAVs and preserve the safety and security of the airspace.

In addition, 5G also enhances existing geopositioning technology. Currently, SATCOMs such as GPS and GLONASS are used for sUAV tracking, but satellite signals face a canyoning effect in dense urban landscapes and are subjected to interruption by buildings and natural landscapes. In indoor environments, sUAVs rely on

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optical flow and ultrasonic sensors for positioning and navigation, but this system is limited to the hardware available on the sUAVs. Cellular technology can augment satellite by using a radio fingerprinting technique, which matches cellular signal measurements against a central calibrated database and does not require an extra device or upgrade to the public safety network.

"The mission critical nature of public safety use cases demands a high level of reliability, scalability and redundancy. Despite still being in the early stage of deployment, 5G has strong potential to solve the pain-points of public safety use cases," concluded Su.

Private LTE: Foundation for 5G Services in End-Vertical Markets

By 2025, the private LTE market comprising healthcare, transport and logistics, manufacturing, smart venues, smart cities and oil and gas will be worth $16.3 billion, according to ABI Research. With the future of mobile service providers (MSP) and network vendors to be defined beyond the consumer market to end-vertical enterprises, private LTE is set to be a key asset to create new revenue streams.

"A new understanding of spectrum usage, spearheaded by the Citizens Broadband Radio Service (CBRS) activities in the U.S., and increasing demand from industry verticals are the main drivers of private LTE," said Pablo Tomasi, senior analyst, ABI Research. "The U.S. is taking the lead in bypassing the issue of spectrum, which has been traditionally one of the roadblocks to private LTE expansion. The CBRS three-tier system provides 150 MHz of spectrum and most importantly, offers the ability for companies to acquire spectrum depending on their needs. Besides CBRS, other developments such as MulteFire and countries considering auctioning regional spectrum, show that this new spectrum paradigm has a global scale," continued Tomasi.

The growth potential and the size of the market, where virtually every sector could benefit from private LTE deployments, means that an increasing number of companies will be attracted to it. Companies with diverse backgrounds including indoor wireless providers and web-scale players are also being attracted to this market. Contrary to this market trend, MSPs are hesitant to fully commit to private LTE, which they see as a competitive threat to their core business and investments. A deeper engagement of MSPs, would not only benefit the category but the wider market as well.

"The delivering of successful projects will show the reliability of cellular technology (and its ecosystem) and will ultimately pave the way for 5G in industrial markets," concluded Tomasi.

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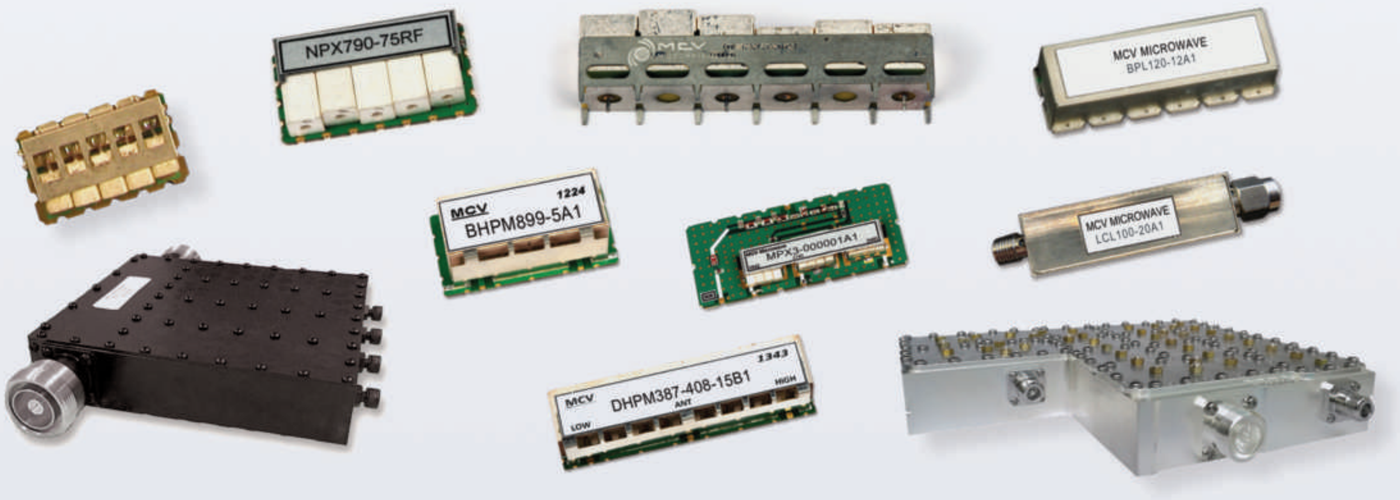

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Electro Technik Industries Inc. has announced the acquisition of **RF Techniques Inc.** in San Jose, Calif. The newly acquired company will be part of the Electro Technik, RF/Microwave Group and report to Alen Fejzuli, the Group's president. RF Techniques has been in business for over 30 years and during this time has developed an outstanding reputation in the industry for designing and delivering high-reliability microwave components. Their products will compliment Res-net Microwave's existing offerings by adding a family of brazed attenuators, resistors and terminations, as well as thin film capabilities.

Electronic Products announced they will be merging with **Semiconductor Enclosures Inc.** of Newburyport, Mass. Semiconductor Enclosures Inc. is a powder to package, fully integrated HTCC precision ceramics manufacturer providing ceramic tape systems, ceramic substrates, multilayer ceramic substrates, metallization services, metal to ceramic assemblies and microelectronic ceramic packaging. With this merger, Electronic Products will specialize in a variety of aluminas, ZTA and AlN, providing ceramic based products and services to customers in the RF/microwave, AlN power, Hi-Rel, military, communications, aerospace, medical, optical and industrial markets.

Microlease and **Electro Rent** in Europe have announced the start of the integration of their European operations. The two companies will merge over the coming months to join the global Electro Rent Corp. It will also consolidate the Microlease and Livingston brands into Electro Rent during this time. This combination will mean better service and support to customers, as well as access to a greater pool of equipment for immediate availability as well as increased technical expertise. Together the new group will have combined equipment assets worth over $1.1 billion, making its inventory the largest in the industry.

CACI International Inc. announced that it has completed its transaction with affiliates of Madison Dearborn Partners and CoVant Management to acquire **LGS Innovations**, a provider of real-time spectrum management, C4ISR and cyber products and solutions to the intelligence community and DoD. The strategic acquisition complements CACI's January purchase of Mastodon Design and accelerates CACI's growth in its intelligence systems and support, space operations and resiliency, communications and cyber security market areas. The combined purchase price of LGS and Mastodon Design, which closed January 28, is expected to be $975 or $835 million net of transaction-related tax benefits worth $140 million on a net present value basis.

COLLABORATIONS

Skyworks Solutions Inc. announced that **MediaTek** is utilizing its Sky5™ suite for their new 5G reference platforms. Specifically, Skyworks' complete 5G front-end architecture is being combined with MediaTek's 5G baseband chipset to deliver highly integrated solutions targeting open market mobile products. The comprehensive sub-6 GHz system enables high speed network experiences with optimized efficiency and near zero latency, empowering revolutionary emerging applications.

United Monolithic Semiconductors and **Tesat-Spacecom GmbH & Co. KG** have developed and manufactured hermetically packaged, GaN microwave power transistor devices for the European Space Agency's Biomass satellite. Prior to starting this activity there were no existing European Space Components Coordination (ESCC) standards for qualification of GaN component technology and therefore the shared knowledge base of ESA (e.g., as gained from its GREAT2 program) and UMS was used as a starting point.

CEVA Inc. and **Autotalks** announced that the companies collaborated to add C-V2X Rel. 14/15 support to the CEVA-XC DSP based Autotalks chipset, making it the world's first and only available solution capable of supporting both DSRC and C-V2X direct communications. The solution was demonstrated at CES 2019 by leading automotive tiers HARMAN, Valeo and others. V2X communication is heading to mass-market adoption as the world's largest OEMs announced intentions to equip their new car models with the technology.

MACOM Technology Solutions Inc. and **GLOBALFOUNDRIES (GF)** announced a strategic collaboration to ramp MACOM's innovative Laser Photonic Integrated Circuit (L-PIC) platform using GF's current-generation silicon photonics offering, 90WG, to meet Data Center and 5G Telecom industry demands. The collaboration will leverage GF's 300 mm silicon manufacturing process to deliver requisite cost, scale and capacity that is expected to enable mainstream L-PIC deployment for hyperscale Data Center interconnects and 5G network deployments at 100G, 400G and beyond. GF's 90WG, built on the company's 90 nm SOI technology using 300 mm wafer processing, enables low-cost integration of optical devices like modulators, multiplexers and detectors into a single silicon substrate.

ACHIEVEMENTS

Rohde & Schwarz has been active in helping define the test ecosystem and overcoming challenges of device certifications for TD LTE. The company has also been a multiple-time winner of GTI awards ever since the organization was founded in 2011, including the GTI Gold Award in 2015 for the user experience test solution for TD-LTE mobile services. The GTI awards are usually granted to a device, a program or a so-

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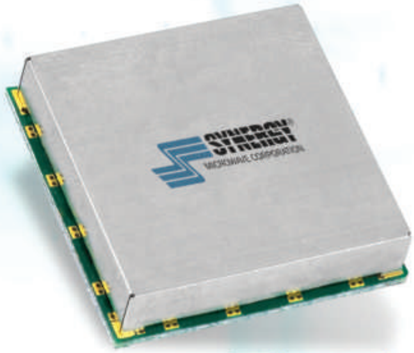

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HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-150
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142
HFSO914R8-5	914.8	0.5 - 12	+5 VDC @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-137
MSO1000-3	1000	0.5 - 14	+3 VDC @ 35 mA	-138
HFSO1200-5	1200	0.5 - 12	+5 VDC @ 100 mA	-140
HFSO1600-5	1600	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO1600-5L	1600	0.5 - 12	+5 VDC @ 100 mA	-133
HFSO2000-5	2000	0.5 - 12	+5 VDC @ 100 mA	-137
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lution, but this time the recipient of the Honorary Award was Dr. Thomas Eyring, senior director of Network Operator Test Systems Development at Rohde & Schwarz.

Mouser Electronics Inc. has been named 2018 Distributor of the Year by **Amphenol SV Microwave**. Mouser carries a full line of Amphenol SV Microwave RF connectors and cable assemblies. The Distributor of the Year award recognizes Mouser for continued growth in customer counts and POS, NPI investments and technology and innovation advancements. SV Microwave also lauded Mouser for continued focus on mindshare and best practice improvements. In the past 10 years, Mouser has received several awards from Amphenol Corp. and its subsidiaries.

Lattice Semiconductor Corp. announced **Mie Fujitsu Semiconductor Ltd. (MIFS)** as its 2018 Supplier of the Year. Every year, Lattice recognizes one of its suppliers for outstanding performance in several areas of service, including, operational excellence, commitment to quality and reliability and providing competitive value to enable Lattice's business. Lattice selected MIFS as its 2018 Supplier of the Year in recognition of significant productivity and reliability milestones the two companies achieved together.

AKHAN Semiconductor announced the issuance by the U.S. Patent and Trademark Office (USPTO) of a patent covering AKHAN's next-generation multilayer diamond display systems, key in smartphone/mobile display applications, amongst others. The granted and issued patent, 10,224,514, is a key addition to AKHAN's breakthrough Miraj Diamond® Glass intellectual property portfolio, and enables deeper integration of the Miraj Diamond® Glass technology within the smartphone display module systems. Through integration of high transmission diamond display materials, the novel system allows for lighter and thinner display modules, ultimately enabling a lighter, thinner, stronger smartphone which runs cooler during use.

CONTRACTS

The U.S. Navy has selected **BAE Systems** to compete for future cyber engineering task orders awarded under a seven and a half-year, IDIQ contract. The contract vehicle is intended to be used by naval, joint and national agencies seeking lifecycle service support for command, control, communications, computers and combat systems. Additional task orders may be awarded to enhance the capabilities and security of various signals intelligence, imagery intelligence, EW, surveillance and reconnaissance systems. The ceiling value for all future task orders awarded under the contract is $898 million.

Teledyne Technologies Inc. announced that its **Teledyne Defence & Space** business unit, part of the Teledyne Defense Electronics Group, developed and

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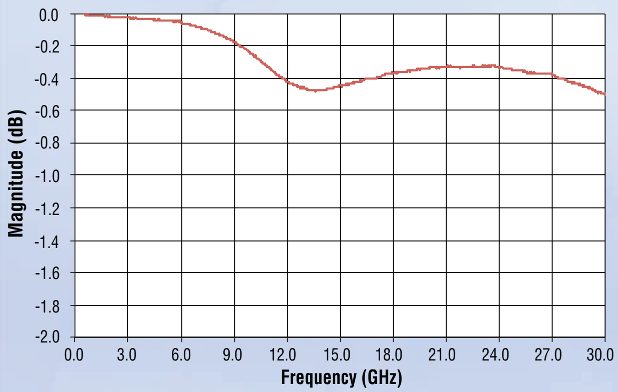
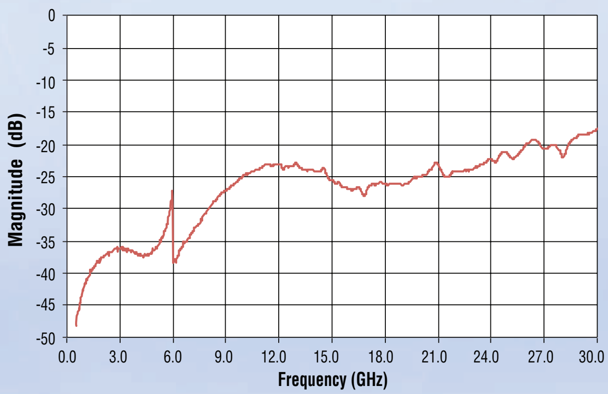


531Z Return Loss (S11)



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provided critical microwave communication products to support **Airbus OneWeb Satellites'** mega constellation to bridge the digital divide. The first six satellites and supporting payload were launched February 27, on Soyuz VS21. Teledyne's $95 million production contract was awarded in 2018 and follows an initial development award received in June 2016. Production is expected to continue through 2021. Teledyne Defence & Space will provide flexible channelisers, also known as converters, for each of the Airbus OneWeb Satellites, as well as microwave and mmWave filter assemblies.

Science Applications International Corp. won a $37 million Seaport-e task order to provide mission support services to the **Naval Surface Warfare Center**, Panama City Division. The JEXC2 family of systems provide the military with a wide range of technology and communications capabilities. On this contract, SAIC will deliver technical support to fielded military command and control systems. The company will also provide 24/7 help desk support and field service representatives deployed with each system. These representatives will help the JEXC2 end-users with system employment, operations and maintenance. The task order has a five-year period of performance.

Mercury Systems Inc. announced that it received an additional $5.5 million in follow-on orders against its previously announced $152 million five year sole-source basic ordering agreement (BOA) to deliver advanced Digital RF Memory (DRFM) jammers to the **U.S. Navy.** The orders were received in the second and third quarters of the company's fiscal 2019 year are expected to be delivered over the next several quarters.

Comtech Telecommunications Corp. announced that during it second quarter of fiscal 2019, its Santa Clara-based subsidiary, which is part of Comtech's Commercial Solutions segment, has received a contract for more than $1.5 million for Ku- and Ka-Band high-power traveling wave tube amplifiers (TWTA) for a transportable SATCOM ground system. Comtech Xicom Technology Inc. is a leader in high-power amplifiers, manufactures a wide variety of tube-based and solid-state power amplifiers for military and commercial satellite uplink applications.

PEOPLE

▲ *Thomas Wild*

Würth Elektronik eiSos GmbH & Co. KG appointed **Thomas Wild** as CEO effective immediately. Since 2007, Wild has been authorized signatory and, since 2009, CFO of the Würth Elektronik eiSos Group. In his new role, Wild will continue to be responsible for finance, controlling, reporting and administration worldwide. Wild has been working successfully since 2001 for the Würth Group and, since 2005, at the api technologies corp.

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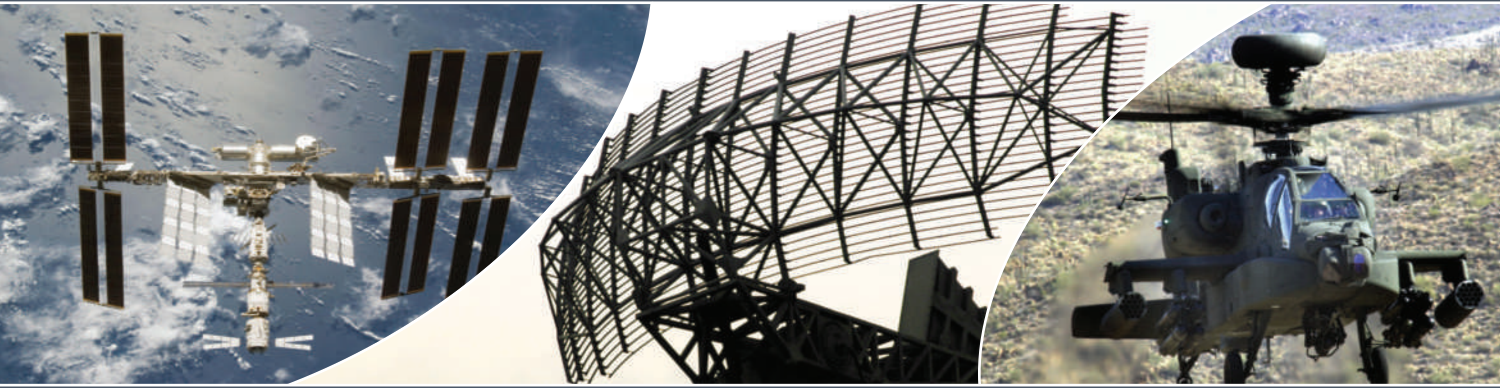

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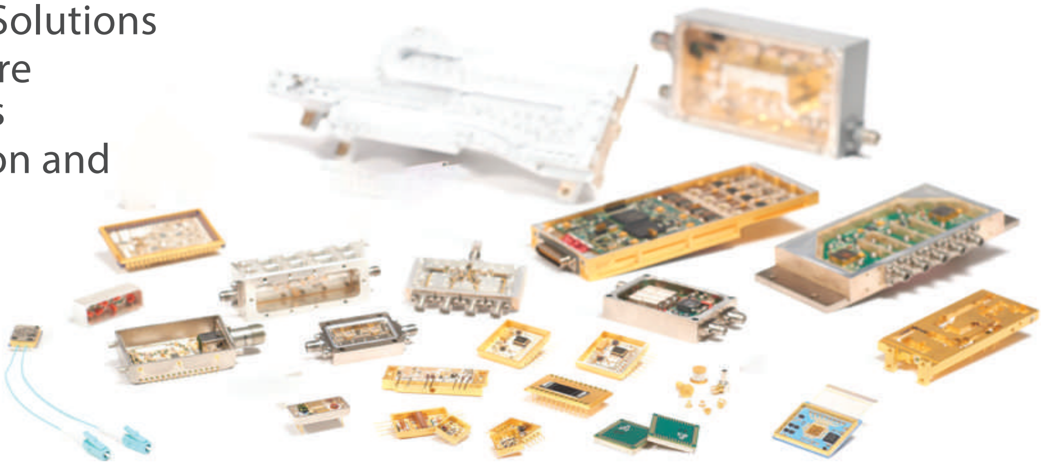

Call +1 (888) 553 7531 or visit micro.apitech.com | Check us out on social leading manufacturer of electronic and electromechanical components. Previously, he held leading positions at Wagener & Simon WASI GmbH & Co. KG and Adolf Würth GmbH & Co. KG.

▲ *Nancy Viter*

▲ *Mathew Stevenson*

Sunstone Circuits® announced the promotion of **Nancy Viter** to vice president of operations and **Mathew Stevenson** to vice president of sales and marketing. Viter and Stevenson have helped contribute to Sunstone's growth and will continue to play a key role in Sunstone's success in the PCB industry. Viter joined Sunstone in 1991, and, after a succession of management positions within the company, was named director of operations in 2015. Stevenson started in the PCB industry in 1995, and came to Sunstone in 2006 as quality manager and progressed to director of marketing in 2015.

Infinite Electronics Inc. announced **Gabriel Guglielmi** as the company's new vice president of product management. Guglielmi brings to the company more than 25 years of experience in the electronics components industry, serving in various senior management positions including general manger at ST Microelectronics, vice president of business development and strategy at Smiths Connectors and president of Smiths Interconnect Devices. Guglielmi has a B.S. in mechanical engineering from INSA in Lyon, France and a M.S. in strategic management from HEC in Paris.

▲ *Gabriel Guglielmi*

▲ *Peter Rabbeni*

Peter Rabbeni has been promoted to lead the RF business at **GLOBALFOUNDRIES**, a role responsible for the company's RF technology portfolio, business development and product line financial performance. Rabbeni has more than 30 years experience in RF technology, circuits and systems, including positions in product development, field applications engineering, marketing, technical sales and business development. He joined GLOBALFOUNDRIES in October 2012, and supported the company's acquisition of the IBM Microelectronics specialty foundry business in 2015.

Lansdale Semiconductor Inc. has promoted **Michael "Mac" McNaughton** to quality assurance manager. According to R. Dale Lillard, Lansdale's president, "McNaughton will be responsible for all the company's smiths interconnect

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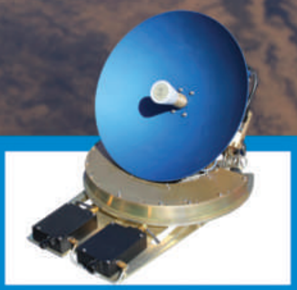

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▲ *Michael McNaughton*

quality assurance and control functions, including Lansdale's ISO9001/2015 Certification and the Qualified Military Line to Mil-PRF-38535 requirements." McNaughton has been employed by Lansdale for over 30 years in the company's hi-rel quality activities.

REP APPOINTMENTS

Mini-Circuits has welcomed **Spectrum Sales** to their trusted team of authorized sales representatives. Spectrum Sales will provide superior service and technical support to Mini-Circuits customers in New York, northern New Jersey and southern Connecticut. Spectrum's team brings deep expertise and extensive background in the RF/microwave industry, and they will be a valuable source of industry-leading service to Mini-Circuits customers in the greater New York metro area.

PLACES

StratEdge Corp. announced that it has moved its global headquarters into new facilities in Santee, Calif., near San Diego. The new facility incorporates StratEdge's corporate offices, the design and manufacturing operation for its high frequency, DC to 63+ GHz packages, and its Assembly Services Division. StratEdge's new ISO 9001:2015 facility has a Class 1000 cleanroom and Class 100 work area with workstations for performing sensitive operations. It is fully equipped with the most modern assembly equipment, enabling StratEdge services to include high speed fine wire wedge and ribbon bonding. The new component placement die attach system is the fastest and most reliable multiple die-type bonder on the market.

ETS-Lindgren has inaugurated a new 37,700 square feet factory located in Wuqing, Tianjin, China. The new factory will enable ETS-Lindgren to increase its manufacturing capabilities and expedite product shipments to customers in China and throughout Asia. ETS-Lindgren's popular wireless device test systems, such as the industry leading series of Antenna Measurement Systems (AMS) as well as smaller test boxes for 5G applications, will be manufactured at the new factory. The factory will also produce Models AMS-7000, AMS-8050, AMS-8055, AMS-8040 and GTEM! test systems.


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INVITED PAPER

Designing a Narrowband 28 GHz Bandpass Filter for 5G Applications

David Vye and John Dunn
NI AWR Group

Dan Swanson
DGS Associates

Jim Assurian and Ray Hashemi
Reactel Inc.

Philip Jobson
Design Consultant

This article examines the factors driving the physical, electrical and cost constraints for 5G filters. To address these challenges, a narrowband filter design methodology using classic filter network theory, parameterized electromagnetic (EM) simulation and port-tuning techniques is presented. The approach is demonstrated using the NI AWR Design Environment platform to develop a narrowband 28 GHz bandpass cavity filter targeting mmWave backhaul applications.

5G will increase network capacity, reduce latency, and lower energy consumption through a number of innovative technologies aimed at enhancing spatial and spectral efficiency. The use of carrier aggregation, mmWave spectrum, base station densification, massive MIMO and beamforming antenna arrays will combine to support the goals of 5G communications at the cost of more signals operating in close spectral and spatial proximity. These enabling technologies place new demands on the filters required to mitigate signal interference across a dense network of base stations and mobile devices.

5G APPLICATIONS

5G will be deployed in stages to address three main thrusts; enhanced mobile broadband (EMBB), massive machine-type communication (mMTC) and ultra-reliable and low-latency communication (URLLC) for remote sensing and control for medical and autonomous vehicle applications. On the infrastructure side, densely-populated urban environments will utilize the mmWave frequency spectrum for higher data rates. Wireless backhaul is likely the most cost-effective and versatile solution to connect 5G base stations to the core network. Filters developed for the wireless backhaul application will face cost and volume challenges that must be considered early in the design stage.

DESIGN APPROACH AND FILTER SPECIFICATIONS

Ideal filter responses are well defined by math functions. This has led to the development of numerous commercial synthesis tools that can generate circuits for an exact filter response based on ideal element values; however, the parasitic behavior of the filter components must be considered early in the design stage. For this reason, synthe-

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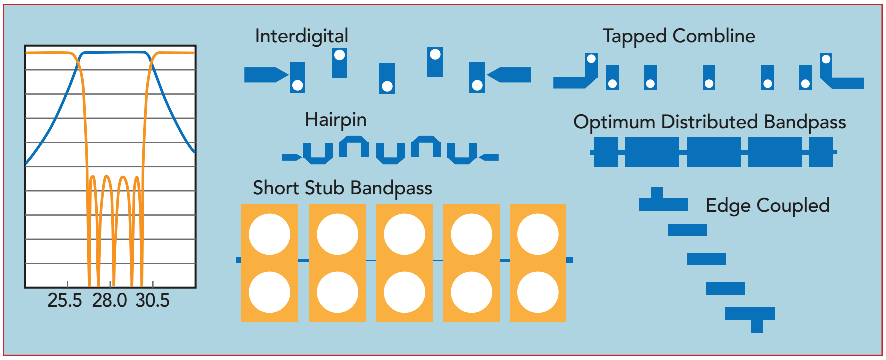

Fig. 1 Several types of narrowband filters that can be synthesized based on microstrip technology.

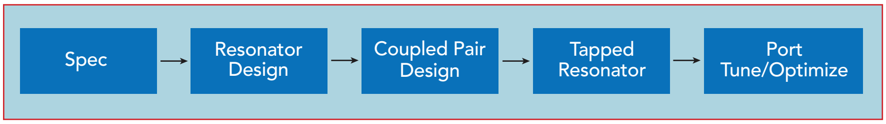

Fig. 2 Steps for designing a physically-realizable 5G filter.

sis is excellent for accelerating the initial design phase and generating mathematical filter solutions to serve as a starting point to define ideal lumped or distributed networks. Synthesis, however, is also limited in its ability to generate a physically-realizable filter. In this case, the synthesis tool provides critical coupling coefficients and external Q targets, but the ideal electrical design has limited usefulness.

Synthesis tools such as iFilter™ filter synthesis within NI AWR software can perform the math to produce ideal LC filters and precise distributed designs such as edge coupled, hairpin, interdigital and combline, based on ideal distributed microstrip and stripline models. ***Figure 1*** shows several types of narrowband filters that can be synthesized based on microstrip technology with ideal distributed models that do not incorporate manufacturing limits and tolerances. Addressing these uncertainties can be very difficult without a process for converting ideal designs into physically-realizable ones.

The method used in this design is based on a technique introduced by Dishal and adopted for use with modern circuit and EM simulation by co-author Dan Swanson. EM modeling is used to efficiently determine three fundamental filter properties: the unloaded Q of the internal resonators, the coupling between two adjacent resonators and the external Q of the two resonators that form the input and output connections. Parametric studies with EM analysis are critical in modifying the physical structure in order to obtain specific values for these filter properties, which are determined by the Dishal method. Port tuning is then applied using circuit simulation and optimization with ideal lumped-element components, specifically, capacitors that are placed in strategic locations. Port tuning is used to guide adjustments that must be made to the final physical design.

Design by Optimization

General purpose optimizers are not particularly efficient for filter design unless they are able to take advantage of the mathematical foundation that defines a filter's optimal response. For a lossless Chebyshev filter, the optimal behavior is an equal ripple insertion and return loss response in the pass band. Thus, if the optimizer can consistently find this equal ripple response, optimization can reliably be used. The optimizer that is used in this project is available as an add-on module to the NI AWR Design Environment platform using the software's API COM interface to integrate fully with Microwave Office circuit design software and AXIEM and Analyst™ EM simulators.

Designing a Physically-Realizable 5G Filter

The design methodology follows a set of well-defined steps that scale for the desired frequency and bandwidth (see ***Figure 2***). The process starts with specification of the filter requirements, including bandwidth, passband return loss and stopband rejection, from which the filter order is determined and the lowpass Chebyshev parameters are determined and scaled to the required frequency.

An EM model of a single resonator is built, and its length for a desired resonant frequency and unloaded Q is determined. Additional EM models are created to generate the coupling coefficient and external Q curves that guide the determination of key physical dimensions such as resonator spacing and tap height. These individual components are then assembled, and port tuning is used to tweak the design for the optimum equal ripple response using optimization.

Narrowband Bandpass Filter Design

The filter is designed with a center frequency of 28 GHz, (3GPP band n257). The construction is based on a single in-line cavity using an interdigital arrangement to achieve 30 dB of rejection at 800 MHz off center frequency and an in-band return loss of 20 dB. This sets the in-band ripple at 0.044 dB.

TABLE 1

IDEAL CHEBYSHEV LOWPASS FILTER RESPONSE BASED ON CUTOFF FREQUENCY NORMALIZED TO 1 Hz

N	g0	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	Σ g1- gN
2	1.0000	0.6682	0.5462	1.2222								1.2144
3	1.0000	0.8534	1.1039	0.8534	1.0000							2.8144
4	1.0000	0.9332	1.2923	1.5795	0.7636	1.2222						4.5727
5	1.0000	0.9732	1.3723	1.8032	1.3723	0.9732	1.0000					6.4989

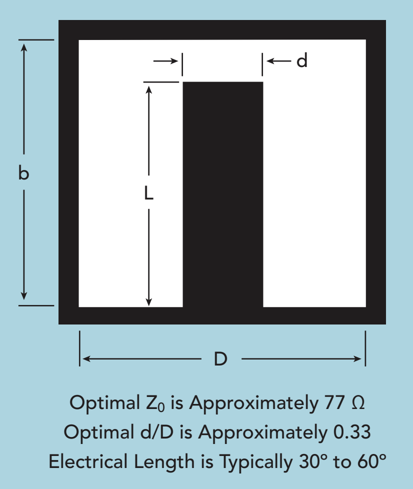

Fig. 3 Coaxial resonator cross section.

From these specifications, the expected insertion loss and the necessary filter order are determined.

The mathematical foundation for an ideal filter response is well established, with parameter values derived for an ideal lowpass Chebyshev filter response based on a cutoff frequency normalized to 1 Hz (see ***Table 1***). Once the prototype ripple level is determined from the desired in-band return loss, the filter order N can be estimated based on the desired stopband rejection, as shown in Equation 1. A fifth-order filter is needed to achieve the desired selectivity and bandwidth.

$$N > \frac{\text{Rejection}(\text{dB}) + \text{RtnLoss}(\text{dB}) + 6}{20\log_{10}\left(S + \sqrt{S^2 - 1}\right)} \quad (1)$$

Where:
Rejection = Stopband Insertion Loss
RtnLoss = Passband Return Loss
S = Rejection Bandwidth/Filter Bandwidth

Design Details

The design is based on an interdigital configuration made up of coupled resonators with the open ends on a substrate or cavity alternately pointing in opposite directions. The length of the resonators determines the resonant frequency and the coupling between resonators is controlled by their separation. The width of the housing, for a cavity filter should be λ/4 at the operating frequency.

In addition to the cavity dimensions, another early concern is determining the cross-sectional dimensions of the resonator post. The resonator post cross section in relation to the outer cavity wall determines the characteristic impedance of the resonator. For a coaxial resonator, literature indicates an optimum resonator characteristic impedance of around 77 ohms, as determined by the resonator cross-section, resulting in a post-to-cavity width ratio of about 33 percent (see ***Figure 3***). In this case, the optimum unloaded Q (Q_u) is not achieved due to physical constraints. A coaxial transmission line calculation approximates the resonator Zo ~46 ohms.

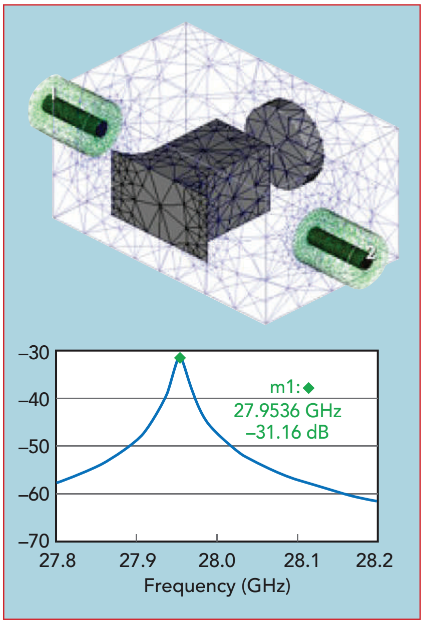

Fig. 4 Coaxial resonator EM model.

Resonant Frequency and Q_u Simulation

With the cavity and resonator cross-section dimensions determined, an EM model of a single resonator is defined with the resonator length parameterized so that the resonant frequency can be controlled, as shown in ***Figure 4***. The EM model uses two coaxial feed structures that are loosely coupled to the waveguide cavity to act as the input and output ports. The frequency response for several different resonator lengths (see ***Figure 5***), demonstrates that the resonant frequency increases with a shortening of the resonator.

The Q_u of an individual resonator is calculated from the simulated time delay and insertion loss using Equation 2.

TABLE 2
FREQUENCY RESPONSE FOR SEVERAL DIFFERENT RESONATOR LENGTHS

R length	*F_0 (GHz)*	*Q_u*
0.07883 in.	27.9535	1975.2
0.07878 in.	28.022	2040.6
0.07773 in.	28.043	1978.1

$$Q_u = \pi f_0 t_d \frac{10^{IL(dB)/20}}{10^{IL(dB)/20} - 1} \quad (2)$$

For lowpass Chebyshev parameters, center frequency, and simulated Q_u are shown in ***Table 2***. An expected insertion loss of approximately 0.25 dB is calculated for the entire filter at mid-band using Equation 3.

$$\text{Loss}(f_0) = \frac{4.343 f_0}{\Delta f\, Q_u}\sum_{i=1}^{N} g_i\,(\text{dB}) \quad (3)$$

Where:

Δf is the equal ripple bandwidth of the filter

Q_u is the expected average unloaded Q for the resonators

g_i are the normalized lowpass filter element values, calculated for a given ripple in the Table 1.

An accurate accounting of manufacturing factors such as surface roughness and plating details are missing from the model used for EM simulation, so the in-band insertion loss will likely be higher than this initial estimate. The model approximates 80 percent of the ideal conductivity as a starting point. The quality of the silver plating is very process dependent. The measured data from the manufactured and tested filter can be used to adjust model conductivity information.

Coupling Coefficient Simulation

From the Chebyshev lowpass filter parameter values (g in Table 1) the external Q and the coupling coefficients (k_{ij}) for the resonant pairs are calculated based on Equations 3 and 4, respectively, using a 2.85

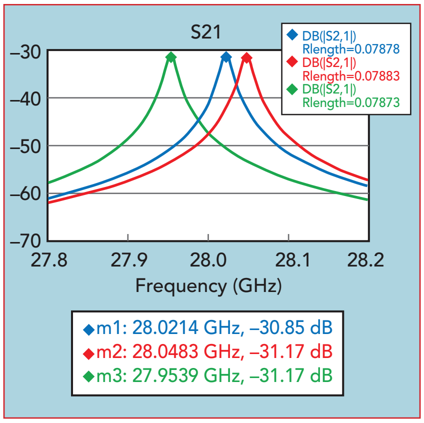

Fig. 5 EM resonator simulation results for different resonator lengths.

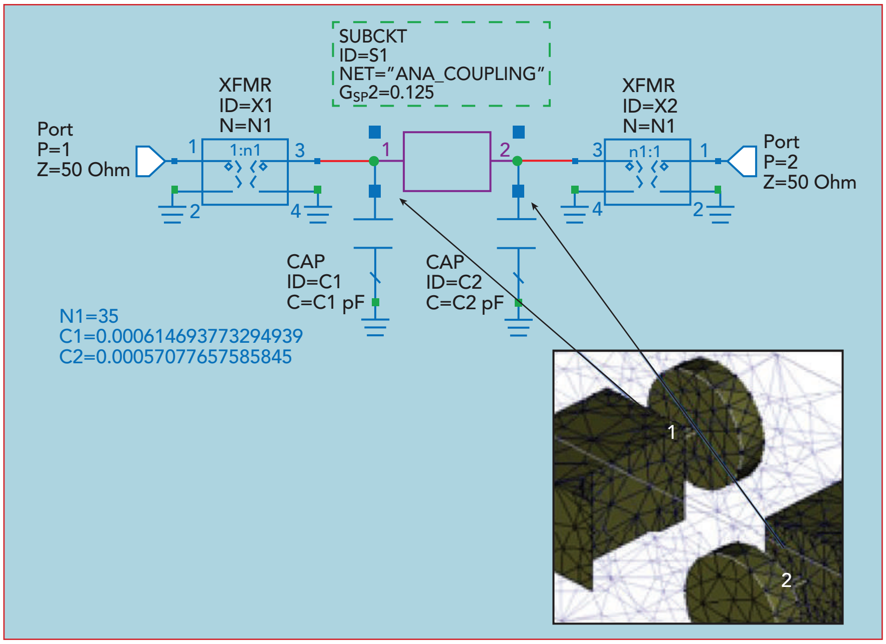

Fig. 6 Ports introduced for port tuning of coupled resonators.

percent bandwidth.

$$Q_{ex} = \frac{f_0 g_0 g_1}{f_2 - f_1} = \frac{g_0 g_1}{BW}$$

$$K_{ij} = \frac{(f_2 - f_1)}{f_0 \sqrt{g_i g_j}} = \frac{BW}{\sqrt{g_i g_j}} \quad (4)$$

$$f_0 = \frac{f_1 + f_2}{2} \qquad BW = \frac{f_2 - f_1}{f_0}$$

f_1 = bandpass filter lower equal ripple frequency

f_2 = bandpass filter upper equal ripple frequency

f_0 = bandpass filter center frequency

BW = percentage bandpass

g_i = Prototype element value for element i

Note: Equations assume Q_u is infinite.

These calculated values provide the targets for the physical design. The next step is to build the coupling coefficient design curves using an EM model of the coupled resonators in order to determine the necessary spacing.

Two resonators based on the initial resonator study are enclosed in a metal cavity and loosely coupled to the input and output ports, as shown in ***Figure 6***. The resonators are identical and resonate at frequency f_0. The coupling between the resonators results in a displacement Δf of the resonant frequencies, which is known as the coupling bandwidth. By dividing the coupling

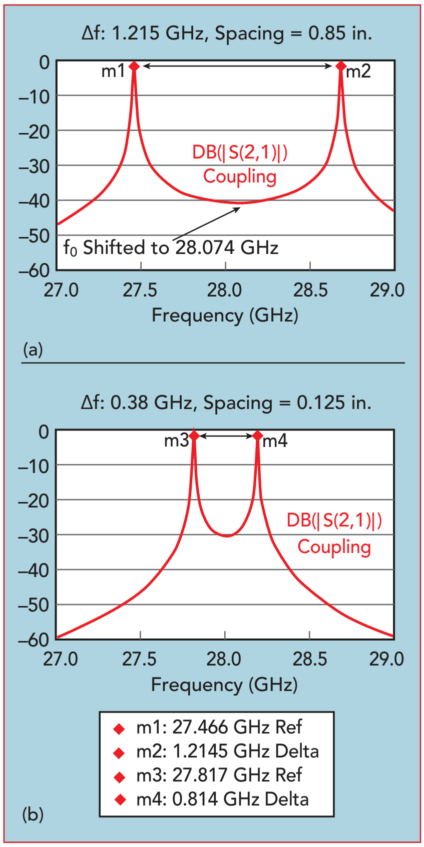

Fig. 7 Simulated transmission characteristics of two resonators enclosed in a metal cavity and coupled to input and output ports: cavity spacing equals 0.085 in. (a) and 0.125 in. (b).

bandwidth by the ripple bandwidth of the filter, the normalized coupling coefficient is obtained. The normalized coupling coefficient divided by the center frequency provides the

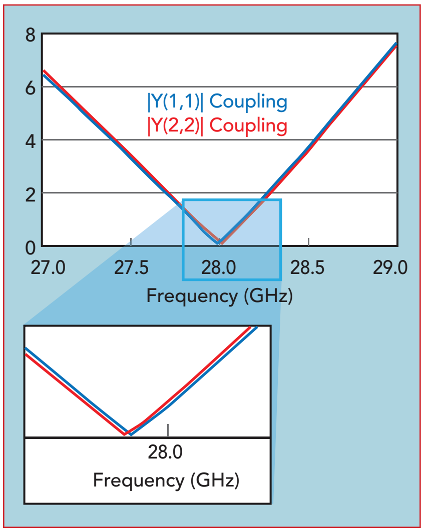

Fig. 8 The f_0 shift is addressed through tuning c1 and c2 values using optimization.

Chebyshev lowpass coupling coefficient. The resonant frequency occurs at the mid-point between the two peaks, as shown in ***Figure 7***.

The more closely the resonators are spaced, the farther apart are the resonant peaks; this corresponds to higher coupling. As the resonators move farther apart the coupling gets progressively weaker and the two peaks merge together at the original resonant frequency. It can also be seen that the center frequency between the peaks in Figure 7a are shifted upward 74 MHz for the case where the resonator spacing is 85 mils. The admittance

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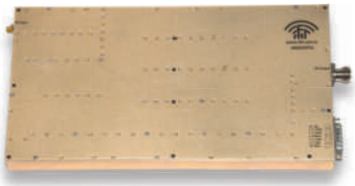

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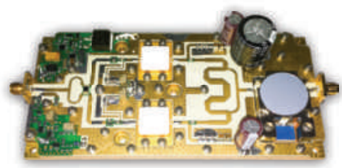

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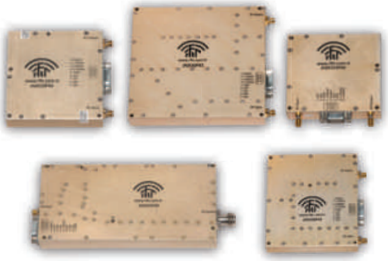

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Calculating K_{ij} Curves From Parametric EM Analysis

Dividing the normalized coupling coefficients by the 28 GHz center frequency provides the coupling co-

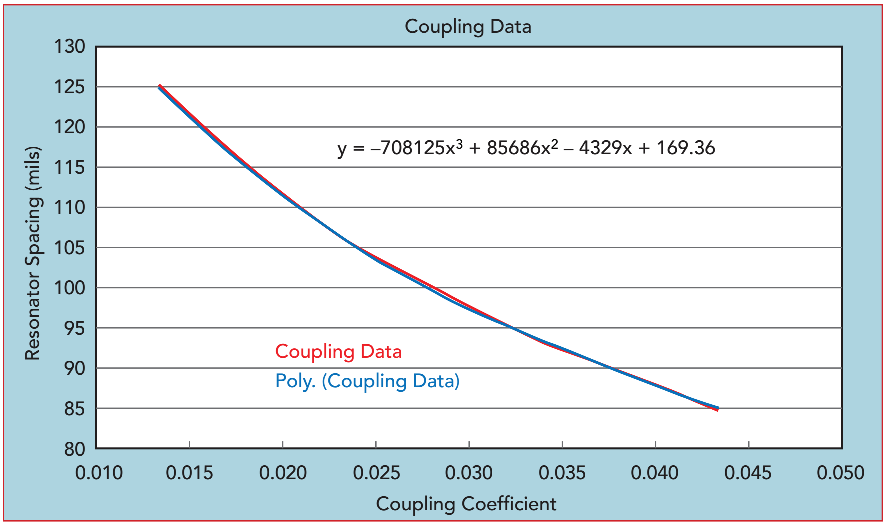

Fig. 9 Inverse relationship between the amount of coupling between resonators and their spacing.

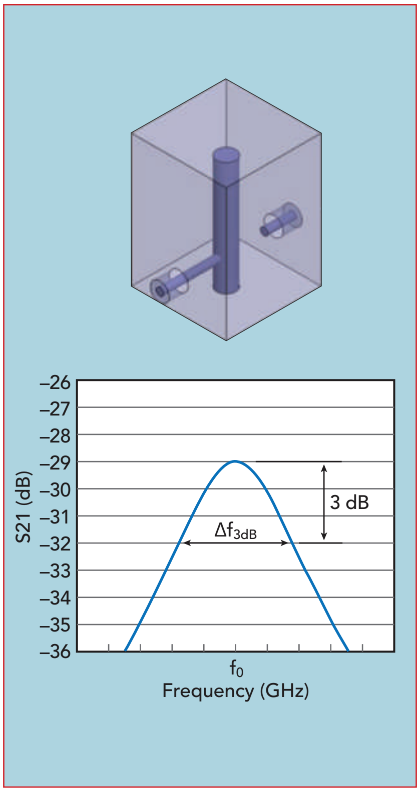

Fig. 10 External coupling is found by measuring the 3 dB bandwidth of the resonance curve.

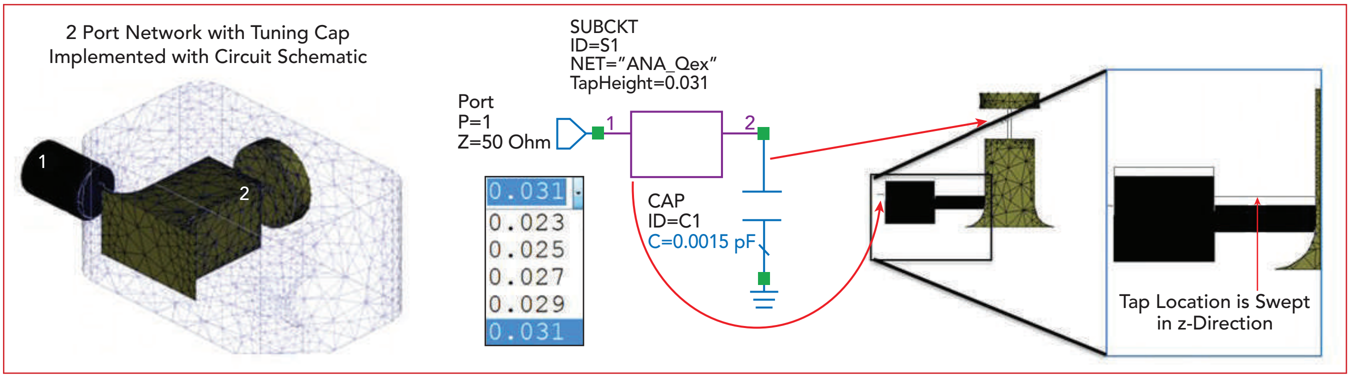

Fig. 11 Single resonator EM model includes a coaxial feed with a parameterized tap feed height to adjust external Q.

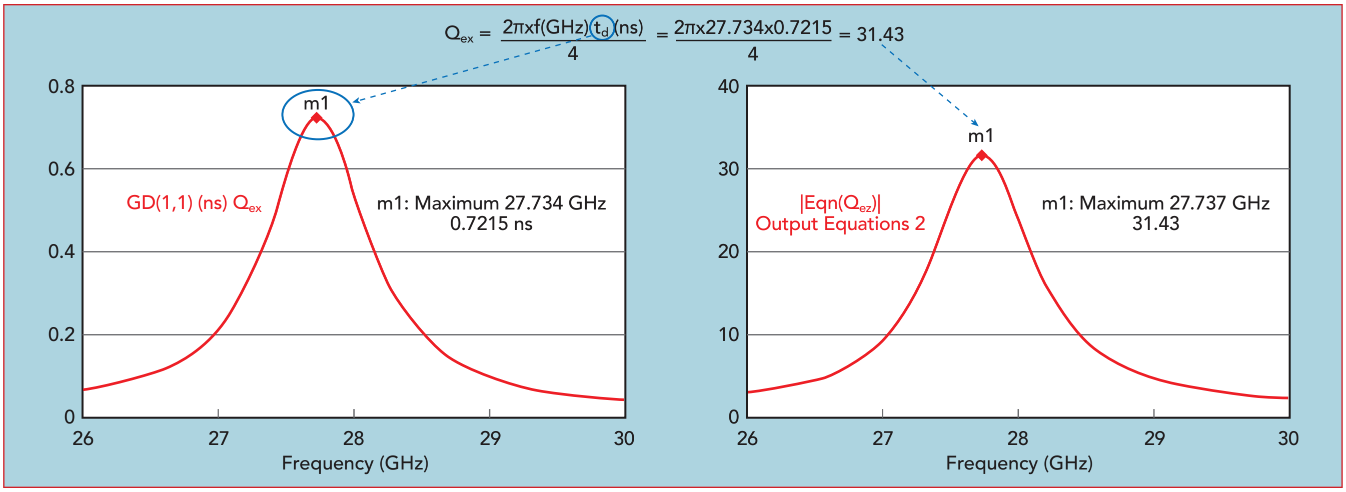

Fig. 12 Simulated reflected time delay for a given tap height.

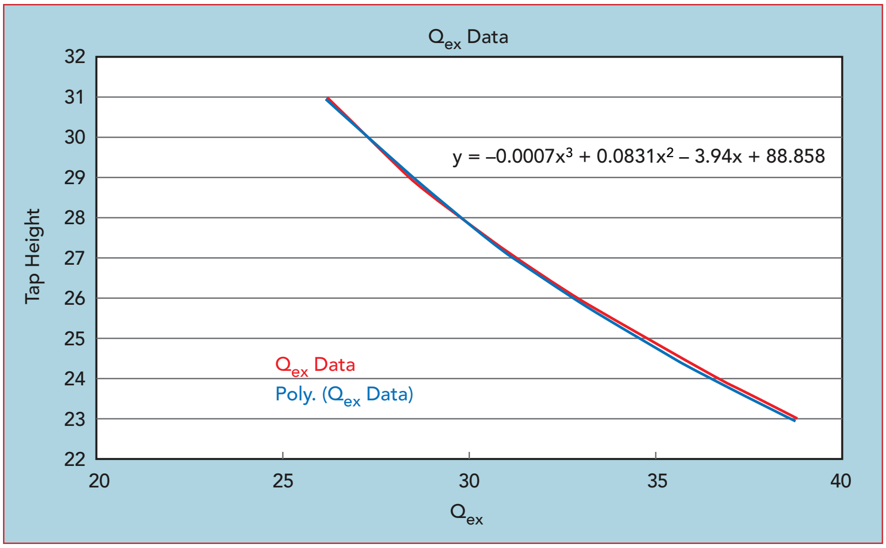

Fig. 13 Q_{ex} vs. tap height based on a parameterized swept EM analysis of reflected time delay.

efficients that are needed to match up to the lowpass Chebyshev parameter values.

From K_{ij} calculations:

$[K_{1,2}],[K_{4,5}] = 0.02466$

$[K_{2,3}],[K_{3,4}] = 0.01812$

Coupling bandwidth [1,2][4,5] = 690 MHz

Coupling bandwidth [2,3][3,4] = 507 MHz

(= K_{ij} × 28GHz)

By parameterizing the spacing and tweaking the resonator length through port tuning, a curve relating coupling coefficients to very accurate resonator spacings based on EM analysis can be calculated. From this curve the spacing necessary to achieve a required coupling is determined. The curve in ***Figure 9*** shows the anticipated inverse relationship between the amount of coupling between resonators and their spacing.

Parametric Modeling of the Tapped Resonator

The next step is to determine the physical details of the tapped resonators that provide the input/output to the filter. The external coupling is found by measuring the 3 dB bandwidth of the resonance curve denoted by Δf3dB (see ***Figure 10***). The external Q is Qext = Qloaded = f0 / Δf3dB. It is also possible to determine the external Q by measuring the group delay of S_{11}.

A parameterized EM model including a coax feed that taps into a single resonator is created and the distance from the bottom of the housing to the center of the coax tap is parameterized so that it can be adjusted to different heights to achieve the external Q calculated from the Chebyshev lowpass parameter. A lumped port is also placed between the resonator and tuning screw to support port tuning for addressing shifts in the resonator frequency due to the tap (see ***Figure 11***).

EM analysis of the tapped resonator provides the time delay response as a function of frequency for different tap heights (see ***Figure 12***). The time delay response is used to derive the external coupling. Parametric simulation enables the generation of an external Q vs. tap height curve, from which the tap height necessary for the required Q_{ex} can be directly chosen (see ***Figure 13***).

Port Tuning

Parameterization is used to sweep values and generate the individual components that are combined to reproduce the entire filter and finalize the design through port tuning using the equal ripple optimization routine. While today's EM simulators are quite fast and powerful, EM simulation times for low-order filters is still on the order of minutes or tens of minutes. Port tuning moves the optimization process from the EM domain to the circuit theory domain, where simula-

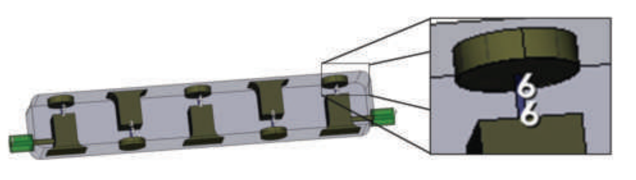

Fig. 14 Adding a port at each resonator enables tuning the frequency of each resonator and the coupling between resonators.

tion times are much faster. Adding a port at each resonator enables rapid tuning of each resonator and the coupling between resonators (see ***Figure 14***).

With each resonator loaded by a 50 ohm port, the raw coupling between resonators (not coupling coefficients per se) is simulated and the S-parameter variation across the simulation domain is extremely smooth (see ***Figure 15***). In fact, for a narrowband filter, only five to 10 discrete frequencies across the simulation domain are required for the circuit simulator to generate a smooth frequency response plot through interpolation.

With port tuning, the resulting capacitance values reveal the tuning requirements for the 3D EM model. Both positive and negative capacitance values can be used in circuit simulation. For the resonator tuning (port to ground capacitors), a negative capacitance value indicates that the resonator (EM model) is tuned too low. Positive capacitance represents a resonator that is tuned too high. For adjusting the coupling (port to port capacitors), a positive series capacitance indicates that the coupling is too strong in the EM model (the resonators are too close).

The process is repeated until the capacitances become sufficiently small. Convergence is guaranteed if the changes are not too large. Once resonator sensitivities (kHz per mm) are known, capacitance values can be converted into physical changes of the structure. ***Figure 16*** shows the dimensions for the final design, derived from the port tuning.

SIMULATED VS. MEASURED RESULTS

From this design, the filter manufacturer (Reactel Inc.) built and tested the cavity filter, shown without the cover in ***Figure 17a***. The fre-

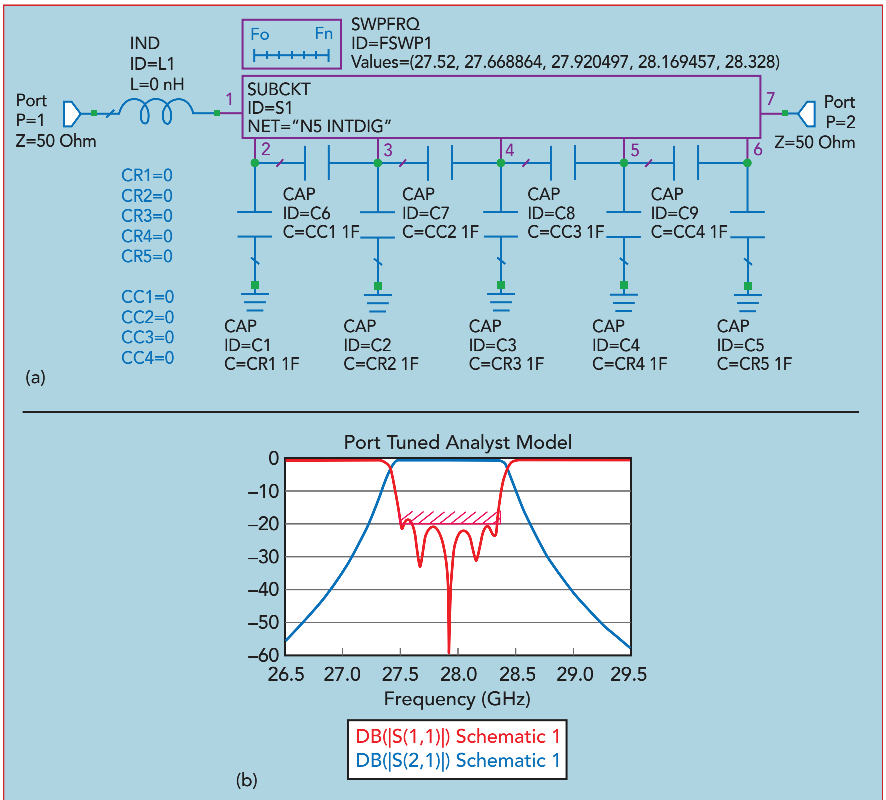

Fig. 15 Coupling parameter simulation (a) and resulting S-parameters (b).

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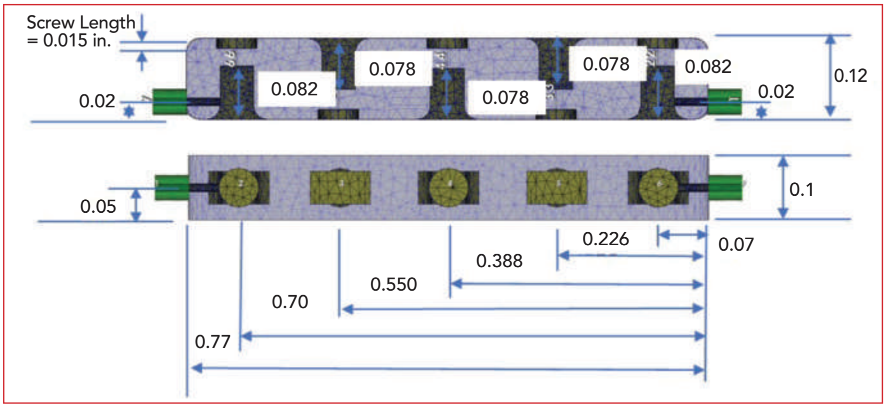

Fig. 16 Final dimension of the filter design, derived from port tuning.

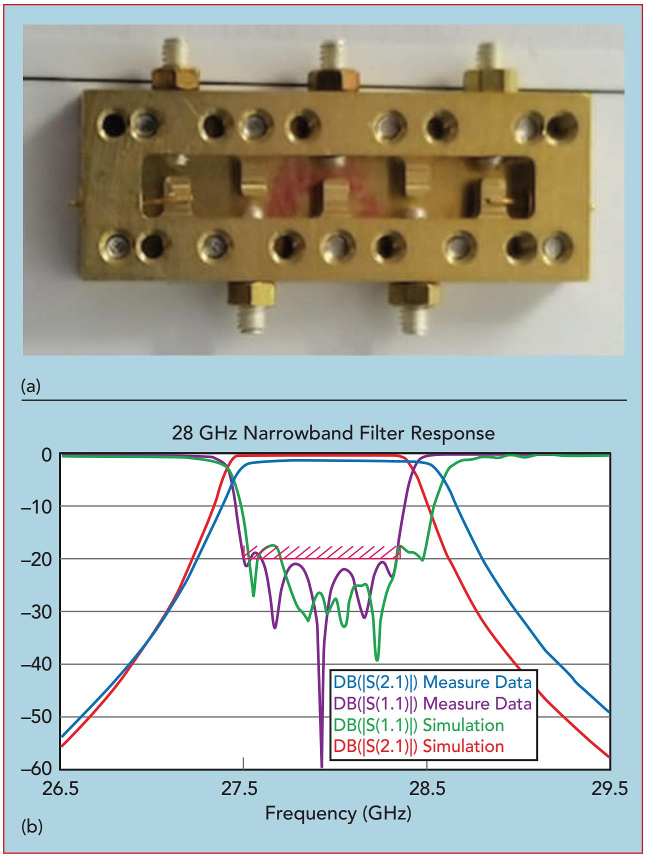

Fig. 17 Pre-plated cavity (a) and simulated vs. measured results (b).

quency response of the measured filter and simulated model is shown in ***Figure 17b***. As designed, the target response is achieved with moderate screw tuning. More precise tuning would better replicate the optimized, simulated result.

Manufacturing Tolerances and Yield Analysis

Modern CNC machines offer 0.0002 in. tolerances, not including tooling and fixturing. The relationship between 3D EM model and port tuning capacitors (resonators and coupling) can be used to perform yield analysis using the circuit simulator, allowing physical tolerances from manufacturing process to be translated into capacitor tolerances for yield analysis. Yield analysis of microwave circuits is often done with a Monte Carlo-type analysis with a large number of iterations. Running these iterations in the EM domain is prohibitive, but if the computed sensitivities convert a capacitance to a physical dimension, yield optimization is possible through the circuit simulation.

CONCLUSION

A practical design method that is independent of filter type/construction has been demonstrated, showing a robust equal ripple filter optimization that is a fast and intuitive alternative to design by synthesis and an efficient approach for port tuning complex EM-based filter models. EM tools continue to mature and add capabilities/speed, making it practical to include them in an optimization loop. This technique has been used to address the challenge of designing highly sensitive mmWave filter designs.■

INVITED PAPER

Multi-Beam Phased Array with Full Digital Beamforming for SATCOM and 5G

Divaydeep Sikri and Rajanik Mark Jayasuriya
SatixFy UK Ltd., Farnborough, U.K.

As we usher in the age of large capacity wireless access systems demanding high spectral efficiencies, array antennas are playing an increasing role. MIMO antenna arrays have become integral to the standards for cellular and wireless local area networks. These active antenna arrays will play an equally important role in next-generation high throughput satellite (HTS) communications. Also, the large low Earth orbit (LEO) and medium Earth orbit (MEO) constellations planned by companies like OneWeb, Telesat, SES and SpaceX will need ground terminal antennas that track multiple satellites. This convergence of trends is driving a shift from passive antennas with static fixed beam patterns to fully steerable, active smart antennas.

In this article, we discuss the advantages of digital beamforming (DBF) for capacity, control and flexibility. Until now, DBF was largely a concept because of the cost and complexity to implement a usable solution. We will describe a commercial ASIC implementing DBF with true time delay (TTD) that realizes its potential. DBF combined with an integrated RF front-end (RFFE) enables modular electronically-steerable multi-beam array (ESMA) antenna systems for a wide range of applications.

Mobile wireless communications systems require increasingly high data rates with virtually worldwide coverage. Because terrestrial networks do not cover the globe, high data rate services are not available in remote areas or onboard ships and aircraft. SATCOM and SATCOM-on-the-move (SOTM) are essential capabilities to achieve high capacity communications with global coverage. With large capacity wireless access requiring high spectral efficiency, array antennas have emerged as a key architecture for wireless communication systems, and MIMO antenna arrays are included in the standards for cellular and wireless local area networks. These active antenna arrays will play an equally important role in next-generation HTS communications. The development of large LEO and MEO constellations, planned by companies like OneWeb, SES and SpaceX, will require ground terminals able to track multiple satellites. Parabolic dish antennas have been the defacto design for SATCOM Earth antennas. They have advantages such as good performance, power consumption and cost, yet they are stationary and have lower efficiency. In comparison, electronically-steerable antennas have many benefits: self-installation, multi-SATCOM, satellite tracking and their payloads can be more flexible, enabling techniques such as multi-beam, beam hopping and flexible beam shaping. All-electronic control eliminates mechanical parts, which are slow and more likely to malfunction.

As Ku-Band capacity is widely available from the existing geostationary (GEO) satellite networks above the planet, market interest has largely been for satellite services at Ku-Band, namely digital TV broadcast, broadband internet access and IoT networks. The growth of these services will depend on the development of new high performance and low-cost user terminals with the ability to track satellite position while in motion. The antenna at the terminal must be capable of wide-angle scanning while keeping fabrication costs as low as possible, since most applications are consumer markets. For low-cost applications such as the IoT, the cost of the antenna can be reduced using energy efficient waveforms, such as half-duplex, which optimize link and resource utilization. The cost using such waveforms can be reduced with a single antenna that can serve both receive (Rx) and transmit (Tx).

BEAMFORMING OPTIONS

Antennas convert RF signals into electromagnetic transmission and vice versa. Each antenna has a radiation pattern defining the direction of the energy radiated by the antenna. An antenna's gain and directivity go hand in hand: the greater the gain, the more directive the antenna. It is this feature of the antenna that has become the focus for increasing capacity, particularly with the next-generation of wireless communications systems for both SATCOM and 5G.

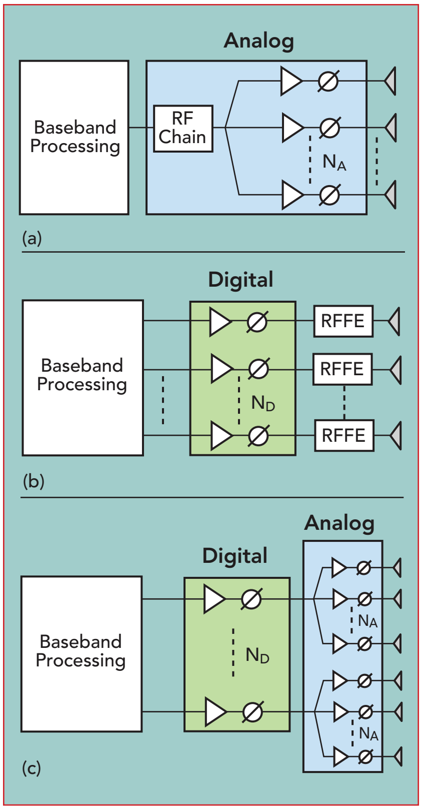

Fig. 1 Analog RF (a), digital (b) and hybrid (c) beamformers.

Beamformers comprise an array of antennas making the combined aperture directive. They control the radiation pattern through the constructive and destructive superposition of signals from the different antenna elements. In general, beamforming can be classified as passive and active. Passive beamformers are fixed directive antennas made of passive components, such as transmission lines, that point the beam in a fixed direction. Active beamformer antennas—commonly known as phased arrays—have active phase shifters at each antenna element to change the relative phase among the elements; because they are active, the beam can be dynamically steered. Electronically-steerable antennas can adopt one of three approaches to beamforming: analog, digital and hybrid (see ***Figure 1***).

Analog Beamforming

Analog beamforming (ABF) can be implemented in three ways: RF, local oscillator (LO) and analog baseband.

With RF beamforming, phase shifting is implemented in both the RF Rx and Tx paths prior to the mixer. Reduced component cost is one of the reasons for its popularity, particularly at mmWave, where the small size of the phase shifter allows better integration in the RFFE. However, phase shifter precision and noise figure degradation due to the phase shifters are performance challenges for this technique. Also, the phase shifters and beamforming network (BFN) must be designed for the frequency of operation.

LO beamforming uses the LO distribution network for phase shifting, addressing the noise figure challenge by shifting the phase shifter from the signal path to the LO path. However, this increases power consumption, and the complexity scales with the size of the antenna.

With analog baseband beamforming, beamforming occurs in the baseband, after down-conversion and before up-conversion, enabling use of higher precision phase shifters. However, the size of the phase shifters and the complexity of the BFN—mixers in each RF chain and a network of baseband splitters and combiners—are challenges.

Digital Beamforming

With digital beamforming (DBF), beamforming is performed digitally at baseband, requiring one beamformer and RFFE at each antenna element. Offering a high degree of control, DBF is considered the most flexible beamforming approach and superior to ABF for receiving and transmitting wideband signals and, more importantly, for multi-beam applications. The digital implementation has greater reconfigurability and enables treatment of RF impairments at each antenna element. However, it requires data converters and RFFEs for each antenna element, increasing the complexity and power consumption. Fortunately, recent advances in silicon processes have reduced the complexity, power and cost of digital beamforming, making it feasible for some phased arrays.

Hybrid Beamforming

Hybrid beamforming uses the best of both alternatives: analog and digital. To reduce the complexity of digital beamforming, requiring control at each antenna element, the hybrid approach uses "two stage" beamforming—the concatenation of analog and digital beamforming—and provides a reasonable compromise between performance and complexity. Each analog beamforming network serves as a subarray for the next level of digital beamforming, forming a more directive "super element" whose signal is coherently combined in the digital domain with the signals from the other super elements. Hybrid beamformers provide limited multi-beam capability, although the performance is sub-optimal compared to digital beamforming.

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DIGITAL BEAMFORMING WINS

Given the ongoing improvement in silicon technology, DBF is the preferred approach for phased array antennas. It offers:

Wideband signal reception and transmission: Wider signal bandwidth improves the spectral efficiency of the system, increasing the capacity of the terminal. DBF enables ready implementation of high precision phase shifters and delay compensation (TTD), so the array can operate over a large signal bandwidth without beam squint.

Ability to scale to build large antennas: To build large antennas, the beamformer architecture should be modular to enable relatively simple scaling. To reduce beam squint, large antennas need to correct for the delays from scanning and system routing, which becomes more challenging with large antennas. DBF supports modular design and can easily scale while maintaining performance.

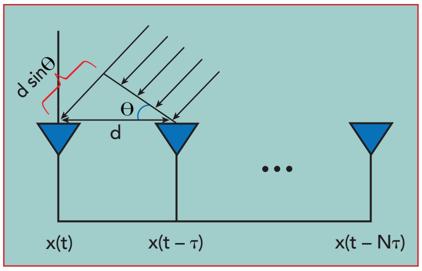
Large number of beams: MIMO with multi-beam capability is the most effective way to increase channel capacity. With SATCOM, it enables simultaneous communication with multiple satellites. DBF supports large numbers of beams using the entire antenna aperture, which provides the same antenna gain and directivity for each beam.

Fast beam steering: DBF supports fast beam switching and steering, i.e., within microseconds. This enables fast acquisition and tracking in high dynamic channel environments.

Flexibility: Active beamforming with flexible reconfiguration enables the array to adapt for multiple applications, such as online calibration, configuring dynamic subarrays and monitoring processing and synchronization.

Precise beamforming and nulling: With precise control of the phase and gain, DBF enables fine control of the radiation pattern, including side lobes, null depth and null positioning. This fine control can form the radiation pattern to meet regulatory masks and suppress unwanted directional interference, maintaining a high signal-to-noise ratio (SNR).

Antennas on conformal structures: The ability of DBF to calibrate and compensate for phase and delay allows decoupling the antenna's geometry from its performance, making conformal antennas feasible, i.e., unrestricted to a 2D plane. Geometric shapes such as hemi-spheroidal 3D antennas or other conformal shapes can be implemented using DBF.

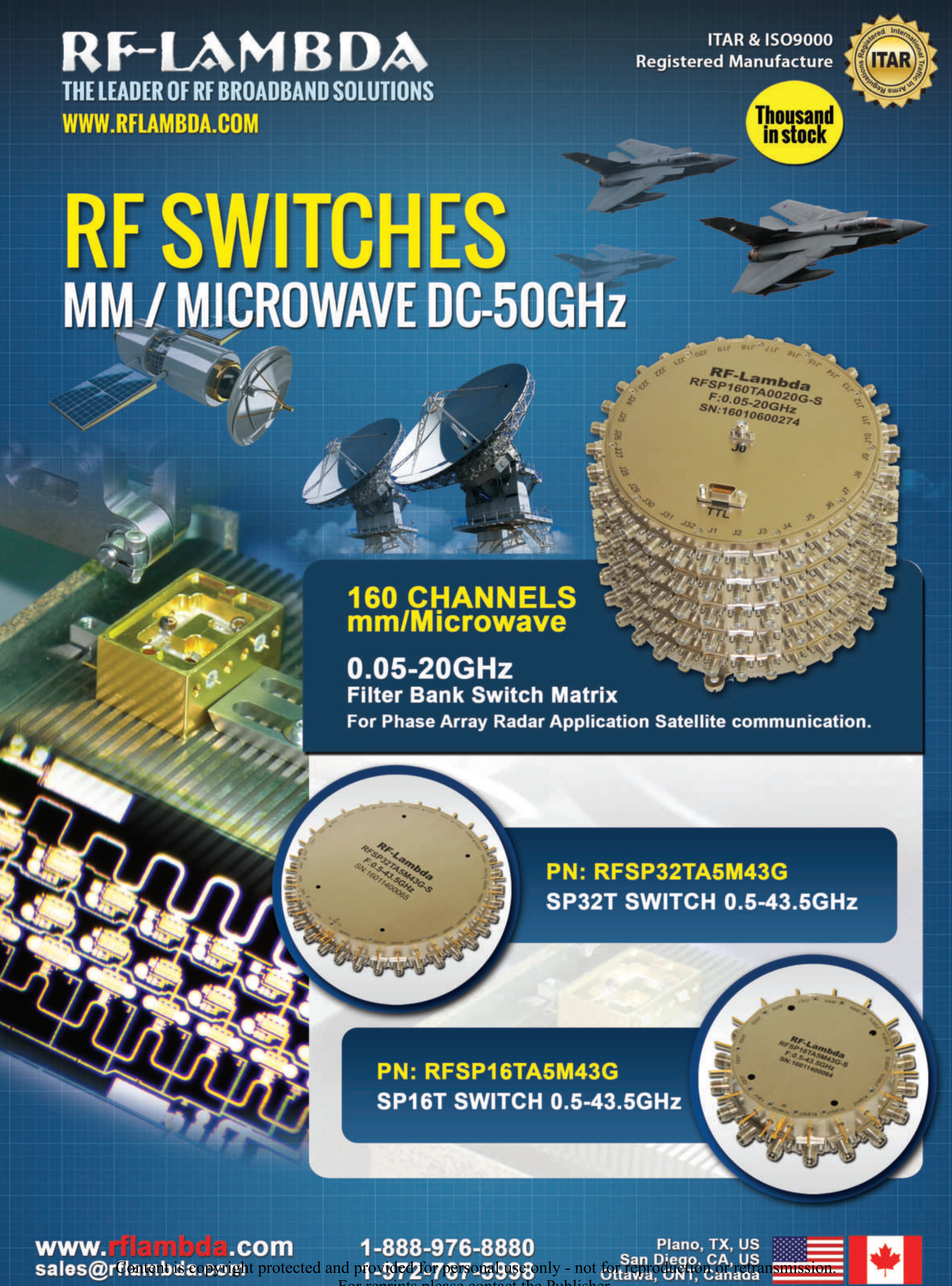


▲ Fig. 2 Uniform linear array geometry.

TTD BEAMFORMING

As shown in ***Figure 2***, with a uniform linear array, the incident wavefront at an angle θ results in a delay (τ…Nτ) for the signals arriving at different elements. This delay causes the antenna array to have a pattern depending on the frequency. To have a flat pattern over the desired frequency range, the antenna's coherent bandwidth should be greater than the bandwidth of the signal. This implies that $N\tau \ll T_s$, where T_S is the duration of the symbol. This condition requires the system to have the capability to perform delay compensation to coherently combine signals. ***Figure 3*** shows the beam squint resulting from the frequency selectivity of an array, which does not occur with TTD beamforming. The relationship $N\tau \ll T_s$ indicates the antenna's delay spread can become very large relative to symbol duration if either the antenna is very large (N) or the symbol duration is very small (T_S), i.e., the bandwidth is very large. This point is illustrated in ***Figure 4***.

SatixFy has developed the industry's first TTD DBF in a form that is efficient in power and cost (see ***Figure 5***). The Prime ASIC has a modular and flexible architecture supporting real-time reconfiguration, online calibration and the scalability to build large antennas. Prime digitizes the signal at each antenna element with high speed analog-to-digital converters (ADC) and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SP16T SWITCH 0.5-43.5GHz
www.rflambda.com
1-888-976-8880
Plano, TX, US
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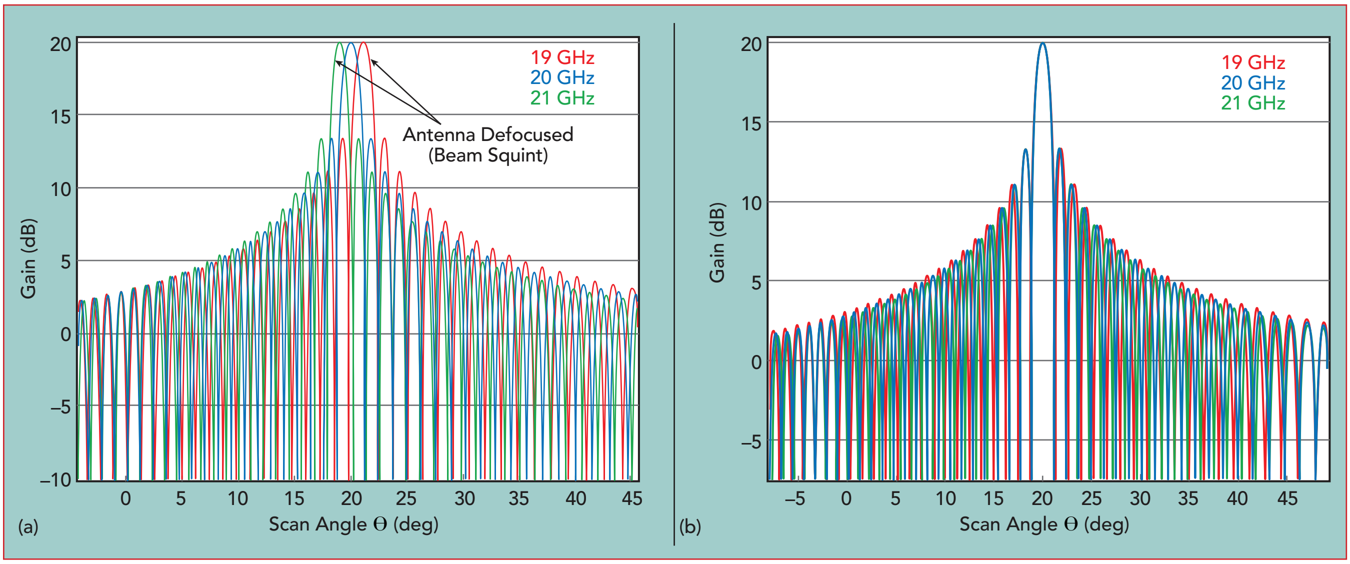

Fig. 3 Phased array radiation patterns showing beam squint vs. frequency (a) and no beam squint with true time delay (b).

digital-to-analog converters (DAC), processing more than 2 Tbps data rates. Prime connects to RFFEs containing the RF transceivers via a high bandwidth I/Q interface. Within each DBF, the ADCs and DACs are connected to high-resolution digital phase shifters and digital delay circuits which implement TTD to avoid beam squints, enabling wideband signal transmission and reception. The DBF chips are connected to each other via a high speed digital serial bus (SERDES), which enables a highly integrated, controllable and scalable antenna system. The key features of the Prime DBF are:

- Over 1 GHz instantaneous signal bandwidth.
- Multi-beam capability: up to 32 beams with independent phase, gain and delay control for each beam (see ***Figure 6***).
- Equalization/pre-equalization and digital predistortion for each beamformer chain.
- 2 GHz analog baseband interface.
- Tight integration with SatixFy's

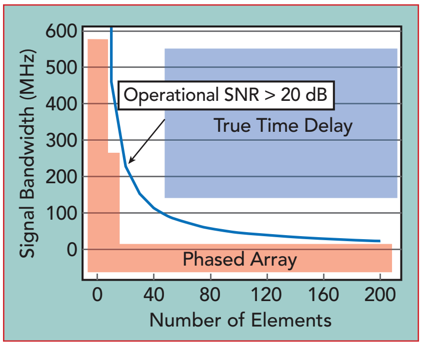

Fig. 4 Maximum signal bandwidth vs. number of elements in a uniform linear array.

Fig. 5 SatixFy Prime DBF ASIC.


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QPA2626
Qorvo's QPA2626 is a packaged, high-performance, low noise amplifier fabricated on Qorvo's production 90nm pHEMT (QPHT09) GaAs process. Covering 17-22 GHz, the QPA2626 provides 25 dB small signal gain and P1dB of 20 dBm, while supporting a noise figure of 1.3 dB and IM3 levels of -55 dBc (at Pout=0 dBm/tone). Packaged in a small 4x4mm plastic overmold QFN, the QPA2626 is matched to 50 ohms with integrated DC blocking caps on both I/O ports for easy handling and simple system integration.
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Sx3000 modem via SERDES interface.

- Support for an external modem with an L-Band interface.
- Very high speed beam tracking and beam steering.
- Linear and circular polarization control.
- Self-calibration with internal synchronization engines.
- Antenna control integrated with the Sx3000 modem.
- Power saving modes and configurations tailored to the application.

RF TRANSCEIVER

A companion to the Prime DBF, Satixfy's first-generation RFFE is a Ku-Band RFIC which links the Prime's I/Q signals with the Ku-Band antenna elements (see ***Figure 7***).

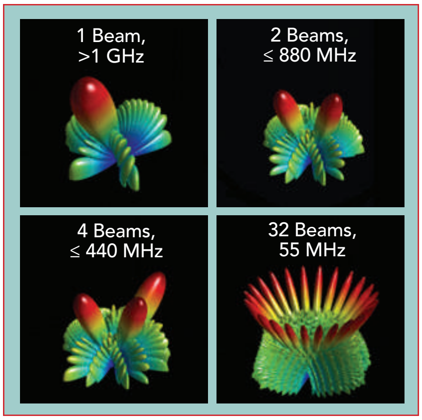


Fig. 6 Prime DBF capability: number of beams vs. bandwidth.

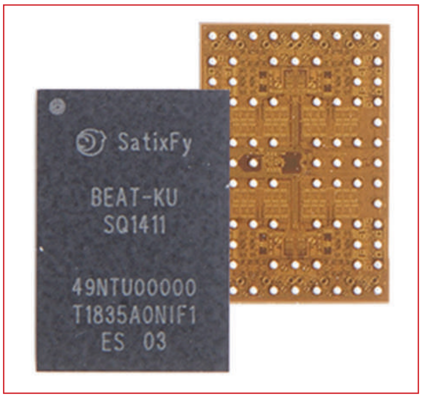


Fig. 7 SatixFy Beat Ku-Band front-end.

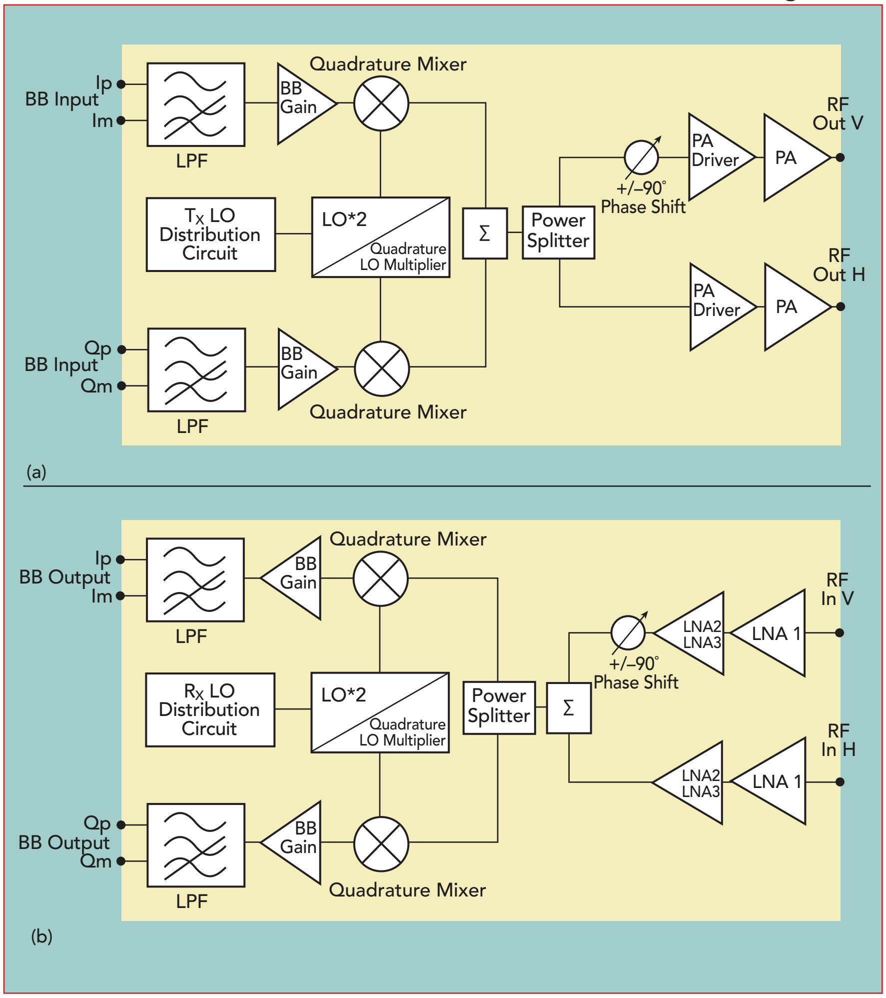


Fig. 8 Block diagram of a single element, circularly polarized Tx (a) and Rx (b).

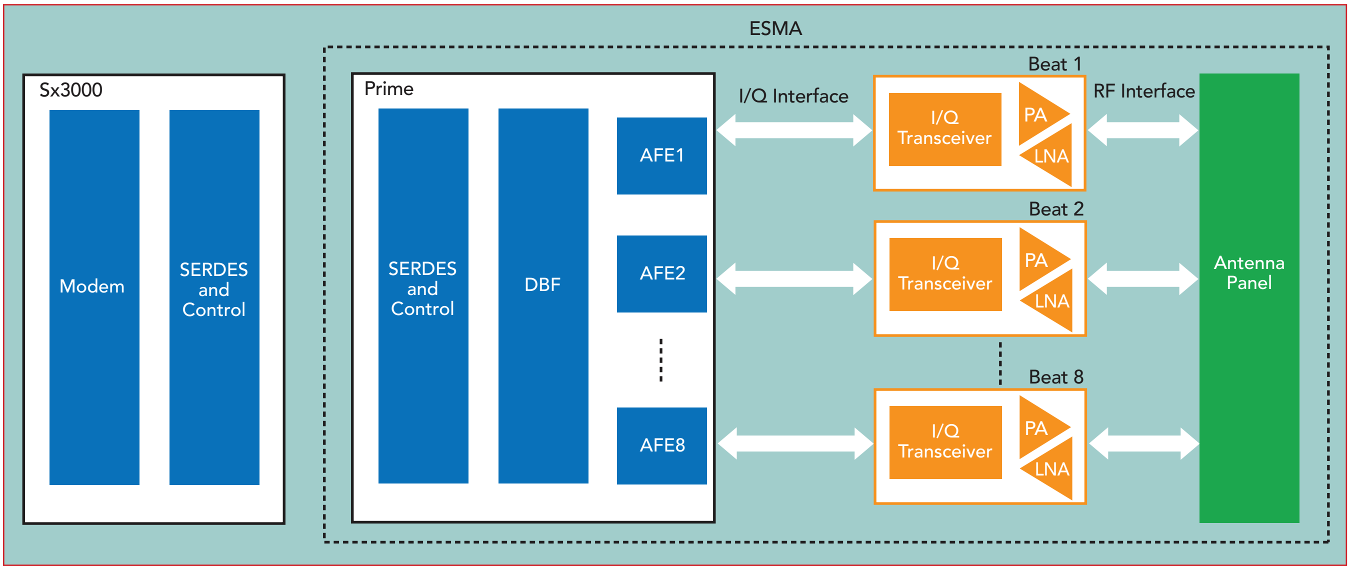


Fig. 9 System architecture.

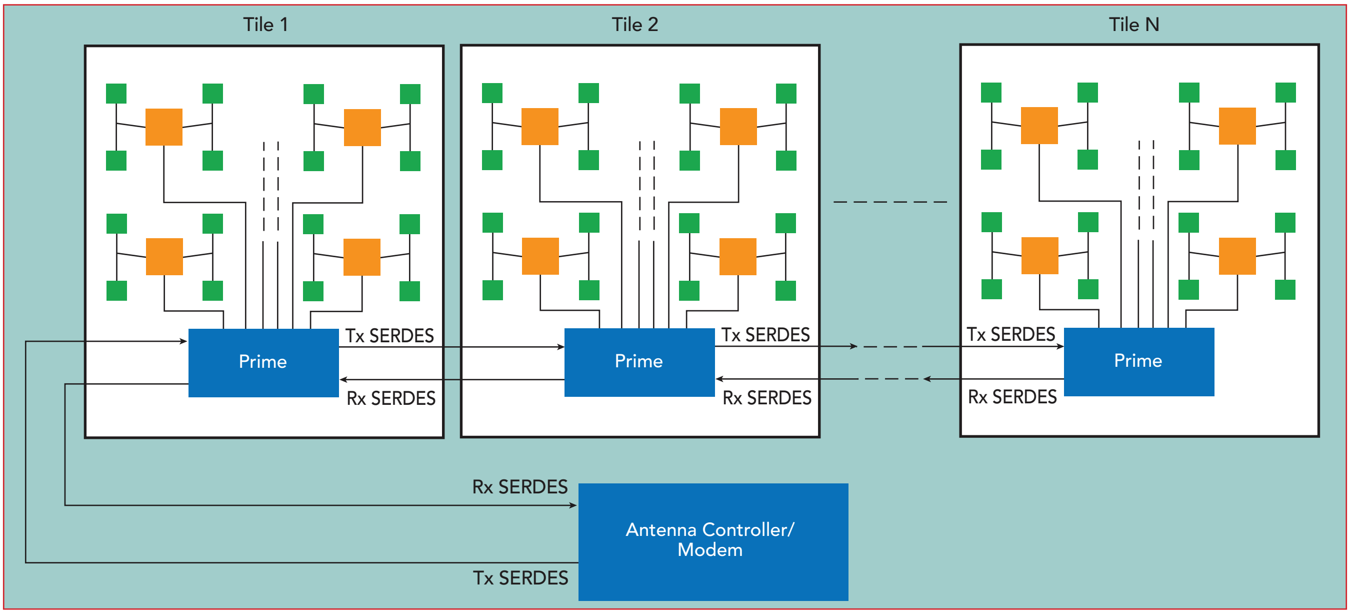


Fig. 10 Tiled ESMA to increase aperture size.

Called Beat, the RFFE integrates the transmit driver and power amplifier, transmit up-converter, receive low noise amplifier, receive down-converter and antenna polarization control, either linear or circular (see ***Figure 8***). A single Beat supports four Ku-Band antenna elements operating in half-duplex mode.

Figure 9 shows the block diagram of a fully integrated ESMA system composed of the Prime DBF, Beat RFFE and the antenna panel. The Prime DBF at the heart of the

TABLE 1

Ku-BAND ESMA

Topology	Tx/Rx Half Duplex TDD
# Beams	Up to 32 Simultaneous Beams
Frequency Coverage	Rx: 11 to 12 GHz Tx: 13.75 to14.5 GHz
# Elements	256
# DBFs	8 Primes
# RFICs	64 Beats
RF Bandwidth	1 GHz
Channel Bandwidth	880 MHz
Tx Antenna Gain	28 dBi
Rx Antenna Gain	26.5 dBi
Modem	Sx 3000-Based Modem
Digital Interconnectivity	4 SerDes Lanes at 9.4 Gbps/Lane
Terminal Functionality	Self-Sufficient System, Single Board Design, Minimal External Interfaces

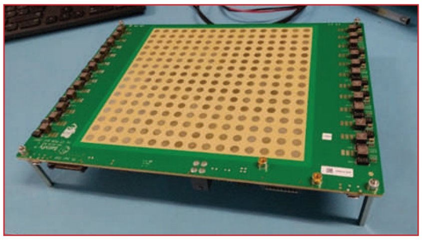
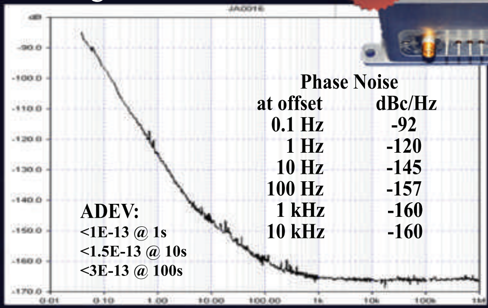


Fig. 11 Ku-Band 256-element ESMA.

Ultra-Low Phase Noise OCXOs

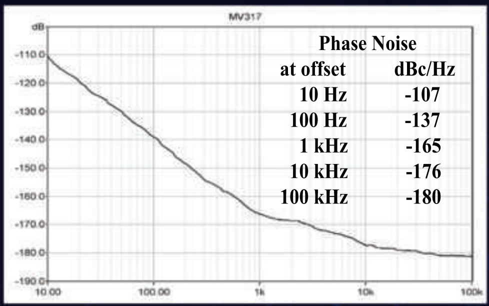
10 and 100 MHz

MV336 10 MHz, +12V
- Temperature Stability: 2E-11
- Aging: ±1E-8 per year
- Package: 92x80x50 mm



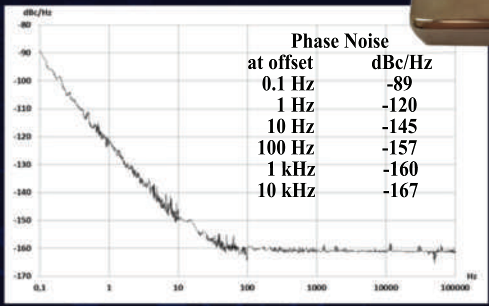
Phase Noise at offset	dBc/Hz
0.1 Hz	-92
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-160

MV317 100 MHz, +5V/+12V
- Temperature Stability: 1E-8
- Aging: ±1E-7 per year
- Package: 25.8x25.8x10.3 mm



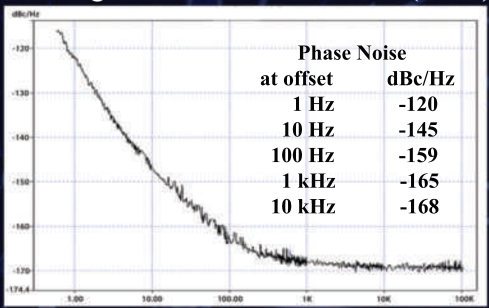
Phase Noise at offset	dBc/Hz
10 Hz	-107
100 Hz	-137
1 kHz	-165
10 kHz	-176
100 kHz	-180

MV341 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <2E-13 per sec.
- Package: 50.8x50.8x12.7 mm



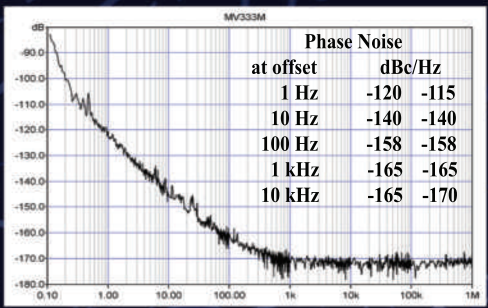
Phase Noise at offset	dBc/Hz
0.1 Hz	-89
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-167

MV272M 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <4E-13 per sec.
- Package: 41.0 x 30.0 x 17.0 mm (SMD)



Phase Noise at offset	dBc/Hz
1 Hz	-120
10 Hz	-145
100 Hz	-159
1 kHz	-165
10 kHz	-168

MV333M 10 MHz
- Temperature Stability: 3E-9
- Allan Deviation: <5E-13 per sec.
- Package: 25.8x25.8x12.7 or 36x27x16 mm



Phase Noise at offset	dBc/Hz	
1 Hz	-120	-115
10 Hz	-140	-140
100 Hz	-158	-158
1 kHz	-165	-165
10 kHz	-165	-170

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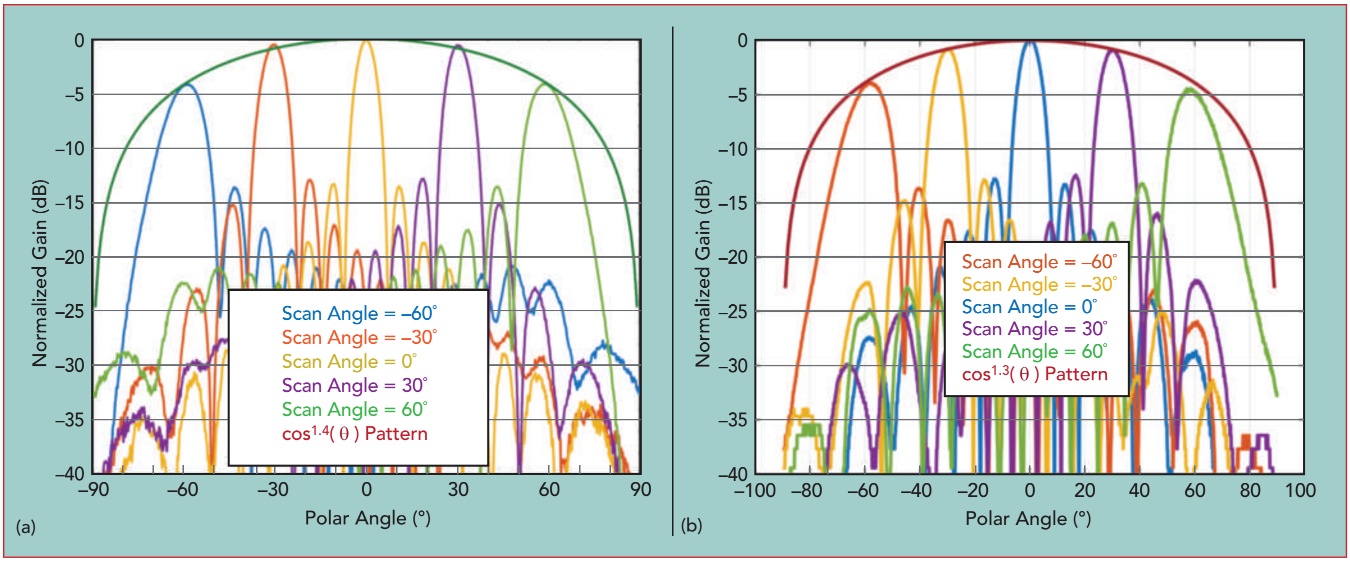

Fig. 12 Measured 256-element ESMA H-plane radiation patterns vs. scan angle: Tx at 13.75 GHz (a) and Rx at 11.7 GHz (b).

electronically-steerable antenna is connected to the Beat RFFE via an analog I/Q interface and to the Sx3000 modem via high speed SERDES. This level of integration enables a highly configurable antenna supporting different applications. Within this architecture, the DBF is band-agnostic, meaning to build phased array antennas for different satellite (Ku-, Ka- or X-Band) or 5G (sub-6 or 28 GHz) bands, only the RFFE and antenna panel need to be modified. The backbone of the BFN remains the same, greatly simplifying antenna designs for different applications and frequency bands. For phased array antennas at VHF and UHF, Prime can be used with an LNA and PA without up- or down-converters.

The modular architecture of the ESMA enables it to be scaled to larger arrays by tiling. An example is shown in ***Figure 10***, where a single tile of 32 antenna elements requires eight Beats and one Prime. The tiles are daisy-chained via high speed SERDES, which provides both data and the control plane to and from the antenna controller.

SatixFy recently introduced the world's first fully digital 256-element ESMA for Ku-Band SATCOM (see ***Figure 11*** and ***Table 1***). The ESMA antenna can serve both as a standalone IoT terminal or a building block for a larger array. The antenna is a single board design with a shared aperture antenna (Rx and Tx), operating from 11 to 12 GHz for Rx and 13.75 to 14.5 GHz for Tx. The 256-element ESMA comprises eight Primes daisy-chained and 64 Ku-Band Beats. The antenna can simultaneously point, track and manage multiple beams with multiple polarizations. ***Figure 12*** shows the antenna radiation patterns, measured in an anechoic chamber.

APPLICATIONS

The flexible ESMA architecture enables low-cost, adaptive and steerable antenna system with low weight and power consumption. This makes this system viable and attractive for various applications:

IoT

In rural areas, satellites can provide the missing coverage to connect sensors and other entities to the cloud, such as sensors for agriculture, water metering, weather, petrol and gas metering. The ESMA enables compact, low-cost and low-power IoT antennas that can automatically search, acquire and track satellites. Advantages of the ESMA include eliminating bulky mechanical structures and self-installation and tracking, which significantly reduce installation cost and enables mobile applications on vehicles, ships, aircraft and drones. The small antenna size is feasible using appropriate waveforms,[1-2] making it possible to communicate at very low SNR.

Broadband Communications for Land, Maritime and Aeronautical Applications

High capacity GEO networks and new constellations of LEO and MEO satellites will help serve the demand for broadband access, both for fixed terminals in remote areas and SOTM applications. During the past decade, the demand for broadband connectivity and in-flight entertainment on commercial airlines has demonstrated the need for low drag and highly reliable antenna systems, making a conformal antenna based on ESMA a good solution. The simultaneous multi-beam capability enables simultaneous connectivity with multiple satellites and make-before-break connections to ensure seamless connectivity—particularly when switching beams with LEO satellites at high speed. These same benefits extend to land mobile and maritime applications, where ESMA based SATCOM links can co-exist with terrestrial wide area communications. The ESMA can be scaled according to the required link budget, physical size, weight and power consumption constraints of the platform.

5G Fixed Wireless Access

The jump in 5G data rates, compared to 4G, relies on smart antennas with multiple, wideband, directive beams. ESMA's beamforming capability can increase spectrum utilization by up to two orders of magnitude. The high precision phase shifters and TTD in the DBF makes it suitable for the both mmWave and sub-6 GHz arrays. The ESMA's flexibility enables dynamically reconfiguring the beams, combined with 1D and 2D dual-polarized scanning for both line-of-sight and non-line-of-sight channel conditions. With TTD beamforming, high gain and squint free antenna patterns can be achieved across the entire cellular band.

SUMMARY

This article introduced a scalable ESMA with two building blocks: a digital ASIC (Prime) with TTD, which performs the signal processing and beamforming, and an RFFE containing the RF amplification and up- and down-conversion, which is the interface between the DBF and the antenna element. The chipset enables a flexible and scalable architecture, with the resulting ESMA achieving extremely small size, low power consumption and low-cost, compared to other approaches. Products based on ESMA will support a wide range of applications, including SATCOM (GEO, LEO and MEO) and 5G.

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INVITED PAPER

RF Transceivers Enable Forced Spurious Decorrelation in Digital Beamforming Phased Arrays

Peter Delos, Mike Jones and Mark Robertson
Analog Devices

A technique to force spurious signals to be uncorrelated by offsetting local oscillator (LO) frequencies and digitally compensating for this offset is implemented and demonstrated.

In large digital beamforming antennas, dynamic range improvements through the beamforming process of combining signals from distributed waveform generators and receivers is highly desirable. A 10logN dynamic range improvement can be obtained in both noise and spurious performance if the associated error terms are uncorrelated. N in this case is the number of waveform generators or receiver channels. Noise by its nature is a random process and therefore lends itself well to the tracking of correlated and uncorrelated noise sources. Spurious however are signals. This makes it less obvious how to force spurs to be uncorrelated. Therefore, any design method that can force spurious signals to be uncorrelated is valuable in the phased array system architecture.

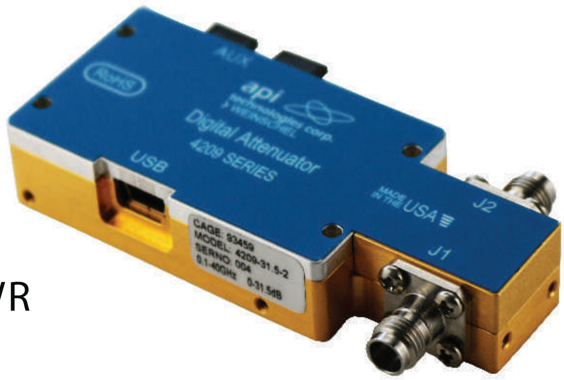
In this article we review a previously published technique to force spurious signals to be uncorrelated by offsetting the LO frequencies and digitally compensating for this offset. We then show how the most recent Analog Devices transceiver product, the ADRV9009, has built in features enabling this capability. We then conclude with measured data demonstrating the results of the technique.

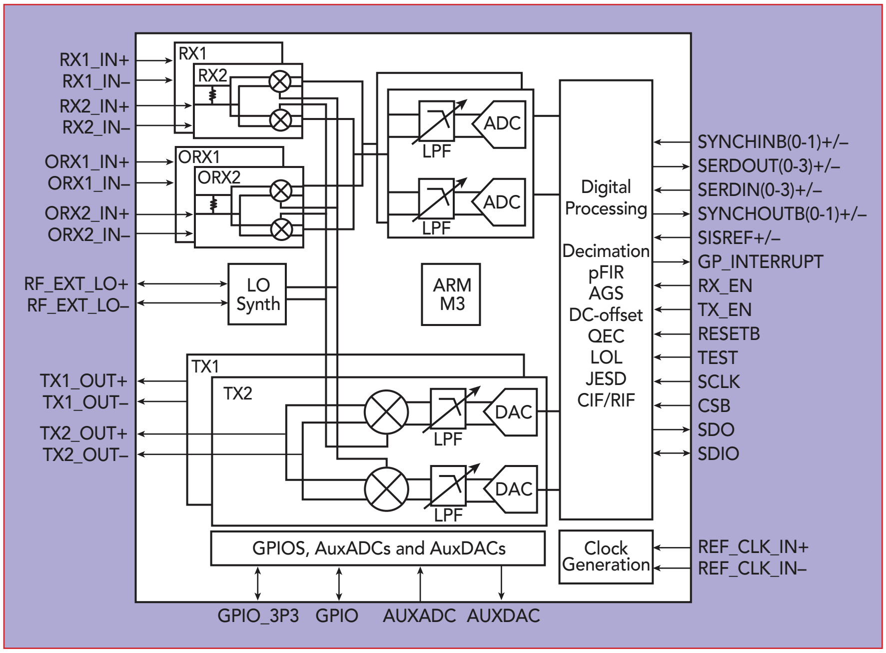
KNOWN SPURIOUS DECORRELATION METHODS

Various methods to force spurious decorrelation in phased arrays have been known for some time. The first known publication dates back to Howard et al. in 2002,[1] where a general method is described. In the approach, signals are first modified in a known way from receiver to receiver. Then the signals become distorted by the receiver's nonlinear components. At the receiver output, the modifications introduced earlier in the receiver are inverted. The intended signals become coherent or correlated, but the distorted terms are not restored. The modification method implemented in their testing was to set each LO synthesizer to a different frequency, then correct for the modification by digitally tuning numerically controlled oscillators (NCO) in the digital processor. Several other methods have also been published.[2-4] Today, with the integration of full transceiver subsystems on a single monolithic silicon chip with embedded programmable features, the original spurious decorrelation method is readily enabled.

TRANSCEIVER FEATURES ENABLING SPURIOUS DECORRELATION

We describe the method and show data for an Analog Devices product, but the method is equally applicable to any transceiver array. A functional block diagram of the Analog Devices transceiver ADRV9009 is shown in ***Figure 1***. Each waveform generator or receiver is implemented with a direct conversion architecture.[5] The LO frequencies can be programmed independently on each IC. The digital processing section includes digital up/down conversion with NCOs that can also be programmed independently across ICs.[6]


AUX
Digital Attenuator
4209 SERIES
USB
J2
J1



▲ Fig. 1 ADRV9009 functional block diagram.

To force spurious decorrelation across multiple transceivers, the LOs are offset in frequency by programming the on-board phase locked loops (PLL). Then the NCO frequencies are set to digitally compensate for the applied LO frequency offset. By adjusting both features inside the transceiver IC, the digital data to and from the transceivers does not have to be offset in frequency; the entire frequency translation and spurious decorrelation process is built into the transceiver IC. A representative block diagram for an array of waveform generators is shown in ***Figure 2***.

To illustrate the concept in frequency, an example with two transmit signals from a direct conversion architecture is shown in ***Figure 3***. In these cases, the RF is on the high side of the LO. In a direct conversion architecture the image frequency and third harmonic appear on the opposite side of the LO and are shown below the LO frequency. When the LO frequencies are the same frequency across channels, the spurious frequencies are also at the same frequencies as shown in Figure 3a. Figure 3b illustrates a case where LO2 is set at a higher frequency than LO1. The digital NCOs are equally offset such that the RF signal achieves coherent gain. The images and third harmonic distortion products are at different frequencies and thus uncorrelated. Figure 3c illustrates the same configuration as Figure 3b but adds modulation to the RF carrier.

MEASURED RESULTS

An eight channel transceiver based RF testbed was assembled to evaluate the transceiver product line for phased array applications. The test setup for evaluating the waveform generators is shown in ***Figure 4***. For this test the same digital data is applied to all waveform generators. A calibration is performed across the channels by adjusting the NCO phase to ensure the RF signals are in phase at the 8-way combiner and coherently combine. The transceivers share an LO within a two channel device (see Figure 1), so for the eight RF channels there are four different LO frequencies.

The transceiver NCOs and LOs are first set to the same frequency. In this case the spurious signals produced from the image, the LO leakage and the third harmonic of all channels are at the same frequencies. ***Figure 5*** shows the combined output. The spurs of the image and the LO leakage measured in dBc show some improvement relative to the individual channels, but the third harmonic does not. In our testing we found the third harmonic

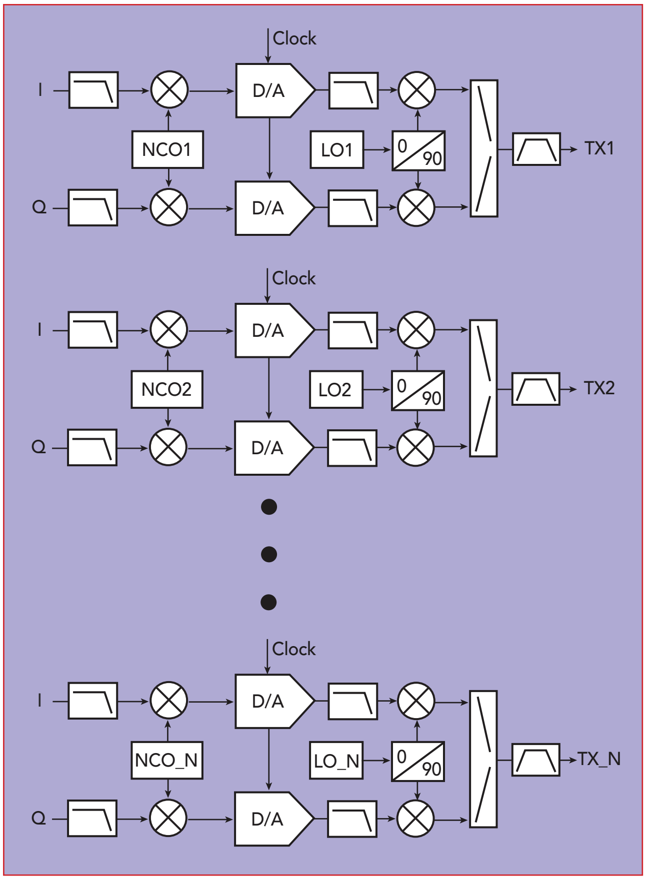
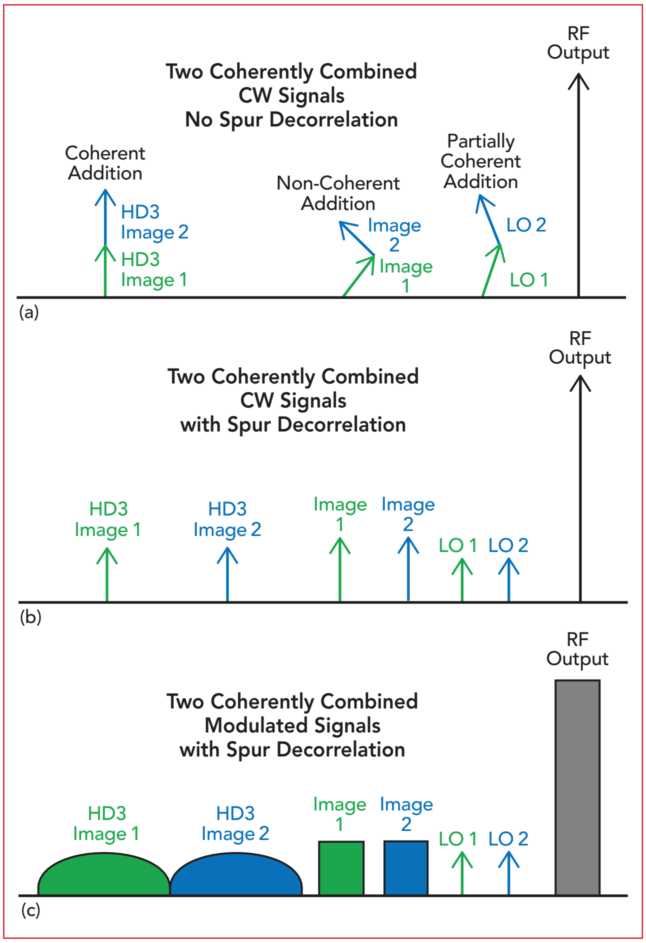


Fig. 2 Forcing spurious to be uncorrelated by programming LO and NCO frequencies across an array of waveform generators.

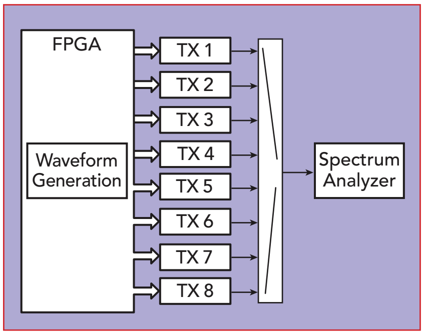
was consistently correlated across channels, the image frequency was consistently uncorrelated and the LO frequency varied depending on startup conditions. This behavior is reflected in Figure 3a, where we show coherent addition for the third harmonic, non-coherent addition for the image frequency and partially coherent addition for the LO leakage frequency.

The transceiver LOs are then set to different frequencies and the digital NCOs are adjusted in both frequency and phase such that the signals coherently combine. In this case the spurious signals produced from the image, the LO leakage, and the third harmonic, are forced to be at different frequencies. ***Figure 6*** shows the combined output. In this case, the spurs of the image, the LO leakage, and the third harmonic measured in dBc begin to spread into the noise and every spur shows an improvement when channels are combined.

When a very small number of channels are combined, as was done in this test, the spurs actually show a 20log(N) improvement in their relative levels. This is due to the signal components combining coherently and adding as 20log(N) while the spurs do not combine at all. In practice, with a large array and a much greater number of channels being combined, the improvement is expected to approach 10log(N). This is for two reasons. First, with a large number of signals being combined it is not practical to spread the spurs out sufficiently such that each one can be considered in isolation. Consider a 1 MHz modulation bandwidth as an example. If a specification says that spurious emissions are to be measured in a 1 MHz bandwidth, then ideally, the spurs would be spread out so that they are at least 1 MHz apart. If this is not possible then each 1 MHz of measurement bandwidth will include multiple spurious components. Since these will be at different frequencies they will combine incoherently and the spurious power measured in each 1 MHz of bandwidth will increase as 10log(N). However, no single 1 MHz of measurement bandwidth will contain all the spurs, so in this case "N" for the spurs is smaller than "N" for the signal. Although the incremental improvement will be 10log(N), once N is large enough for the spurious density to place multiple spurs inside the measurement bandwidth, the absolute improvement will still be better than 10log(N) compared to the system without spurious signal decorrelation, i.e. it will be somewhere between 10log(N) and 20log(N) dB better. Secondly, this test was done with CW signals. Real world signals



▲ **Fig. 3** Spurious signals in frequency: two combined CW signals with no spur decorrelation (a), two combined CW signals with forced spur decorrelation (b), two combined modulated signals with forced spur decorrelation (c).



▲ **Fig. 4** Waveform generator spurious test setup.

will be modulated and this will cause them to spread out, making non-overlapping spurious signals impossible to achieve when a large number of channels are combined. These overlapping spurious signals will be uncorrelated and add incoherently, as 10log(N), in the overlap region.

It is worth noting the LO leakage component when the LO is set to the same frequency across channels. LO leakage is due to imperfect cancellation of the LO in the analog modulator when two signal branches are summed. If the amplitude and phase imbalances are random errors then the phase of the residual LO leakage component will also be random and when many different transceiver LO leakages are summed they will add incoherently, as 10log(N), even when they are at precisely the same frequency. This should also be the case with the modulator's image component but not necessarily the modulator's third harmonic. With a small number of channels being coherently combined it is unlikely that the LO phases would be completely random and thus the cause for partial decorrelation shown in the measured data. With a very large number of channels LO phase approaches a much more random condition across channels and is thus anticipated to be an uncorrelated addition.

CONCLUSION

The measured SFDR results when LOs and NCOs are offset in frequency clearly show that the spurious created are all at different frequencies and are not coherent in the combining process, thus ensuring an SFDR improvement as channels are combined. LO and NCO frequency control is now a programmable feature in the latest Analog Devices transceiver products. The results demonstrate that this feature can be exploited in phased array applications ensuring an array level SFDR improvement over single channel performance.


Where can we take you next?


CMD241

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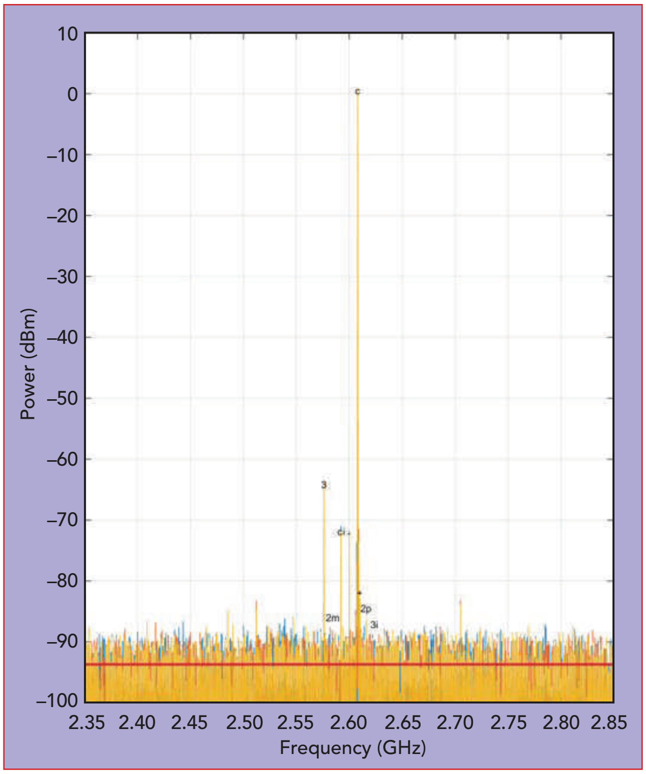
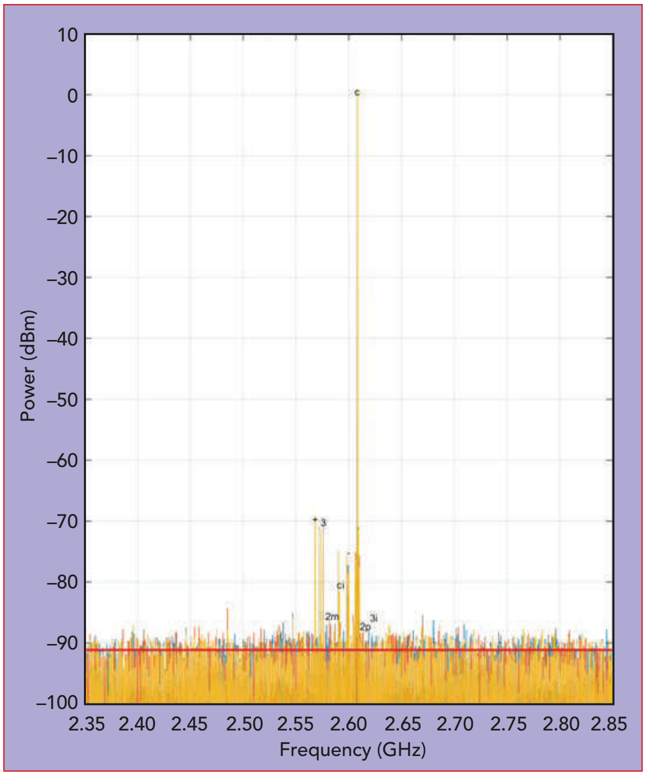


▲ **Fig. 5** Combined waveform generator spurious with LOs and NCOs set to the same frequency.



▲ **Fig. 6** Combined Waveform Generator Spurious with LOs and NCOs offset in frequency.

INVITED PAPER

Measuring Quartz Crystal Oscillator G-Sensitivity

Ivanov Yuri, Nikonov Arkady and Knyazeva Elvira
Morion Inc., St. Petersburg, Russia

Frequency stability is the key requirement for quartz oscillators. It determines the accuracy and resolution sensitivity of radar and radio navigation systems, the measurement error of measuring systems and the quality and reliability of communications systems. Frequency stability depends on many parameters including the acceleration forces applied to the crystal oscillator, which can be constant acceleration, vibration, shock, displacement, inclination or rotation. This article discusses how acceleration impacts frequency stability.

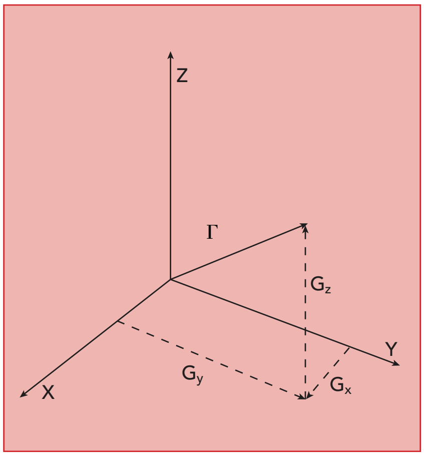


Fig. 1 G-sensitivity is a vector and depends on the direction of the applied acceleration.

The frequency stability of crystal oscillators depends on a number of parameters, including the impact of acceleration or vibration. These are critical for some applications, such as an oscillator operating on a mobile platform. This frequency stability is commonly referred to as crystal oscillator g-sensitivity. It is defined as the relative change of the oscillator's output frequency under 1g (~9.8 m/s) acceleration, and it may vary from 10^{-8} to 10^{-11} per 1g.

G-sensitivity is a vector, depending on the direction relative to three mutually perpendicular crystal oscillator axes, not only on the magnitude of the acceleration.[1] The greatest shift in oscillator frequency occurs when the applied acceleration is parallel to the g-sensitivity vector. The magnitude and direction of the g-sensitivity vector, Γ, is determined by measuring the separate, mutually-orthogonal components within the x, y and z axes (see ***Figure 1***).

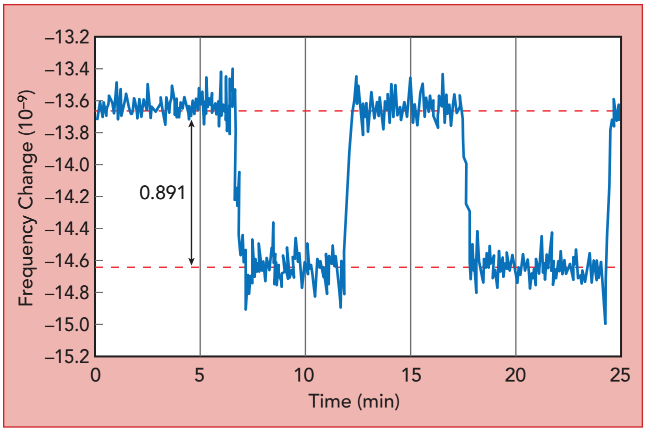


Fig. 2 G-sensitivity measurement for one axis using the tipover method.

2g TIPOVER TEST

The easiest way to measure crystal oscillator g-sensitivity along one of the axes (Gx, Gy or Gz) is to measure the frequency change caused by turning the oscillator with respect to one axis, the so-called 2g tipover test. The frequency is measured immediately before and after the ro-

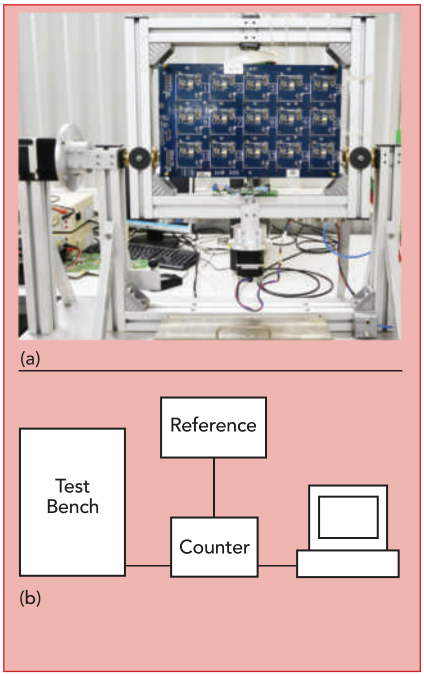


Fig. 3 Automated 2g tipover test bench for measuring 15 oscillators (a) and block diagram (b).

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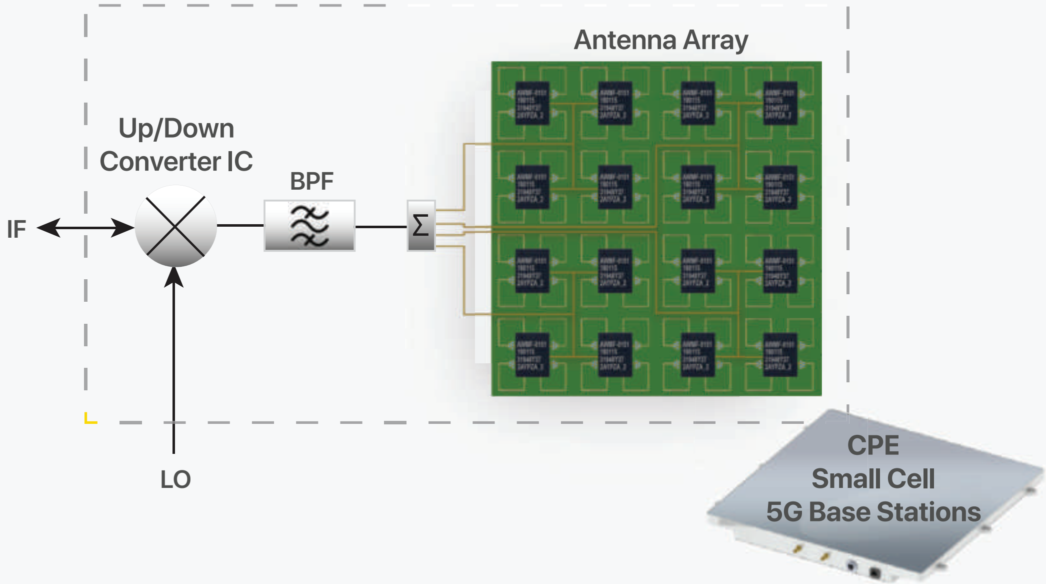

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TABLE 1

G-SENSITIVITY MEASUREMENTS

($\times 10^{-10}$)

Measurement Method	100 MHz Crystal Oscillator			10 MHz Crystal Oscillator		
	DUT #1	DUT #2	DUT #3	DUT #4	DUT #5	DUT #6
2g Tipover	7.6	6.5	10	5.0	6.0	5.1
Constant Rotation	4.5	5.4	4.4	4.7	6.6	5.7
Phase Noise with Broadband Sinusoidal Vibration	3.3	2.2	5.5	5.8	6.6	5.2
Phase Noise Measurement of SIN	3.0	2.6	5.3	6.0	6.5	5.5

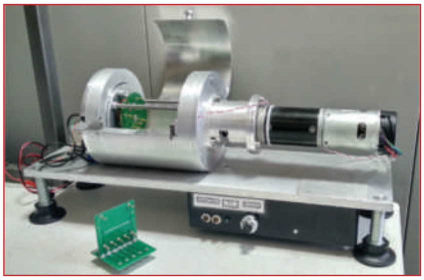


Fig. 4 An automated test bench for measuring the g-sensitivity during constant rotation.

tation. The acceleration changes by 2g during this rotation, so the measured oscillator frequency shift must be divided by two to obtain the g-sensitivity along the axis. To calculate the g-sensitivity vector, similar measurements must be performed for all three axes.[2] Then, the magnitude of the g-sensitivity will be

$$\Gamma = \sqrt{G_x^2 + G_y^2 + G_z^2} \tag{1}$$

Figure 2 shows an example of the frequency shift during several rotations around one axis. The measured shift is 0.89×10^{-9}, so the g-sensitivity along this axis is 0.45×10^{-9}. Measuring the other two axes, the g-sensitivity results are 0.3×10^{-9} and 0.21×10^{-9}, yielding the g-sensitivity vector, $\Gamma = 0.58 \times 10^{-9}$/ g.

The simplicity of the 2g tipover method is a great advantage—such measurement can be performed on a table without any additional instruments. ***Figure 3*** shows the view of the automatic test bench used to perform 2g tipover test. This test bench ensures automatic rotation around each of three oscillator axes and frequency counting immediately before and after rotation. Moreover, the test bench can accommodate 15 crystal oscillators simultaneously.

However, this method is best used to measure the g-sensitivity of

oscillators with good frequency vs. temperature stability; in this case, the measurement results agree with other methods (see ***Table 1***). Unfortunately, the method is not universal, as oscillators with poor frequency vs. temperature stability have additional frequency shifts caused by temperature variation due to convection of the air in the oscillator.

CONSTANT ROTATION

Measurement while the oscillator is constantly rotating is another way to determine g-sensitivity. With constant rotation, the temperature is evenly distributed inside the oscillator, enabling more accurate assessment of acceleration. ***Figure 4*** shows a test bench to perform this type of test. The oscillator is placed inside the cylinder, and the oscillator frequency is measured with a frequency counter during rotation, which measures the g-sensitivity for two axes at once. The test system enables the rotation rate to be varied. During rotation, the oscillator's frequency change is sinusoidal (see ***Figure 5***).

With this test method, calculating the g-sensitivity is more complicated and the results are less apparent, since each rotation changes the acceleration along two axes. Also, a very short time for the frequency count at a high rotation rate may cause significant measurement error.

The 2g tipover and constant rotation tests are only suitable for measuring low frequency oscillators, i.e., 30 MHz and below, with good frequency vs. temperature stability.

INDIRECT MEASUREMENTS

Another approach to measuring g-sensitivity is an indirect method,

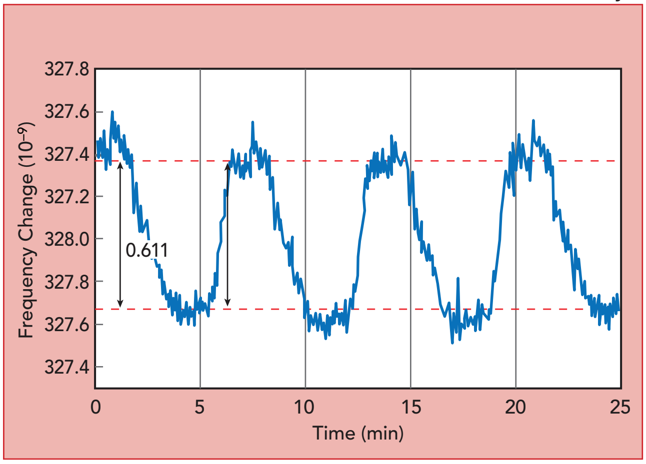


Fig. 5 G-sensitivity measurement with constant rotation of the oscillator.

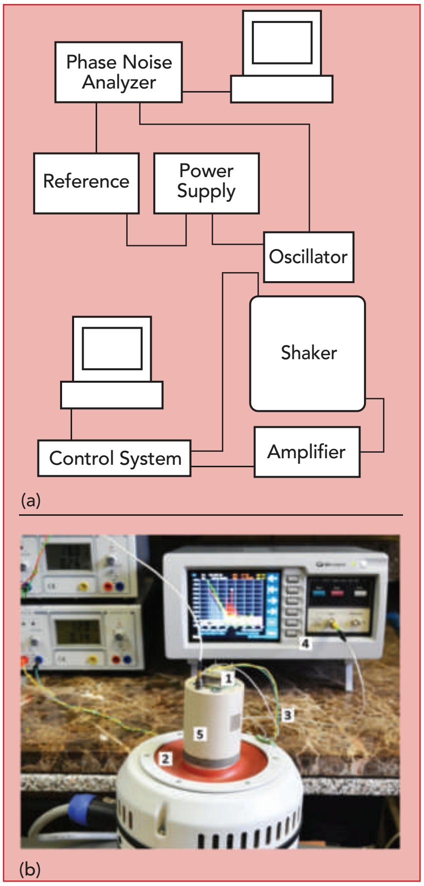


Fig. 6 Test setup block diagram (a) and bench for measuring oscillator phase noise under vibration.

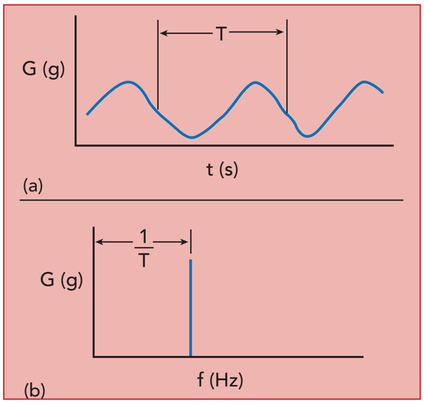


Fig. 7 Sinusoidal vibration (a) generates sidebands in the oscillator signal at the vibration frequency (b).

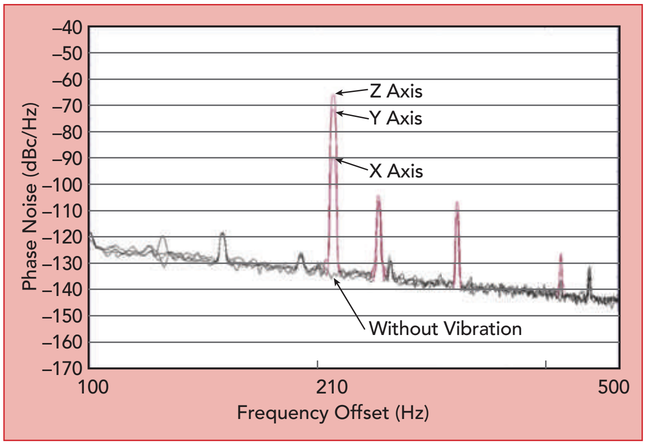


Fig. 8 100 MHz oscillator phase noise under 210 Hz sinusoidal vibration.

calculating the sensitivity from the degradation in oscillator phase noise under vibration. As previously stated, an acceleration force applied to an oscillator causes a frequency shift (Δf) proportional to the acceleration and dependent on the direction. It is calculated as

$$\frac{\Delta f}{f_0} = \Gamma \times \acute{\alpha} = y \qquad (2)$$

where f_0 is the frequency of the oscillator without vibration, $\acute{\alpha}$ is the applied acceleration, Γ is the g-sensitivity vector and y the frequency shift.[3] Using this method, errors may be caused by noise in the signal path, not the oscillator's g-sensitivity.

A test setup for measuring phase noise under vibration is shown in ***Figure 6***. The crystal oscillator (1) is placed on a vibrating plate (2) and exposed to sinusoidal or broadband vibration, defined before the start of the test. Test parameters include vibration amplitude and frequency or the frequency band for broadband vibration. The coaxial cables (3) connecting the oscillator on the vibrating plate with the measuring system (4) must be securely fixed to ensure no additional phase variation. A special fixture made of ZEDEX engineering plastic (5) attaches the oscillator on the vibrating plate to avoid magnetic fields from influencing the test at low frequencies.

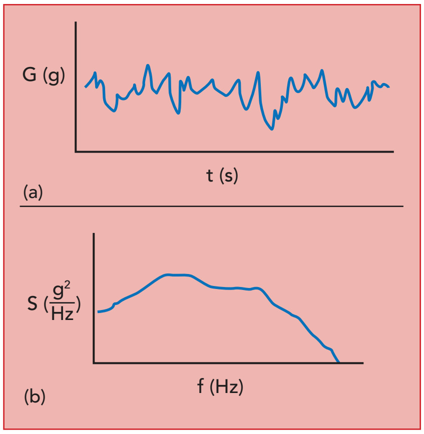


Fig. 9 Broadband sinusoidal vibration (a) creates a spectral power density of randomly distributed frequency, phase and amplitude (b).

Under sinusoidal vibration, additional sidebands appear in the

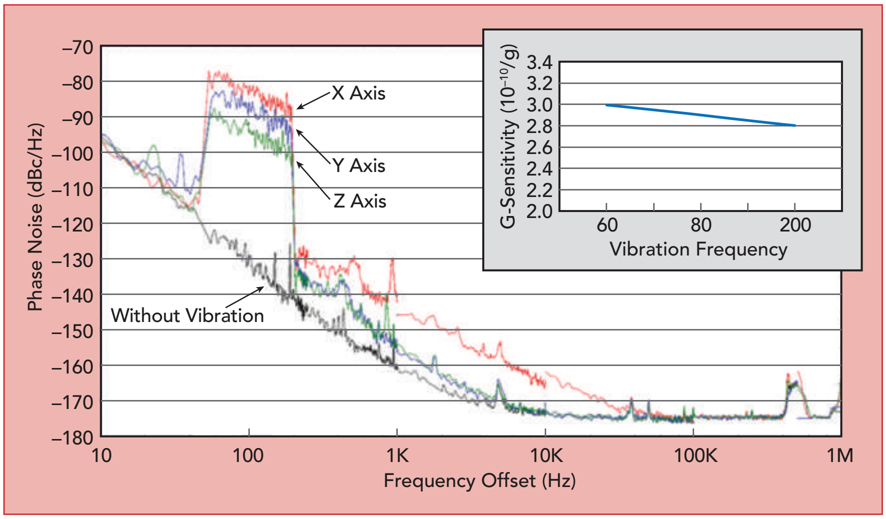


Fig. 10 Oscillator phase noises under broadband sinusoidal vibration from 50 to 200 Hz with a root-mean-square spectral power density 0.17 G^2/Hz.

signal spectrum at the vibration frequency, and the level can be measured by a spectrum or phase noise analyzer (see ***Figure 7***). The g-sensitivity along one of the crystal oscillator axes is calculated by

$$g = \frac{2f_v}{Af_0} 10^{\frac{L(f_v)}{20}} \quad (3)$$

where A is the peak value of the acceleration, f_v is the vibration frequency and $L(f_v)$ is the level of the phase noise at the vibration frequency.[3]

Figure 8 shows a phase noise measurement of a 100 MHz oscillator under sinusoidal vibration at 210 Hz and 5g amplitude. The g-sensitivity is calculated measuring the phase noise for each axis during vibration and then calculating the overall magnitude:

$$G_x = \frac{2f_v}{Af_0} 10^{\frac{L(f_v)x}{20}} = \quad (4)$$

$$\frac{2 \cdot 210}{5 \cdot 100 \cdot 10^6} 10^{\frac{-90}{20}} = 2.66 \times 10^{-11} / g$$

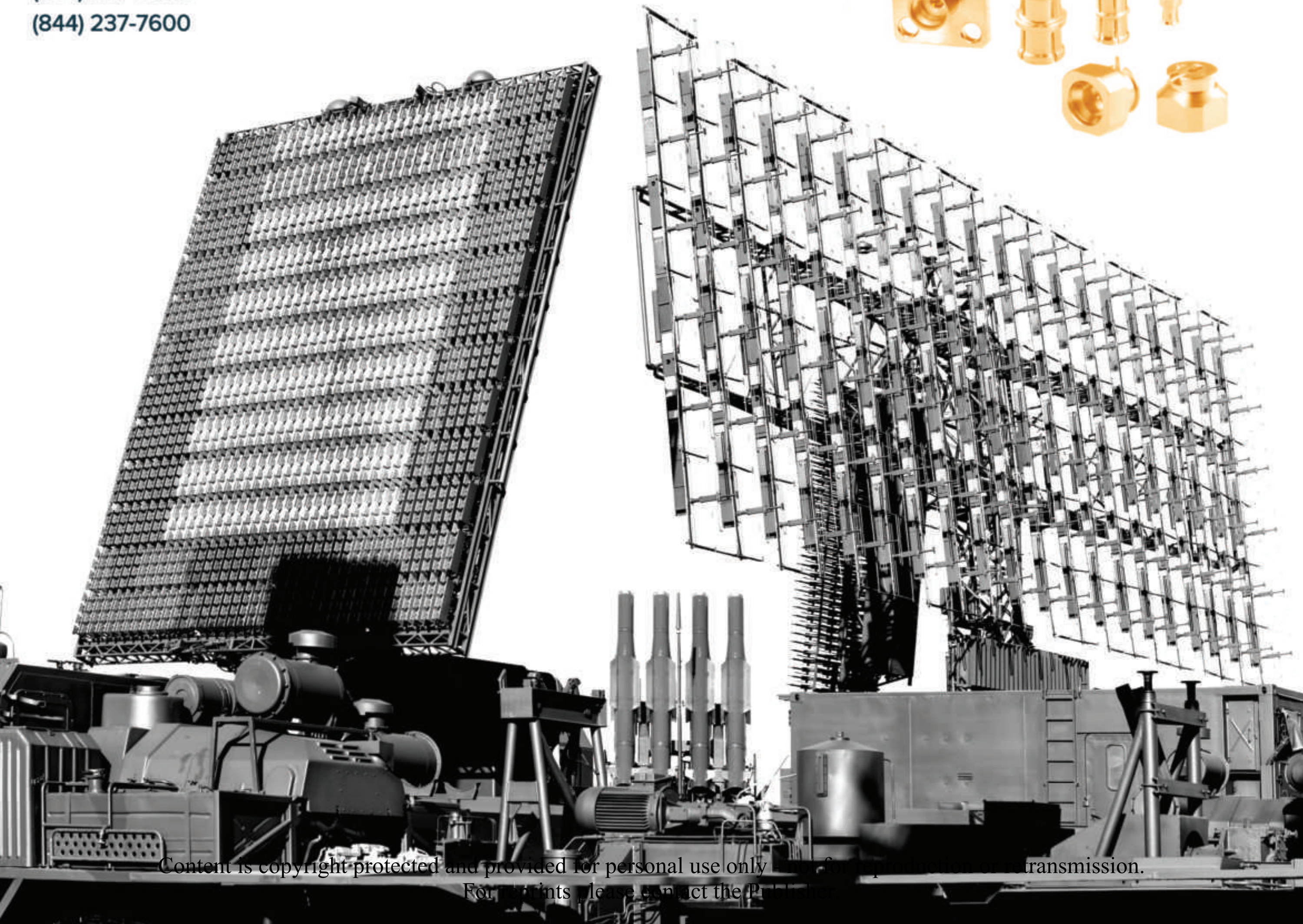
$$G_y = \frac{2f_v}{Af_0} 10^{\frac{L(f_v)y}{20}} = 2.1 \times 10^{-10} / g$$

$$G_z = \frac{2f_v}{Af_0} 10^{\frac{L(f_v)z}{20}} = 4.21 \times 10^{-10} / g$$

$$\Gamma = \sqrt{G_x^2 + G_y^2 + G_z^2} = 4.7 \times 10^{-10} / g$$

Broadband sinusoidal vibration can also be used to evaluate g-sensitivity. In this case, the vibration is randomly distributed over frequency, phase and amplitude (see ***Figure 9***), with the acceleration described as a spectral power density $S_a(f)$.[4] The impact of random vibration on the oscillator's phase noise is calculated from

$$L(f_v) = 20\log\left(G \frac{f_0}{f_v} \sqrt{\frac{S_a(f_v)}{2}} \right) \quad (5)$$



and the g-sensitivity is calculated from

$$G = \frac{f_v}{f_0}\sqrt{\frac{2}{S_a(f_v)}\,10^{\frac{L(f_v)}{20}}} \qquad (6)$$

where $S_a(f)$ is the spectral power density of the random acceleration (g^2/Hz).[3]

Figure 10 shows the degradation of a 100 MHz oscillator's phase noise performance under broadband sinusoidal vibration from 50 to 200 Hz and a root-mean-square spectral power density 0.17 G^2/Hz.

The level of phase noise under vibration depends on the oscillator's g-sensitivity and applied vibration—not on the phase noise of the crystal oscillator itself. To see this, refer to ***Figure 11***, which compares the measured phase noise of four 100 MHz oscillators with random vibration and without vibration. Two of the oscillators, shown by the purple and orange plots, have considerably different phase noise (−129 and −149 dBc/Hz at 100 Hz offset, respectively) yet the same g-sensitivity (1 × 10^{-9}/g with 6g amplitude vibration) and phase noise under vibration (−52 dBc/Hz at 100 Hz). The oscillator with a better g-sensitivity of 3 × 10^{-10}/g (blue curve) has a phase noise under vibration of −63 dBc/Hz at 100 Hz offset—also better. Comparing oscillators under vibration, the level of phase noise of the crystal oscillator with the lower g-sensitivity is lower than the phase noise of the oscillators with high g-sensitivity.

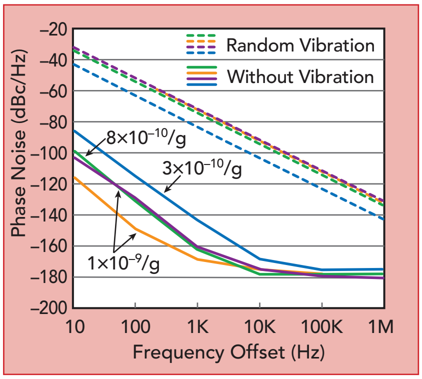


Fig. 11 Oscillator phase noise comparing performance with no vibration and random vibration.

SUMMARY

Table 1 compares the results of several oscillator measurements by the methods described in this article. For 10 MHz oscillators, the results from all the methods are similar, while the results of the 2g tipover test for 100 MHz crystal oscillators show greater values than the indirect measurement methods derived from the phase noise. The g-sensitivity measurement with sinusoidal vibration is less susceptible to thermal processes such as air convection, and this method provides the most accurate evaluation of oscillator g-sensitivity.■

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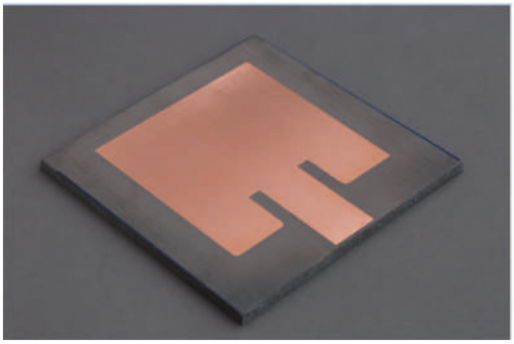
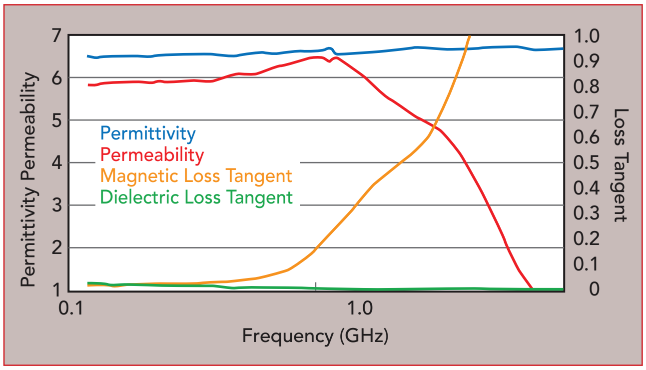


Laminate Materials Simultaneously Increase μ and ε, Reducing Antenna Size

Rogers Corp.
Chandler, Ariz.

MAGTREX™ copper clad laminate with matched permittivity and permeability is another industry first from Rogers Corp. MAGTREX materials have a refractive index dramatically higher than can be achieved in a composite printed circuit board (PCB) material, with an impedance matched to free space. This enables antenna designers to create antennas with a combination of size, efficiency and bandwidth significantly greater than for antennas produced on traditional high dielectric constant substrates.

Antenna miniaturization has been an important topic since the advent of wireless communications. The physical size of an antenna is generally a function of its free space wavelength: $\lambda = c/f$. Antenna miniaturization is particularly important when the operating frequency is low, which normally requires large antennas. Of course, like most engineering problems, antenna miniaturization is a balancing act among trade-offs within fundamental limitations. Generally, when an antenna is miniaturized, its bandwidth, efficiency or both will decrease, limiting the practical use of electrically small antennas.



▲ Fig. 1 Typical MAGTREX 555 properties at 23°C.

One common method for miniaturizing antennas and other wavelength-based RF structures is using materials with a high refractive index: $\sqrt{(\mu_r \varepsilon_r)}$, where μ_r is the relative permeability and ε_r the relative permittivity. With these materials, the effective propagation velocity is slowed below the speed of light, reducing the physical distance of a wavelength in the structure. With most available materials used at frequencies above a few MHz, μ_r is assumed to be 1, and any increase in refractive index is obtained by increasing the relative permittivity (ε_r). While this is effective for antenna miniaturization with some performance requirements, it introduces trade-offs. If the dielectric constant of a substrate is increased, while the permeability remains constant, the substrate's intrinsic imped-

ance (μ/ε) will decrease, adding design complexity. For a given impedance and thickness, the width of the transmission line will decrease, resulting in higher loss per unit length. When the intrinsic impedance drops, the structure is no longer matched to free space, reducing the radiation efficiency of the antenna. MAGTREX materials increase μ and ε simultaneously, mitigating those challenges.

For many years, magnetically permeable materials have been used to produce antennas with extremely small electrical sizes: ferrite core loop antennas for AM radio and other medium frequency (300 kHz to 3 MHz) and high frequency (3 to 30 MHz) applications. These produce receiver antennas which have dimensions in the tens of centimeters at frequencies which have wavelengths from 10 to 1000 m. However, the efficiency of these antennas has limited their practical use to receivers, and the availability of materials restricts frequencies to the low MHz.

Interest in using magnetically permeable materials from the hundreds of MHz to GHz has persisted, increasing after a foundational paper by R. C. Hansen and Mary Burke, who derived a fundamental relationship between microstrip patch antenna bandwidth and magnetic permeability. This publication reached an important conclusion: the reduction in patch antenna size attributable to magnetic permeability does not reduce antenna bandwidth. For a given miniaturization value (the με product), the bandwidth of the antenna improves by a factor of μ.

However, producing a suitable magnetically permeable composite material for use at frequencies above 100 MHz is a monumental challenge, requiring a combination of materials science, chemical engineering and electrical engineering. After years of research, Rogers Corp. introduced MAGTREX 555 materials in 2018. These laminates offer a permeability of six with a matched dielectric constant, with or without copper cladding. The combination of a high refractive index and intrinsic impedance enables designers to use the material and realize advantages over conventional PCB laminates. MAGTREX laminates have well-behaved magnetic properties to roughly 500 MHz, the region where antenna size is the greatest challenge. The photo shows a 300 MHz patch antenna measuring 15 cm x 15 cm.

MAGTREX materials can be used to partially load the area between the radiating structure of an antenna and the ground plane. By optimizing the material shape and thickness, the designer can control the degree of miniaturization and manage the impact on bandwidth and the material's effect on efficiency. Rogers has presented one case study in the webinar "An Introduction to Magneto-Dielectric Materials for Antenna Miniaturization," available for viewing at microwavejournal.com/events/1810.

VENDORVIEW

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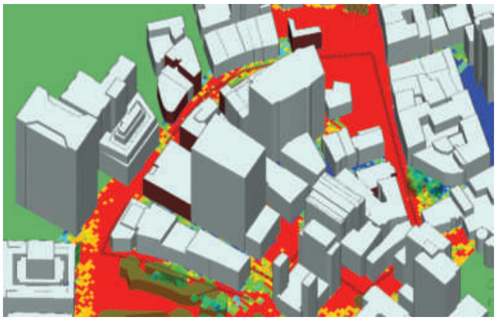
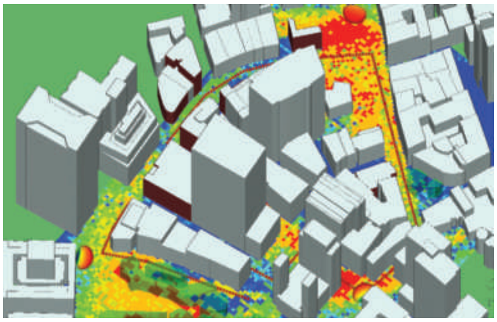
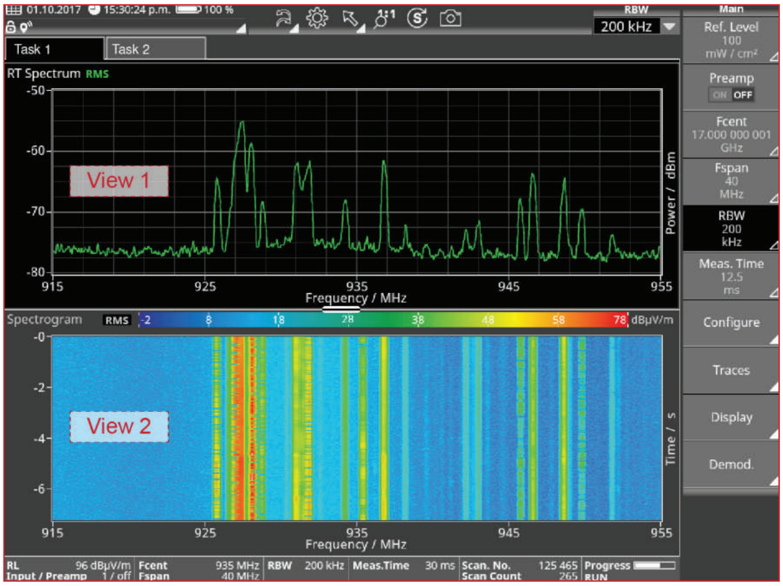




Real-Time Remote Analyzer Based on SignalShark

Narda Safety Test Solutions
Pfullingen, Germany

Narda Safety Test Solutions has released a remote-controlled version of its SignalShark signal analyzer, offering flexibility, reliability and an attractive price/performance ratio. The new SignalShark Remote Analyzer detects, analyzes, classifies and localizes RF signals between 8 kHz and 8 GHz. With 40 MHz real-time bandwidth, the Remote Analyzer can detect pulsed signals down to 3.125 µs with 100 percent probability of intercept. Its output is a 20 MHz stream of 16-bit I/Q data, which is compliant with the VITA 49 standard. In spectrum mode, the scan rate of up to 50 GHz/s ensures signals are captured, even when sweeping large frequency bands. The real-time spectrum, spectrogram and persistence analysis functions enable all captured signals to be analyzed with exceptionally high resolution in both time and frequency (see ***Figure 1***).



▲ Fig. 1 The SignalShark Remote Analyzer has the same graphical user interface as the SignalShark Handheld, so remote control software is not essential; a remote desktop application is sufficient.

Judging by its specifications, the Remote Analyzer is equal to the powerful handheld SignalShark from which it was derived. The remote unit has been modified and optimized for applications requiring efficient, centrally-controlled monitoring, where the analyzers may be widely spaced over a large area. The measurement core of the Remote Analyzer is identical to the handheld SignalShark. It adds four switchable RF inputs, enabling several antennas to be connected covering different directions or frequency ranges. This eliminates the need for a complex, external switch to connect multiple antennas to a conventional analyzer with a single RF input.

The internal computer running Windows 10 evaluates the measurement data and ensures that only processed, relevant data is passed back to the control center—irregularities in the spectrum being observed, for example. The remote unit handles the monitoring tasks on site, using far less bandwidth than sending all signals back to the control center. 99.99 percent of the time, there is no interference and central processing is not required. The remote device is easily accessed whenever needed, to review results for the past 24 hours, for example.

The Remote Analyzer can be operated with an antenna for automatic direction finding and time difference of arrival, techniques used with several spectrum monitoring stations to localize interfering signals in urban areas. One automatic antenna can determine the bearing of an interference source; at least two antennas at different locations are required to determine the position by triangulation. SignalShark Remote Analyzers can be located on top of buildings at several locations, each equipped with an independent power supply, solar cells and a back-up battery. When an interfering signal is detect-

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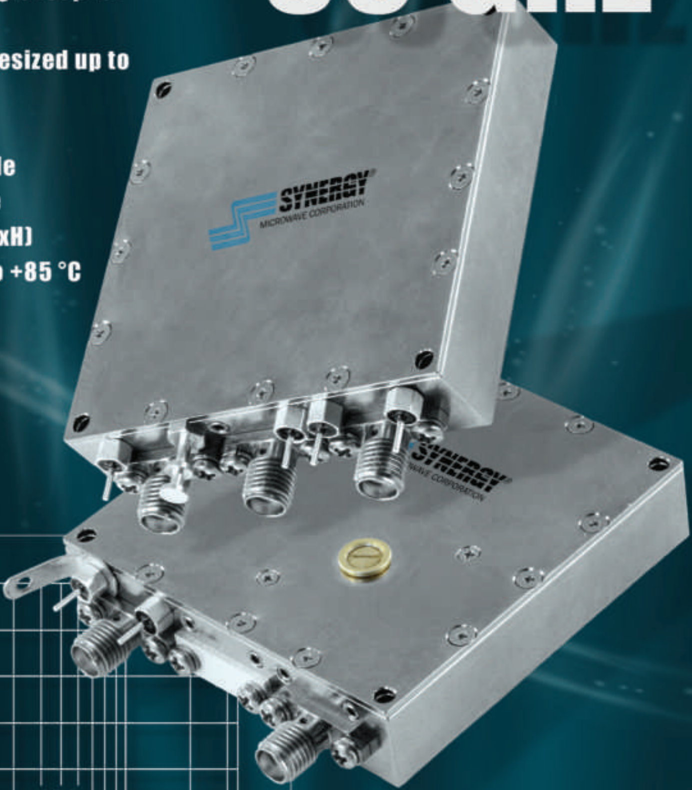

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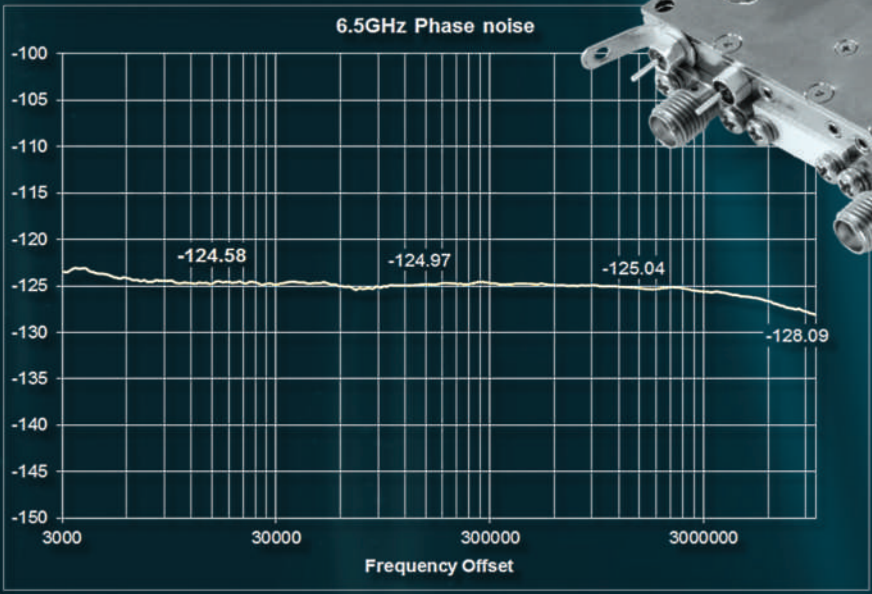

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ed, the data from the remote units is passed back to the system operator's computer via an LTE modem and the cellular network, where the system operator can identify the location of the interfering signal.

To support the full range of centralized monitoring, analysis and direction finding functions from a remote location, the monitoring receiver must be ITU compliant, have good time resolution—including absolute time mapping by GPS synchronization—and be fully remote-controlled with a standardized data transfer protocol. The SignalShark Remote Analyzer uses the Standard Commands for Programmable Instruments remote control language and VITA 49 streaming, which facilitates integration in a network, simplifies development of drivers and ensures the data can be understood by any software. Running on the Windows 10 platform means the Remote Analyzer will run third-party applications, offering users the flexibility to handle an almost unlimited range of spectrum monitoring applications.

Fig. 2 The Remote Analyzer can be used free standing or mounted in a standard rack for fixed installations.

The modular design of the unit, with an aluminum casing and weighing just 2.1 kg, is a further advantage for its versatility, as it can be used free standing. In this mode, the USB ports enable a keyboard and display to be connected. Installed for stationary use, several Remote Analyzers can be installed in a 19 in. rack—in a 1U high double horizontal configuration (see ***Figure 2***) or one above the other (2U high), for example. Using two or more analyzers in the same rack is effective and economical for monitoring larger bandwidths, as several analyzers are considerably cheaper than a single high-end device, and they can be scaled and cascaded to cover the required frequency range. For example, the first unit might cover 360 to 400 MHz, the second from 400 to 440 MHz.

The advantages of the SignalShark Remote Analyzer make it ideal for users needing high precision and reliability for remote RF monitoring. The analyzer is well-suited for regulatory authorities, security and intelligence services, the military, cellular operators and service providers and field engineering. Built on the qualities of the powerful, handheld SignalShark, the new Remote Analyzer solves complex measurement and analysis problems because of its sensitivity, high immunity to overmodulation, reliability and speed.

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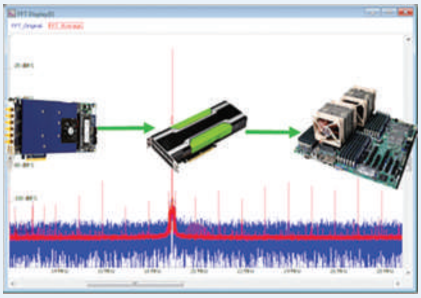


Digitizers with Ultra-Long Signal Averaging

A signal averaging package from Spectrum Instrumentation offers new capabilities for acquiring and averaging signals, particularly low-level signals or signals hidden in random noise. Spectrum's CUDA Access for Parallel Processing (SCAPP), used with the company's digitizers, harnesses the power of any CUDA-based GPU card. SCAPP enables porting data directly to the GPU, using remote direct memory access (RDMA), where high speed time and frequency signal averaging is performed without length limitations. Since the data is ported directly to the GPU card without intervention by the host processor, averaging can be performed on signals of almost any length.

SCAPP works with Spectrum's fast M4i and mid-range M2p series PCIe digitizers, so users can select the performance best matching the signal acquisition requirements. The M4i series samples up to 5 GSPS with 8-bit resolution, 500 MSPS with 14-bit resolution or 250 MSPS with 16-bit resolution. The M2p cards sample from 20 to 125 MSPS with 16-bit resolution, with up to eight channels per card. The digitizer cards include flexible trigger, acquisition and readout modes, enabling them to average signals when trigger rates are extremely high.

The averaging package is part of SCAPP's driver package and includes the RDMA extension for direct data transfer from the digitizer to the GPU, either directly for PCs running LINUX or via the CPU for systems running Windows. The package contains examples for interacting with the digitizer and a set of CUDA parallel processing routines for averaging. All software is written in C/C++, which can easily be modified for users wishing to develop unique algorithms.

VENDORVIEW

Spectrum Instrumentation GmbH
Großhansdorf, Germany
www.spectrum-instrumentation.com

50% Smaller GaN PAs for 5G mMIMO and Small Cells

RFHIC has reduced the size of two of the company's 8 W GaN hybrid power amplifier (PA) modules, making them 50 percent smaller than the previous designs—optimal for 5G massive MIMO and small cell base stations.

The RPAM35008-25 covers 3.4 to 3.6 GHz (200 MHz in band n78), delivering 8 W (39 dBm) average output power and 45 percent power-added efficiency (PAE) with a 7 dB peak-to-average ratio waveform. The PA has a saturated output power of 47 dBm and 25 dB gain. The RPAM37508-25 covers 3.7 to 3.8 GHz (100 MHz in n78) and provides the same performance.

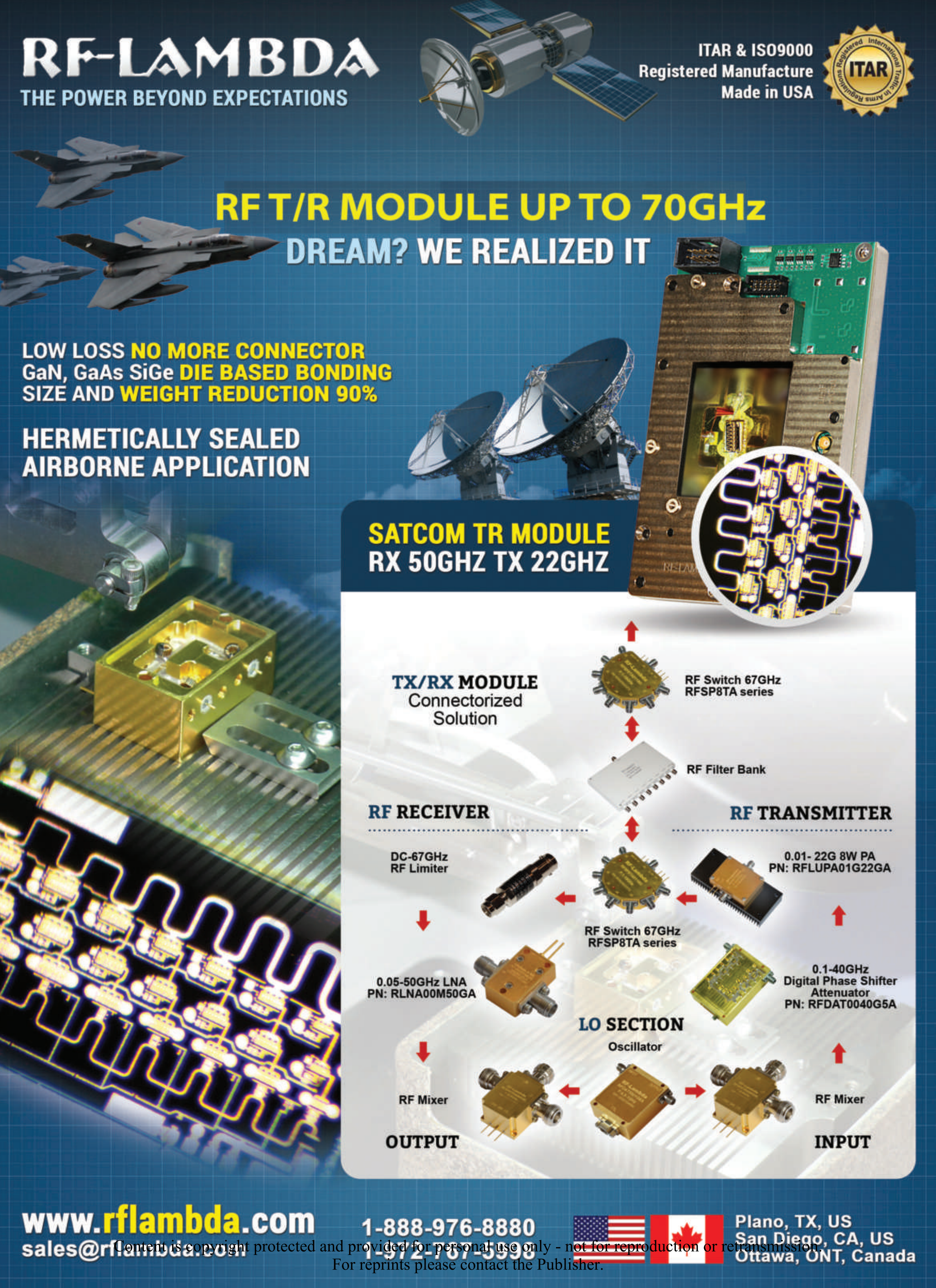
Both PAs are two-stage Doherty designs, using GaN in both amplification stages, and are fully-matched to 50 Ω, requiring minimal external components. The PAs are assembled in plastic QFN surface-mount packages and have excellent thermal performance and a much smaller footprint compared to other modules on the market.

The high PAE of these PAs improves base station power consumption, reducing the operating costs for the service provider. The efficiency also eases base station thermal design, critically important for meeting the size constraints of small cells and massive MIMO antennas.

For other frequencies and power levels, RFHIC can customize these designs to meet unique customer needs.

For more than 20 years, RFHIC has been committed to providing the highest quality GaN transistors, PAs and subsystems for telecom, military and ISM applications.

RFHIC Corp.
Anyang, South Korea
rfhic.com/eng/


RF-LAMBDA
THE POWER BEYOND EXPECTATIONS
ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
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RF T/R MODULE UP TO 70GHz
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTOR
GaN, GaAs SiGe DIE BASED BONDING
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HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
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Solution
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RFSP8TA series
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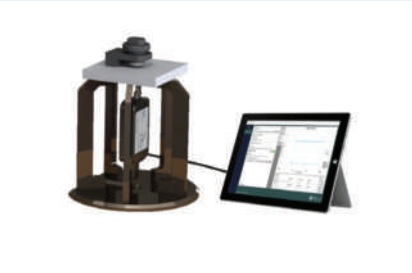
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
OUTPUT
INPUT
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada



Epsilometer Measures Dielectric Properties to 6 GHz

For measuring the dielectric properties of substrate materials, Compass Technology Group and Copper Mountain Technologies (CMT) have developed an epsilometer measurement solution to characterize sheet specimens from 0.3 to 3 mm thick and frequencies from 3 MHz to 6 GHz. The test system combines a measurement fixture with CMT's R60 VNA and software, Epsilometer software and a calibration sample.

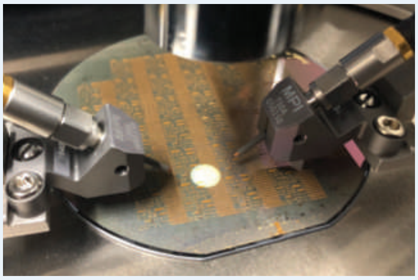
The dielectric analyzer measures the complex dielectric permittivity (epsilon) with a simple, nondestructive methodology: a material specimen is inserted into the device and scanned to obtain its microwave response versus frequency. Unlike other dielectric analysis methods, the epsilometer method uses computational electromagnetic modeling to invert the dielectric permittivity and loss. A database in the epsilometer software is used for the computation and handles permittivity values up to 25.

This technique is a significant advance over conventional capacitive methods, which use analytical approximations and are limited to frequencies below 1 GHz. The computational-based inversion enables a simplified calibration procedure, making the device easy to use, even for engineers and technicians without microwave experience.

The epsilometer measurement solution combines Compass Technology Group's expertise characterizing microwave materials with Copper Mountain Technologies' metrology-grade portable network analyzers to offer an innovative solution for measuring the dielectric properties of materials. The system can be used during the design and manufacturing of microwave and antenna substrates, antenna radomes and packaging materials, and frequency coverage to 6 GHz supports the major wireless standards, including LTE, sub-6 GHz 5G, Wi-Fi, Bluetooth, IoT and GPS.

Copper Mountain Technologies
Indianapolis, In.
www.coppermountaintech.com

Compass Technology Group
Alpharetta, Ga.
www.compasstech.com



GaN on Diamond PAs for CubeSat Radios

Akash Systems is on a mission to create efficient and affordable power amplifiers (PA) and radios for satellites using pioneering materials technology. Since raising seed funding in 2017, Akash has developed GaN on Diamond PAs and radios, offering two radios for high data rate small satellites. The first-generation of CubeSat radios, planned to complete in 2019, will integrate with existing ground station and satellite infrastructure and promise the highest data rates on the market. The X-Band radio will transmit and receive up to 400 Mbps, and the Ka-Band version will exceed 1 Gbps.

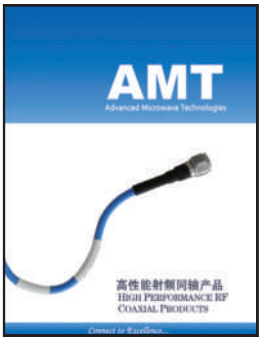
The performance of Akash's radio technology is achieved through its proprietary GaN on Diamond technology, based on a 2003 invention lifting GaN epitaxy from its original growth substrate, silicon, and transferring it to a synthetic chemical vapor deposition diamond substrate. The thermal advantage of synthetic diamond technology keeps the amplifier operating at a cool temperature, increasing the satellite's energy efficiency.

The worldwide demand for data is greater than the bandwidth and power capabilities of today's communications infrastructure. Akash seeks to use its innovative materials and satellite technologies to meet this demand, helping deliver new services to the market—1 Tbps downlink data rates, HD video, high resolution multi-spectral imaging, powerful radars and "burst" communications for mobile, enterprise and campus environments. Akash's customer base of small satellite manufacturers and owners can integrate the CubeSat radio into their satellites, from 3U CubeSats to microsatellites. The primary CubeSat radio users will likely be Earth observation satellites.

Akash's products share a common goal: expanding broadband communications access around the planet by reducing satellite manufacturing and launch costs through smaller, faster, cheaper and more energy efficient satellites.

Akash Systems Inc.
San Francisco, Calif.
akashsystems.com
sales.help@akashsystemsinc.com

High Performance RF Coaxial Products Catalog



Advanced Microwave Technology (AMT) is a leading company in research, development, designing, manufacturing and distribution of RF/microwave and mmWave 50 Ω coaxial cables, connectors, adapters, cable assemblies and passive devices. Based on the profound understanding of material application features and manufacture techniques, using advanced facilities and test equipment, AMT makes excellent products for its customers. AMT offers many different kinds of connect solutions to meet the demands of customers.

Advanced Microwave Technology
www.advancedmicrowave.net/

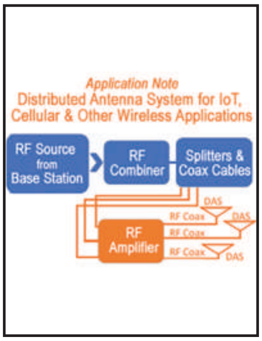
ATC Product Selection Guide

American Technical Ceramics' (ATC) new Product Selection Guide presents a comprehensive overview of ATC's capacitors, inductors, resistive products and thin film components for all RF/microwave applications. User-friendly, color-coded frequency range categories offer fast and easy component look up over a broad range of applications. A separate section for each frequency range category provides additional specifications and attributes for each product. Find RF passive components quickly with ATC's new and improved Product Selection Guide by going to their website.

American Technical Ceramics
www.atceramics.com/Userfiles/prod_select.pdf

DAS for IoT, Cellular and Wireless Applications

VENDORVIEW



The rapid growth in IoT promises lucrative business opportunities. In places where traditional distribution services cannot provide the required signal strength, Distributed Antenna System (DAS) can be used. By deploying a robust and economical DAS system, governments or businesses can ensure robust support for IoT within their facilities and be positioned to deliver critical wireless services now and in the future. AR's process of choosing the right amplifiers and antennas for your DAS requirements helps you select the right system for your application.

AR RF/Microwave Instrumentation
www.arworld.us/html/appNote-request.asp?appnote=78

Products for Radar, EW and More

VENDORVIEW

CPI Beverly Microwave Division (BMD) is the world's largest manufacturer of receiver protectors. CPI BMD designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare (EW), medical and scientific applications. Their products are found in numerous radar systems operated by the U.S. military and militaries around the world. They also manufacture SSPAs, magnetrons, solid-state switches and integrated microwave assemblies, as well as TWTs, CFAs and pressure windows. Contact BMDMarketing@CPII.com for your high-power microwave components upgrades.

CPI Beverly Microwave Division
www.CPII.com/BMD

High Performance RF/Microwave MMIC Selection Guide

VENDORVIEW

Choose from over 160 high performance RF/microwave MMICs from Custom MMIC, a leader in RF/microwave MMIC design. Custom MMIC offers a broad range of MMIC product categories including amplifiers (low noise, distributed, power, driver low phase noise), attenuators (voltage variable, digital), mixers, multipliers, phase shifters, switches, space qualified and evaluation boards. This handy online selection guide provides you with a quick and easy way to find the best MMIC for your application.

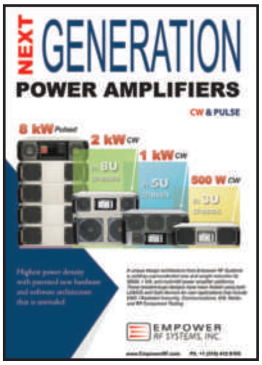
Custom MMIC
www.custommmic.com

New SMP/SMPM Catalog

Delta Electronic Manufacturing offers a full line of SMP and SMPM connectors. These high performance microwave connectors allow devices to be connected in a modular fashion, without the need for cables or threaded coupling mechanisms. Central to the SMP/SMPM design is the floating female to female "Bullet" adapter. This adapter, available in different lengths, provides the axial and radial float required for the blind-mate, plug-in functionality of the interface. Delta's SMP series is designed in accordance with DSCC 94007, 94008 and Mil-STD-348A.

Delta Electronics Mfg. Corp.
www.deltarf.com/pdf/DeltaSMP_SMPM_SMPS.pdf

Next-Gen Power Amplifiers Catalog

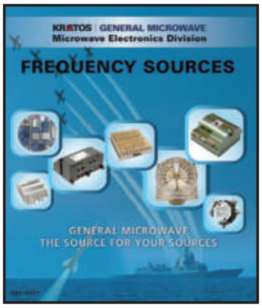


VENDORVIEW

Empower RF's newest catalog of solid-state microwave and RF system amplifiers can be downloaded now. When it comes to delivering big power reliably, efficiently and at lower cost, Empower RF has a superior modern architecture validated with a proven track record delivering high-power CW and pulse RF and microwave amplifiers for radar, EW, communications and product testing. These amplifiers offer high efficiency, accurate metering and self-protection specific to your waveforms.

Empower RF
www.empowerrf.com/download/NextGenSystems.pdf

Frequency Sources Short Form Catalog



General Microwave Corp. has designed and manufactured cutting edge microwave frequency sources since 1987. This Short Form Catalog includes sources ranging from free running voltage and digitally controlled oscillators to fast (1 usec) indirect synthesizers, company profile and a wideband frequency modulation applications and techniques tutorial. Specially featured is the Series SM60 family of fast indirect synthesizers capable of analog and digital frequency modulation while center frequency remains in the pure locked mode.

General Microwave Corp.
www.kratosmed.com

New Space Brochure

K&L Microwave has been a key supplier to space programs since the Apollo 17 lunar sounder experiment in 1972. K&L has supported customers with high-reliability filter products for integration into flight equipment, providing bandpass, highpass, lowpass and bandstop configurations. As a supplier of custom filter products, K&L has the expertise and resources for determining how best to meet customer space flight requirements. A highly trained engineering staff utilizes specialized in-house and purchased software tools to identify and realize advantageous designs. Download K&L's new brochure and find out how K&L can be "Your Partner in Space."

K&L Microwave
www.klmicrowave.com/

250+ Pages of Wired and Wireless Products

L-com's new 2019 Product Guide is now available. This year's product guide is full of wired and wireless connectivity products that were designed to help you get your job done. L-com's product guide has long been regarded as a valuable resource used by technicians, IT professionals and engineers. The guide's detailed tutorials and tips also make it an excellent educational resource. Featured product lines include cables and connectors, WLAN antennas, NEMA rated enclosures, lightning protectors and more.

L-com
www.l-com.com/content/Article.aspx?Type=L&ID=620

GaAs MMIC Portfolio

Marki Microwave's cutting-edge GaAs MMIC portfolio empowers their customers to design faster, simplify production, eliminate complexity and shatter performance barriers. Marki continues to be a leader in high linearity broadband mixers, while applying their passive component expertise to MMIC filters, baluns, quad hybrids, equalizers and multipliers. Marki's latest LO driver amplifiers pair perfectly with all of their mixer products. Products up to 90 GHz are available in bare die, surface mount and connectorized packages.

Marki Microwave
www.markimicrowave.com

Product Guide Featuring MIL-STD-1553B Solutions

The new MilesTek product guide is filled with detailed technical information and specifications covering a host of MIL-STD-1553B, Ethernet and Fiber Optic products and more. Featured product lines include 1553B data bus couplers, bus and stub cables, relay devices, Twinaxial and Triaxial cables and connectors, military/aerospace and harsh environment Ethernet cables and connectors and a range of rugged fiber optic product solutions.

MilesTek
www.milestek.com/t-catalog.aspx

Solutions for 4G and 5G

Pivotone specializes in designing, manufacturing and selling RF/microwave and mmWave components, devices and module products used in 4G and 5G applications including wireless base stations, indoor coverage and network optimization systems, microwave point-to-point communication systems, IoT and SATCOM equipment. Products include low PIM filters and diplexers; dielectric filters; mutiplexers, combiners and POI; TMA, RRU/RRH; RF multiport antenna; 5G MIMO antenna; off-the-shelf products; microwave filter and diplexers; microwave couplers, OMT, isolators and integrated modules. Product technology covers frequency ranges up to 90 GHz and beyond.

Pivotone Communication Technologies Inc.
www.pivotone.com

Test & Measurement Catalog 2019

VENDORVIEW

Almost 300 pages full of information about the Rohde & Schwarz test & measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and the ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order from Customer Support (Order number: PD 5213.7590.42 V 08.00).

Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

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International Sales Manager
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Tel: +44 20 7596 8742

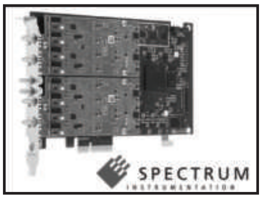
or visit www.eumweek.com

2019 Phase Adjusters Catalog

The catalog shows in detail phase adjusters for different frequency ranges: DC to 2, 3, 8, 12.4, 18, 26.5, 40, 50 and 63 GHz; factory and customer phase adjustable connectors, phase adjustable cable assemblies, etc. Phase adjusters are designed for constant impedance over the whole adjustment range. They are employed to adjust the electrical separation of other components without introducing additional mismatch. All step discontinuities have been carefully compensated. Locking screws are provided to comfort the sliding tension and to lock at the desired adjustment.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com

Updated Catalog
VENDORVIEW



Spectrum Instrumentation have introduced six brand new arbitrary waveform generators (AWG) to their 2018/2019 print and PDF catalog. These new "65" series AWGs are optimized for signal quality, size and cost. They use the latest 16-bit digital-to-analog converters and a card length of only 168 mm to fit into nearly every PC, turning it into a highly flexible signal source with 40 or 125 MS/s and 1 to 4 channels per card.

Spectrum Instrumentation
www.spectrum-instrumentation.com

DC to 110 GHz Products Overview

Suzhou Talent Microwave Inc. manufactures the highest grade microwave cable assemblies, coaxial connectors and microwave components. Talent's products serve more applications than before, which can be found in systems ranging from military communications, telecom communications, radar, satellite to a wide range of test equipment. Talent offers DC to 110 GHz microwave/mmWave cable assemblies, phase and amplitude stable test cable, VNA test cable, coaxial adaptors, power dividers and couplers, mechanical coaxial switch, attenuators and more. Talent Microwave always keeps improving and innovating their products and provides the best products to customers.

Talent Microwave
www.talentmw.com

New Catalog

Shanghai Xin Xun Microwave Technology Co. Ltd. is specialized in the low loss RF cable, RF cable, stationary phase signal communication cables for nuclear power, special high temperature resistant cable, RF coaxial connector, cable assembly and microwave passive components manufacturing enterprises. Currently, the company owns 24 patents in China. In 2019, the company's production base will be moved to Nantong, a city north of Shanghai. The new factory covers an area of more than 4,000 square meters and has four clean workshops. The testing center will be expanded to cover 500 square meters.

Shanghai Xin Xun Microwave Technology Co. Ltd.
http://xinxunmc.com/index.php/Eng/honor.html

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Latest Trends in Active Electronically Scanned Antennas (AESAs)
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Past Webinars On Demand

Critical Material Properties for Millimeter-Wave Radar Applications for Autonomous Driving

Sponsored by: Rogers Corporation

Presented by: Joey Kellner, Market Segment Manager and John Coonrod, Technical Marketing Manager

microwavejournal.com/events/1841

Alternatives for Measuring Linearity of 5G and Radar GaN Devices

Sponsored by: Boonton

Presented by: Walt Strickler, VP and General Manager of Boonton Electronics & Matthew Diessner, Director of Business Development for Boonton Electronics and Noisecom

microwavejournal.com/events/1840

Designing for DDR4 and Beyond

Sponsored by: Keysight Technologies

microwavejournal.com/events/1838

5G mmWave -- A Challenge for Device Testing and How to Solve It

Sponsored by: Rohde & Schwarz

microwavejournal.com/events/1834

NEW PRODUCTS

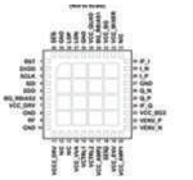
FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE
FEATURING VENDORVIEW STOREFRONTS

COMPONENTS

Wideband Integrated Microwave Up- and Down-Converter

VENDORVIEW

Analog Devices announced the ADMV1013 and ADMV1014, a paired highly integrated microwave up- and down-converter,



respectively. These ICs operate over a very wide frequency range with 50 Ohm match from 24 up to 44 GHz, facilitating ease of design and reducing the costs of building a single platform that can cover all 5G mmWave frequency bands including 28 and 39 GHz. Additionally, the chipset is capable of flat 1 GHz RF instantaneous bandwidth supporting all broadband services as well as other ultra-wide bandwidth transceiver applications.

Analog Devices Inc.
www.analog.com

Switch Cycler

Ducommun's switch cycler is designed to automate switch cycling and allow users to "plug-and-play" versus having to design a custom instrument themselves. The CAT-001 allows users to perform a "burn-in" function for switches that have sat in inventory for long periods of time. The CAT-001 also features an optional strip chart counter to record data for each switch, GUI remote control for automation and a keypad for local control.

Ducommun
www.ducommun.com

26 to 34 GHz, 10 dB Directional Couplers

VENDORVIEW

MECA expanded offering of 5G mmWave products, featuring 10 dB couplers covering 26 to 34 GHz with 2.92 mm interfaces. Typical specifications of 1.5:1 VSWR, 15 dB directivity, 1 dB insertion loss and 0.4 dB frequency sensitivity. Also available are attenuators, terminations, bias tees, DC blocks and adapters. Additionally octave and mulit-octave models covering up to 50 GHz built by J-Standard certified assemblers and technicians. Made in the U.S. and 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

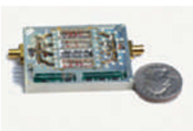
Directional Coupler

VENDORVIEW

The Mini-Circuits ZCDC10-K0644+ wideband directional coupler offers exceptional performance operating over 6 to 40 GHz. This coupler has excellent coupling flatness, good directivity and power handling. It is ideal for lab testing applications as well as for power monitoring over widebands, among other applications.

Mini-Circuits
www.minicircuits.com

10 to 18,000 MHz High Performance Switched Filter Banks



NIC introduces a new line of high performance, custom two to 10 channel switched filter banks that cover frequencies from 1 MHz to 18 GHz. These RF assemblies use low loss, high isolation PIN diode or GaAs switches and are TTL compatible. The filter banks also have low VSWR, excellent passband flatness, fast switching speeds and are housed in compact, laser-sealed, ruggedized enclosures that make them well suited for high-reliability radar, EW and space applications.

Networks International Corp.
www.nickc.com

Satellite Terminals

VENDORVIEW

The 0.9 m Journey Manpack is a high performance, ultra-portable satellite terminal designed for military and commercial applications. The Journey Manpack comes in a lightweight, airline checkable, single backpack including a compact, segmented antenna system, BUC, LNB, optional modem, comprehensive alignment tools. It weighs less than 18 kg (40 lbs) and is ideal for military Special Forces and government applications that require maximum portability. This assisted-acquire satellite terminal can be quickly assembled without tools and requires minimal training.

Norsat International
www.norsat.com

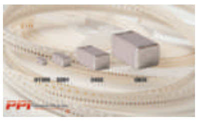
Economical 5G Sub-Harmonic Pumped Mixer Module

OML has developed an economical sub-harmonic pumped mixer down-converter module for the 5G market. M28H2ADC

operates from 24 to 40 GHz with an IF bandwidth > 5 GHz. Its compact size is well suited for both field and lab uses. The M28H2ADC can be connected directly to portable handheld instruments such as Keysight FieldFox and Anritsu Spectrum Master or it can be configured to use with benchtop instruments. It is powered via USB port.

OML Inc.
www.omlinc.com

Broadband Capacitors



Passive Plus Inc. (PPI) has developed a series of broadband capacitors available in four different case sizes: 01005BB, 0201BB, 0402BB and 0805BB. Values available are 10 nF (10,000 pF) and 100 nF (100,000 pF). These capacitors are intended primarily for coupling RF signals or, occasionally, for bypassing them to ground, while blocking DC. The applications for which they are intended require small, surface-mountable devices that provide low RF impedances i.e., low insertion losses and reflections, across extremely large RF bandwidths and temperatures typically ranging from –55°C to +125°C.

Passive Plus Inc.
www.passiveplus.com

TSX Series 4.3-10 Premium RF Surge Protection

The TSX-4310FF and TSX-4310FM are the latest addition to the PolyPhaser TSX family of ultra-low PIM DC short surge protectors.

Using patented SX™ filter design combined with a 4.3-10 connector the bidirectional PolyPhaser TSX-4310 delivers to 4G and LTE networks significant advantages in both PIM performance and surge capacity, while occupying 40 percent less space than traditional designs. The TSX Series is available online with same-day shipping.

PolyPhaser
www.polyphaser.com

3 V, 3400 F Ultracapacitor Cell

Richardson RFPD Inc. announced the availability and full design support capabilities for a new ultracapacitor cell from Maxwell Technologies. The Maxwell 3V, 3400 farad (3400 F) cell has been

designed to be the highest energy, highest power workhorse of its ultracapacitor portfolio. Whether used alone, integrated into a module assembly or in a hybrid configuration, Maxwell's BCAP3400 P300 K04 will help reduce the overall cost and weight of the system while improving the customer's return on investment.
Richardson RFPD Inc.
www.richardsonrfpd.com

High-Power Absorptive Lowpass Filters

RLC Electronics is now manufacturing high-power absorptive lowpass filters. For the RLC high-power absorptive lowpass filters, in-band signals are transmitted through the filter to the output port and out-of-band signals are reflected back to the source. The unit pictured is a 2500 MHz absorptive lowpass, with sharp rejection (50 dB at 4000 MHz) and great overall performance (> 20 dB return loss, < 0.1 dB IL) and is designed to handle 650 W CW over a typical military environment.
RLC Electronics
www.rlcelectronics.com

CABLES & CONNECTORS

Aeroflon® 40 and 50 GHz Test Cables

Sensorview Co. Ltd., a manufacturer of test cables and components for 5G and mmWave industry, released 40 and 50 GHz VNA/interconnect cables for test & measurement solutions. All cables are phase stable, low loss, super-flexible and lightweight with aramid jacket. A wide variety of connectors such as 2.4 and 2.92 mm are available.
Sensorview Co. Ltd.
www.sensorview.cafe24.com

Precision 2.4 to 2.92 mm NMD Between-Series Adapters

SGMC Microwaves introduces their 2.4 to 2.92 mm between-series precision grade NMD connectors that are designed for use with microwave applications requiring excellent performance up to 40 GHz NMD connectors are ruggedized test port connectors that are specially designed to stabilize the test port cable during testing on many network analyzers. SGMC offers an extensive line of precision in-series adapters, between-series adapters, receptacles and cable connectors for various semi-rigid and flexible coaxial cables. Special designs are also available upon request.
SGMC Microwave
www.sgmcmicrowave.com

AMPLIFIERS

6 to 18 GHz Amplifiers with Internal Liquid Cooling

VENDORVIEW

AR's 20S6G18-L and 40S6G18-L are self-contained broadband, Class A solid-state amplifiers with an internal liquid cooling design. The 20S6G18-L, when used with a sweep generator provides a minimum output power of 20 W instantaneously from 6 to 18 GHz, while the 40S6G18-L version delivers 40 W. Typical applications include radiated and conducted immunity testing, TWTA replacements and EW.
AR RF/Microwave Instrumentation
www.arworld.us/html/12200_microwave_amplifier.asp

Solid-State Power Amplifier Module

Comtech PST introduced the highest power density solid-state RF modules available in the marketplace today. Comtech's latest development expands on its proven innovative integrated RF GaN power amplifier designs by further increasing the RF power density, while improving overall operating efficiency. Consistent with its

New**Products**

planned technology development roadmap, Comtech is leading the field with the latest in GaN-based RF device performance and advanced amplifier development. These highly integrated designs are ideal for use in communication, EW and radar transmitter systems where space, cooling and power are limited. Applications include ground (mobile or fixed), surface and airborne platforms.

Comtech PST
www.comtechpst.com

Detective Log Video Amplifier

VENDORVIEW

PMI Model No. ERDLVA-2G8G-65-70MV is a 2 to 8 GHz, CW immune ERDLVA. This model has a TSS of –71 dBm and a log slope of 70 mV/dB ±3 mV/dB. It has a max VSWR of 2.3:1 and a dynamic range of –65 to 0 dBm. This unit is supplied with SMA female connectors and a 9 Pin D-Sub female connector in a housing with dimensions of 2.82 × 2.25 × 0.50 in.

Planar Monolithics Industries
www.pmi-rf.com

CATV Amplifier IC

VENDORVIEW

RFMW Ltd. announced design and sales support for a GaAs pHEMT/MESFET 75 Ohm power doubler RF amplifier IC. Qorvo's model QPB8857 provides over 28 dB of flat gain and low noise of 4.5 dB for DOCSIS 3.1 amplifiers, head-end CMTS equipment and broadband CATV hybrid modules from 47 to 1218 MHz. Using a single 24 V supply, the QPB8857 offers low noise and low distortion at high efficiency, consuming only 10.5 W in a 5 × 7 mm, QFN package.

RFMW Ltd.
www.rfmw.com

SOURCES

Amplitude and Control Module Series Model ACM

Designed specifically for high performance simulator and ATE systems, General Microwave's amplitude control module provides precise amplitude control of signal amplitude and pulse modulation over a high dynamic range with fine resolution. With 10 BIT TTL control, modules provide up to 100 dB attenuation, harmonics < –60 dB and pulse modulation 80 dB, 25 ns control. Available in bands from 0.5 to 40 GHz and can be upgraded to include optional phase control.

General Microwave Corp.
www.kratosmed.com

Miniature Low G-Sensitivity Ultra-Low Phase Noise OCXO: MV317 Type

Morion's MV317 100 MHz OCXO is now available with improved G-sensitivity up to 2E-10/G. Frequency stability vs. temperature to 5E-8 is available, with aging to 1E-7/year. Phase noise < –140 dBc/Hz at 100 Hz and < –180 dBc/Hz at 100 kHz. MV317 OCXO is available with 5 and 12 V voltage supply and SIN output. Package is 25 × 25 × 10.6 mm.

Morion US LLC
www.morion-us.com

Wideband VCO

The DCMO110250-5 is a wideband VCO with a bandwidth greater than an octave (1100 to 2500 MHz) and a tuning range of 28 V. This device operates with +5 V bias voltage and a current draw of 35 mA max. Other specifications include min. output power of +6 dBm, typical tuning sensitivity of 30 to 90 MHz/V and harmonic suppression of 18 dB. The typical phase noise performance is –100 and –120 dBc/Hz at 10 and 100 kHz offsets.

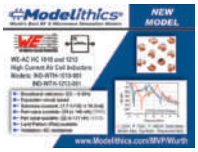
Synergy Microwave Corp.
www synergymwave.com

NewProducts

SOFTWARE

Microwave Global Models™

VENDORVIEW



Modelithics has introduced new equivalent circuit-based scalable microwave global models for Würth Elektronik WE-AC HC (High Current) 1010 and 1212 Air Coil Inductors. The models are validated up to 6 GHz and feature substrate, pad and part value scaling over the full range of the inductor series for both coil sizes, 23 to 146 nH for the 1010 series and 22 to 117 nH for the 1212 series.

Modelithics
www.Modelithics.com

ANTENNAS

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Introducing a low loss, broadband radome designed to protect a phase interferometer array for optimal electrical performance. This radome operates in a demanding military airborne environment and includes a protective rain erosion coating. The radome is specifically designed to provide a uniform phase response to each antenna contained within, regardless of location.

Meggitt Baltimore Inc.
www.meggittbaltimore.com

TEST & MEASUREMENT

PIM Master™ Field Analyzer

VENDORVIEW

Anritsu Co. introduced the PIM Master™ MW82119B-0600, a 600 MHz field passive PIM analyzer to verify installation of LTE at 600 MHz cell sites currently being deployed. Leveraging the industry-leading performance of the PIM Master platform, the new model supports 600 MHz PIM measurements generated by IM3 and IM5 products and has a second built-in 1900 MHz receiver port to measure PIM generated by third harmonic products falling in the 1900 MHz PCS bands.

Anritsu Co.
www.anritsu.com

Bench Top PIM Analyzer

The iBA Series PIM Analyzer is a complete bench top and rack mounting PIM test solution used with a system controller and intuitive user software. This economical solution comes in model variations that cover all major commercial wireless bands. The iBA base model (A-Series) measures reverse/reflected IM only. The B-Series adds a second test port to support a Reverse IM measurement on either port and a forward IM measurement port-to-port.

Kaelus
www.kaelus.com

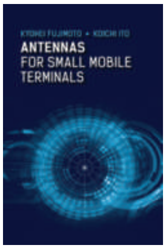
WLAN 2×2 MIMO Signaling Tester for IEEE 802.11ax

VENDORVIEW

Rohde & Schwarz unveiled a test solution for WLAN 2x2 MIMO stations in line with the IEEE 802.11ax standard. Using the well-established R&S CMW270 wireless connectivity tester, developers can test the RF characteristics of both transmitters and receivers. This solution also allows them to determine the data throughput in the transmit and receive directions. In signaling mode, the R&S CMW270 emulates a WLAN 11ax access point (AP) to which the DUT, a WLAN station, is connected in normal mode.

Rohde & Schwarz
www.rohde-schwarz.com

MICRO-ADS



Antennas for Small Mobile Terminals

Kyohei Fujimoto and Koichi Ito

"Engineers receive a primer on using small antennas in a range of small systems, from mobile phones to radio watches, and will learn about different types of small antennas and their applications. Charts, scanning data and an extensive bibliography concluding each chapter packs in technical details... should be in any serious engineering reference holding."

—*Midwest Book Review*

With the progress and rapid increase in mobile terminals, the design of antennas for these small systems is becoming more and more important. This forward-looking volume offers professionals current and comprehensive coverage of the design, development and implementation of small, compact and lightweight antennas in mobile communication terminals. The book discusses a wide range of communication systems, from RF identification (RFID) and near field communications (NFC), to wireless power transmission (WPT) and broadband wireless networks. Engineers learn how to use small antennas in mobile phones, wearable systems, laptop computers, radio watches and broadband wireless networks such as WLAN and WiMAX.

To order this book, contact:

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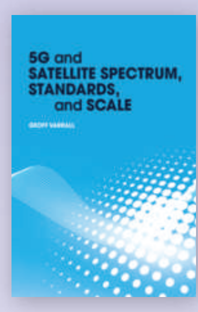

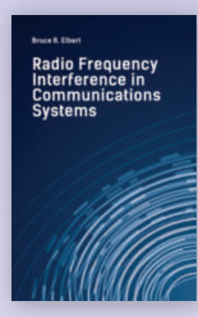

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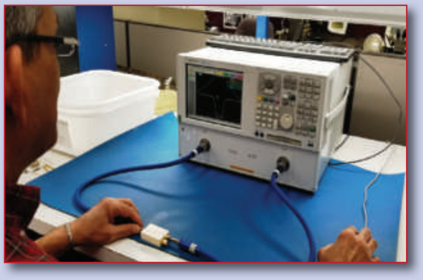
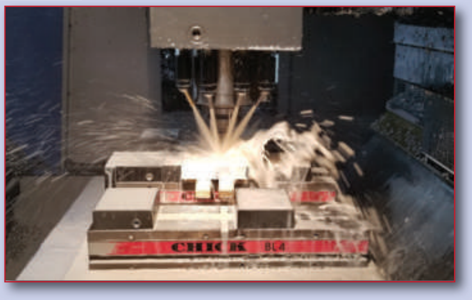
A 40-Year Tradition Built on Service





Say "Maryland" and the average person thinks fondly of Blue Crabs and crab cakes. To someone in the RF/microwave industry, it is arguable whether filters or crabs will first come to mind. For those who think filters, the name Reactel will be synonymous—a highly regarded filter company and one of the only microwave companies still in the family after 40 years.

Manny Assurian formed Reactel in 1979, after 12 years with I-tel, renamed Cir-Q-Tel, a filter company he joined as an engineer right out of college. Serving in virtually every role at the small company, he worked his way to president, developing the confidence that he could run his own company. After fulfilling a one-year non-compete agreement, Assurian launched Reactel's filter business with an ad saying "Manny's back." The phone started ringing, soon followed by the first filter order, from COMSAT, for nine custom designs totaling $1,086.

Today, Reactel is a team of some 40 and operates from a 15,000 square foot facility in Gaithersburg, Md. Most of the company's business comes from U.S. customers, roughly split between defense and commercial. Filters remain the core product, available in many configurations spanning from low RF to 50 GHz. Reactel's filter designs encompass discrete component, cavity, combline, interdigital, waveguide, suspended substrate, ceramic and tubular, and they can be integrated into more complex products such as multiplexers and multifunction assemblies.

Filter performance reflects the combination of a company's design and manufacturing capabilities. Reactel's development team, although small, is "well seasoned" from years of hands-on experience. While most new designs are unique to a customer's application, Reactel has decades of filter designs to draw on, reducing lead time and performance risk. To assure manufacturing consistency and product quality, Reactel does pretty much all manufacturing steps internally, including five CNC machines in a fully automated machine shop. All RF testing is performed in-house, and a nearby facility handles any environmental screening that cannot be done internally. The company is certified to AS9100 and ISO-9001 and registered with the U.S. State Department for ITAR compliance.

Reactel supports defense, space and commercial programs—always has throughout its 40-year history, never letting the peaks in any one market capture the company's design and manufacturing capacity. This strategy of "riding the waves" serves Reactel well: always nurturing strong relationships with its broad customer base, from Google to Raytheon.

Jim Assurian, Manny's son who is responsible for new business development, attributes Reactel's success to service. In an industry where technology and quality are givens, service makes the difference. Short lead times. Responding to small orders. "We want to answer the customer before our competitors open the RFQ." This philosophy is reflected in the customer success stories and volume of repeat business, either follow-on orders for existing programs or new opportunities from those same customers. Reactel's 40-year heritage reflects a tradition built on service and is a testament to the talented and dedicated staff who bring that philosophy to life in the work they do.

www.reactel.com

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Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
C8740	Dual	20-512	200	40	0.3	Tabs	1.5 x 0.95 x 0.55
C9655	Dual	20-1000	100	30	0.7	Tabs	1.5 x 0.95 x 0.55
C8631	Dual	20-1000	150	40	0.35	Tabs	1.5 x 0.95 x 0.55
C10561	Dual	20-1000	250	50	0.1	SMT	1.35 x 1.0 x 0.15
C8025	Bi	500-3500	125	30	0.3	Drop-In	1.3 x 1.0 x 0.07
C8098	Bi	800-2000	200	30	0.25	Drop-In	1.3 x 1.0 x 0.07

0° (In-Phase) Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Isolation (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
D9888	2-Way	1000-3000	500	15	0.35	SMT	2.8 x 2.2 x 0.27
D9922	2-Way	2000-6000	200	15	0.35	SMT	1.4 x 1.1 x 0.14

90° & 180° Hybrids

Model	Type	Frequency (MHz)	Power (W CW)	Amp. Bal. (±dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
QH9056	90°	30-520	400	1.2	0.80	Drop-In	4.0 x 1.7 x 0.29
QH9304	90°	60-1000	150	1.0	1.0	Drop-In	2.0 x 1.0 x 0.16
QH8849	90°	80-1000	250	1.0	0.65	Drop-In	2.9 x 2.1 x 0.31
QH11489	90°	80-1000	600	0.8	0.6	Drop-In	3.33 x 2.25 x 0.31
QH8100	90°	100-512	250	0.5	0.45	Drop-In	3.3 x 1.52 x 0.28
QH8922	90°	150-2000	100	1.0	0.75	SMT	1.47 x 1.13 x 0.16
QH11643	90°	200-1000	200	0.55	0.4	SMT	2.8 x 0.75 x 0.16
QH10900	90°	380-2500	150	0.6	0.55	Drop-In	1.3 x 1.3 x 0.15
QH7900	90°	450-2800	125	0.45	0.55	SMT	1.5 x 1.1 x 0.095
QH7622	90°	500-3000	150	0.6	0.55	Drop-In	1.65 x 1.1 x 0.09
QH11687	**90°**	**500-6000**	**150**	**0.7**	**0.75**	**SMT**	**1.28 x 1.08 x 0.13**
QH11113	90°	600-4000	150	0.7	0.5	SMT	1.29 x 0.99 x 0.12
QH10756	90°	700-6000	100	0.6	0.55	SMT	0.75 x 0.45 x 0.09
QH10541	90°	700-6000	150	0.6	0.5	SMT	0.86 x 0.66 x 0.09
QH10089	90°	800-2800	200	0.4	0.35	SMT	1.25 x 0.55 x 0.08
QH11805	90°	800-3200	200	0.5	0.4	Drop-In	2.2 x 0.8 x 0.174
QH8105	90°	800-4200	150	0.5	0.55	Drop-In	1.5 x 1.08 x 0.09
H10125	180°	1000-3000	350	0.3	0.5	SMT	2.31 x 1.21 x 0.25
QH10827	90°	1000-7500	100	0.7	0.65	SMT	0.86 x 0.61 x 0.09
QH10828	90°	1000-8000	100	0.7	0.9	SMT	0.65 x 0.5 x 0.07
QH10148	90°	2000-6000	100	0.5	0.3	SMT	0.75 x 0.45 x 0.08
H10126	180°	2000-6000	100	0.4	0.8	SMT	1.15 x 0.6 x 0.14

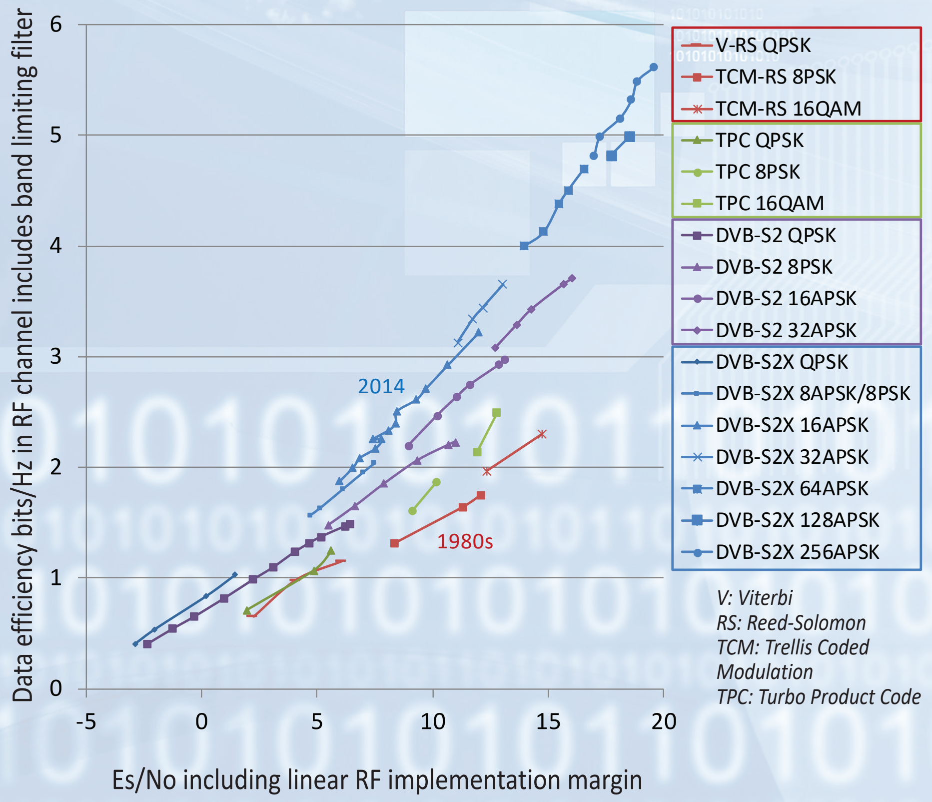
Werlatone, Inc. 17 Jon Barrett Road Patterson, NY 12563 845-278-2220 sales@werlatone.com www.werlatone.com

SatCom - Quietly Linking the World

While most people aren't even aware of it, satellite communications is underpinning much of their lives from entertainment, to internet access, to navigation. Teledyne Technologies has contributed to this. From spacecraft propulsion and imaging sensors to communication payload components, we've been there from the beginning as the industry has grown. Teledyne Paradise Datacom has a track record of decades equipping earth stations - a partner you can rely on. Here we present a quick reference guide we hope you find you can also rely on.

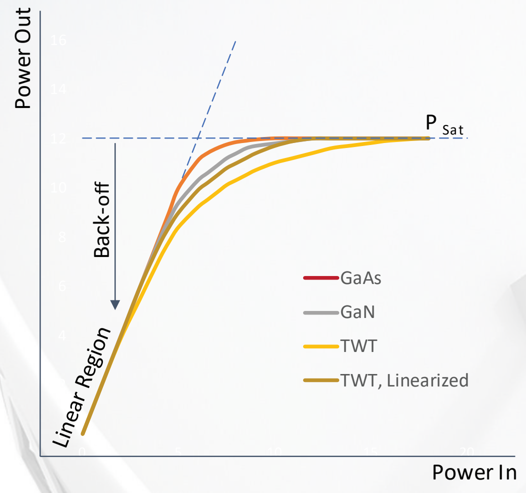
1. Coding Comparison

Performance comparison of historical digital satellite channel performance from the early 1980s to present day. 1980 technology used 35% filter roll-off typically implemented in analog circuitry with 1.4 times symbol rate channel spacing. DVB-S2 brought a 20% filter roll-off (1.2 times symbol rate channel spacing), higher order modulation and advanced forward error correction in 2005. Advances in FPGAs supported digital filter implementations and affordable processing power for advanced forward error correction. 2014 brought DVB-S2X (extensions to DVB-S2) that reduced filter roll-off to 5% (1.05 times symbol rate channel spacing), extended modulation order to 256 APSK (7 data symbols per constellation point) along with additional error correction code rates.



2. Power Amplifier Figures of Merit

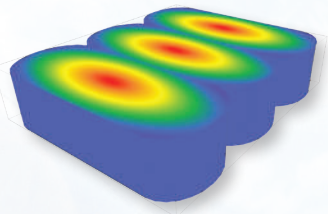
- The output powers of most power amplifiers are specified at the saturated power, P_{sat}
- Most communications amplifiers are used in their linear region
- Real amplifiers differ from ideal in that there is a soft compression (knee) as the amplifier goes into the saturation region
- How much do you need to back off from maximum power (P_{sat}) in order to be operating in the linear region?
- Depends on many factors, including single carrier, multi-carrier, modulation schemes, etc.
- For standard two-tone (CW) testing, back-off varies by technology as:
  - GaAs: ~3 dB
  - GaN: ~4 dB
  - GaN with linearizer: ~3 dB
  - TWT: ~7 dB
  - TWT with linearizer: ~4 dB
- Usable power will be lower than the P_{sat} figure on the data sheet



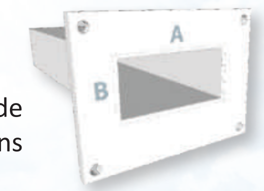
3. Waveguide Sizes

Rectangular Waveguide Name RCSC	EIA	IEC	Recommended Frequency (GHz)	TE_{10} Cut-Off (GHz)	Inner Dimensions of Waveguide Opening A mm	B mm
WG00	WR2300	R3	0.32 to 0.49	0.26	584.20	292.10
WG0	WR2100	R4	0.35 to 0.53	0.28	533.40	266.70
WG1	WR1800	R5	0.41 to 0.62	0.33	457.20	228.60
WG2	WR1500	R6	0.51 to 0.75	0.39	381.00	190.50
WG3	WR1150	R8	0.63 to 0.97	0.51	292.10	146.05
WG4	WR975	R9	0.75 to 1.15	0.61	247.65	123.83
WG5	WR770	R12	0.96 to 1.46	0.77	195.58	97.79
WG6	WR650	R14	1.13 to 1.73	0.91	165.10	82.55
WG7	WR510	R18	1.45 to 2.20	1.16	129.54	64.77
WG8	WR430	R22	1.72 to 2.61	1.37	109.22	54.61
WG9A	WR340	R26	2.17 to 3.30	1.74	86.36	43.18
WG10	WR284	R32	2.60 to 3.95	2.08	72.14	34.04
WG11A	WR229	R40	3.22 to 4.90	2.58	58.17	29.08
WG12	WR187	R48	3.94 to 5.99	3.15	47.55	22.15
WG13	WR159	R58	4.64 to 7.05	3.71	40.39	20.19
WG14	WR137	R70	5.38 to 8.17	4.30	34.85	15.80
WG15	WR112	R84	6.57 to 9.99	5.26	28.50	12.62
WG16	WR90	R100	8.20 to 12.50	6.56	22.86	10.16
WG17	WR75	R120	9.84 to 15.0	7.87	19.05	9.53
WG18	WR62	R140	11.9 to 18.0	9.49	15.80	7.90

Rectangular Waveguide Name RCSC	EIA	IEC	Recommended Frequency (GHz)	TE_{10} Cut-Off (GHz)	Inner Dimensions of Waveguide Opening A mm	B mm
WG19	WR51	R180	14.5 to 22.0	11.57	12.95	6.48
WG20	WR42	R220	17.6 to 26.7	14.05	10.67	4.32
WG21	WR34	R260	21.7 to 33.0	17.36	8.64	4.32
WG22	WR28	R320	26.3 to 40.0	21.08	7.11	3.56
WG23	WR22	R400	32.9 to 50.1	26.34	5.69	2.84
WG24	WR19	R500	39.2 to 59.6	31.39	4.78	2.39
WG25	WR15	R620	49.8 to 75.8	39.88	3.76	1.88
WG26	WR12	R740	60.5 to 91.9	48.37	3.10	1.55
WG27	WR10	R900	73.8 to 112	59.01	2.54	1.27
WG28	WR8	R1200	92.2 to 140	73.77	2.03	1.02
WG29	WR6	R1400	113 to 173	90.79	1.65	0.83
WG30	WR5	R1800	145 to 220	115.71	1.30	0.65
WG31	WR4	R2200	172 to 261	137.24	1.09	0.55
WG32	WR3	R2600	217 to 330	173.57	0.86	0.43



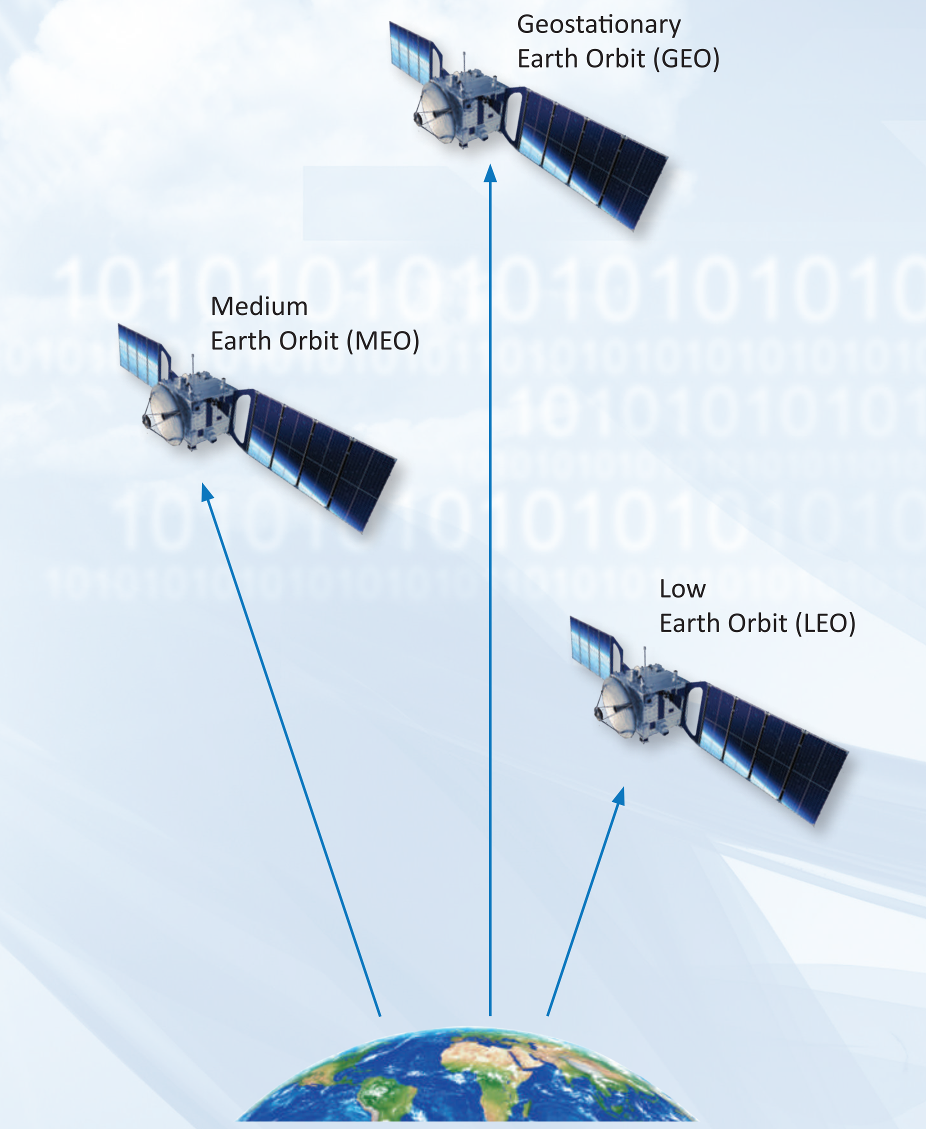
Heat map of electrical field in a rectangular waveguide for TE_{10} mode



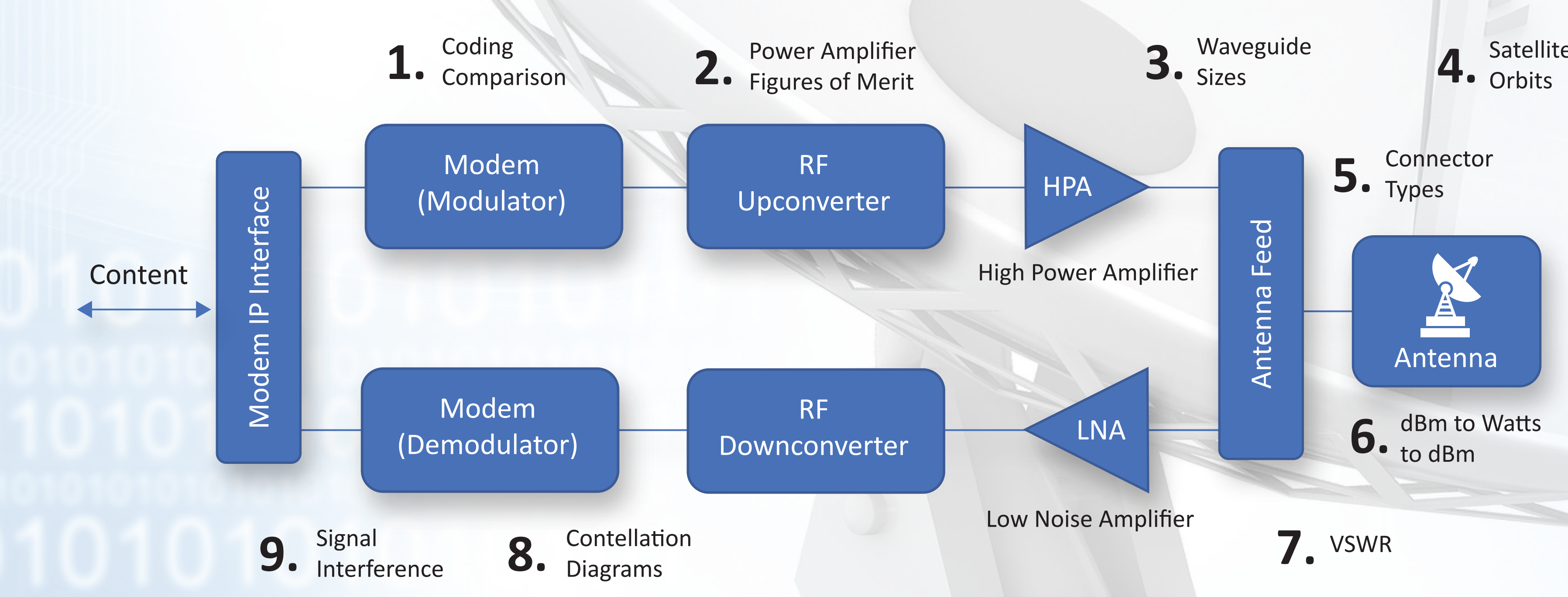
Internal waveguide dimensions

4. Satellite Orbits

	LEO	MEO	GEO
Distance from earth (km)	500 - 1,500	5,000 - 12,000	35,786
Flight velocity (km/s)	7.6 - 7.1	5.9 - 4.6	3
Oribital period (hr:min)	1:34 - 1:56	3:34 - 6:53	~24
Example latency (each way, ms)	1.7 - 5	16.7 - 40	119
Free Space Loss each way, at 6/13/30 GHz (dB)	166/173/180	188/195/202	199/206/213
Typical number of satellites to cover majority of earth's surface	50 - 200+	12 - 20	3
Typical lifespan (years)	5	15	15
Number of handoffs	High	Low	None



Earth Station Block Diagram



6. dBm to Watts to dBm

dBm	Watts	mW
-30.00	0.0000010	0.001
-25.00	0.0000032	0.003
-20.00	0.000010	0.010
-15.00	0.000032	0.032
-10.00	0.00010	0.10
-5.00	0.00032	0.32
0.00	0.0010	1.00
1	0.0013	1.26
2	0.0016	1.58
3	0.0020	2.00
4	0.0025	2.51
5	0.0032	3.16
6	0.0040	3.98
7	0.005	5.01
8	0.006	6.31
9	0.008	7.94
10	0.010	10.0
15	0.032	31.6
20	0.100	100.0
25	0.316	316.2
30	1.0	1,000
35	3.2	3,162
40	10.0	10,000
45	31.6	31,623
50	100	100,000
53	200	199,526
55	316	316,228
60	1,000	1,000,000

Watts	mW	dBm
0.0000010	0.001	-30.00
0.000010	0.010	-20.00
0.00010	0.10	-10.00
0.0010	1.00	0.00
0.010	10	10.0
0.10	100	20.0
0.20	200	23.0
0.30	300	24.8
0.40	400	26.0
0.50	500	27.0
0.60	600	27.8
0.70	700	28.5
0.80	800	29.0
0.90	900	29.5
1	1,000	30.0
2	2,000	33.0
3	3,000	34.8
4	4,000	36.0
5	5,000	37.0
6	6,000	37.8
7	7,000	38.5
8	8,000	39.0
9	9,000	39.5
10	10,000	40.0
15	15,000	41.8
20	20,000	43.0
50	50,000	47.0
100	100,000	50.0
200	200,000	53.0

5. Connector Types

F-Type
- 75Ω
- To ~2GHz
- From ~1950s

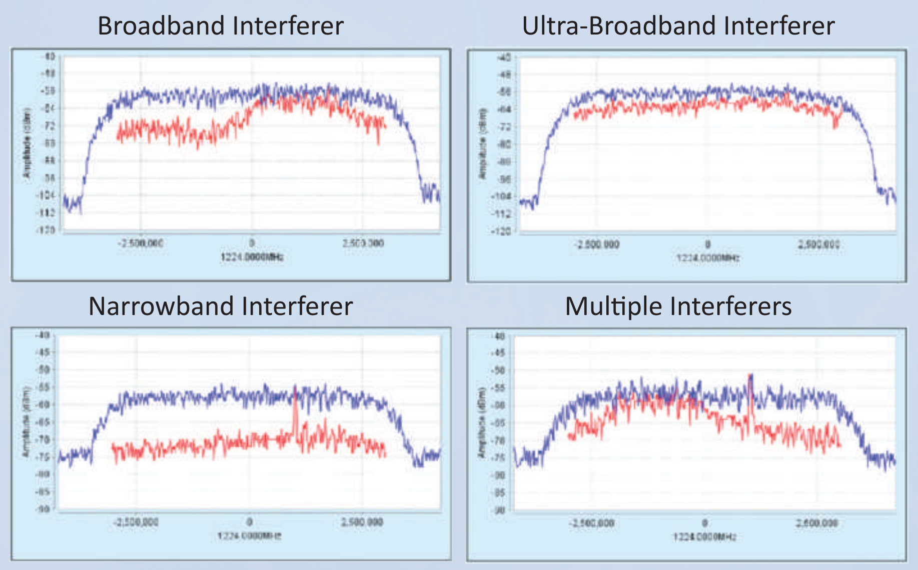
BNC
- 50Ω/75Ω
- To 4GHz
- Patented 1951

N-Type
- 50Ω/75Ω
- To 11GHz (normal)
- To 18GHz (precision)
- From ~1940s

SMA
- 50Ω
- To 26.5GHz
- From 1960s

9. Signal Interference

While interference can come from many sources, diagnosing it is usually difficult. These examples show different types of interference displayed using the Paradise LinkGuard™ spectral monitoring function revealing wanted signal and in-band effects from sources such as radars, Wi-MAX, jammers and other modulated carriers.

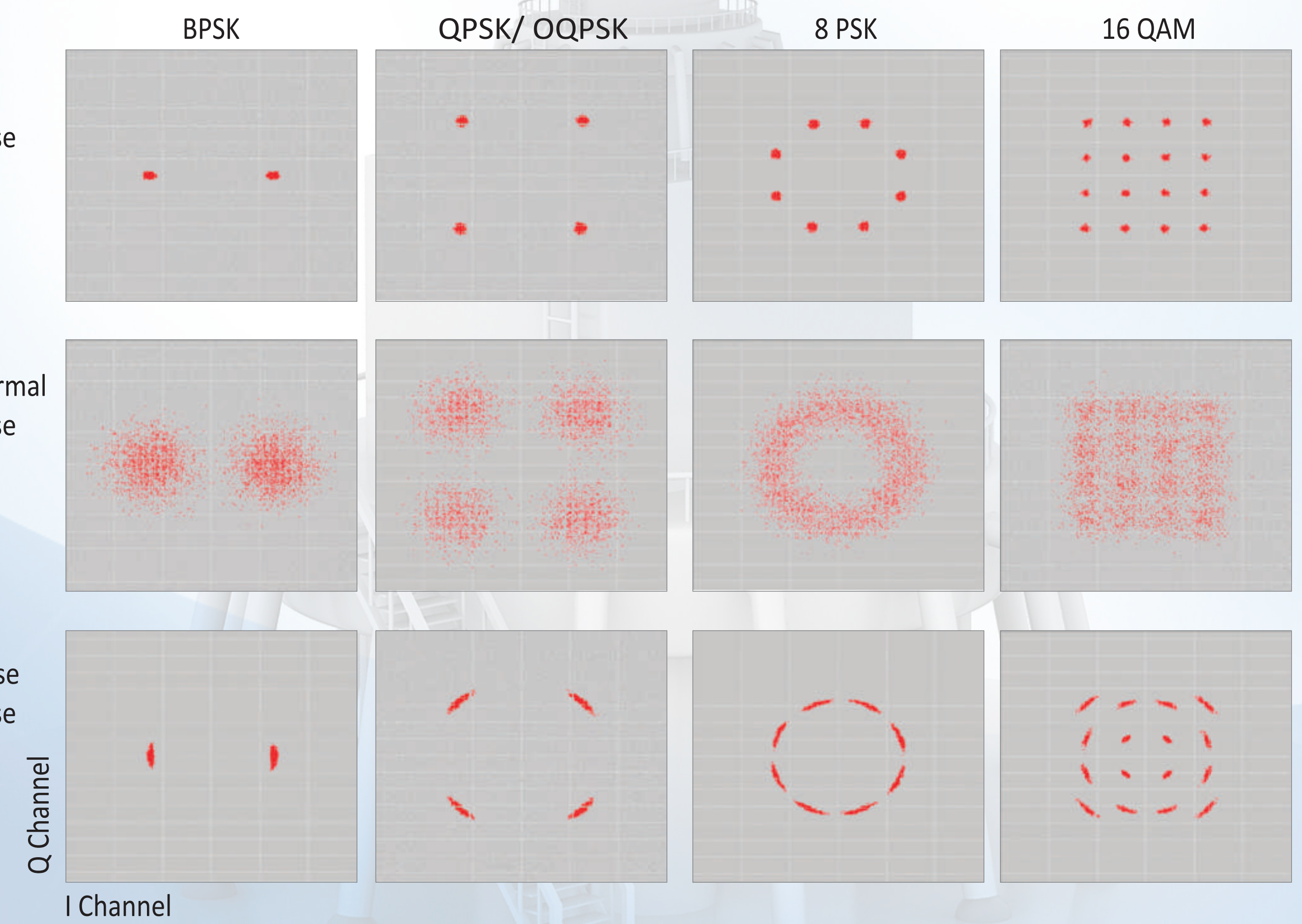


8. Constellation Diagram Diagnosis

Constellation diagrams are a powerful way of viewing physical layer performance in the I/Q modulation domain.

Many types of test equipment can display constellation diagrams. These examples were captured using the Paradise Q-Flex built-in test equipment which is able to access signals conveniently and directly.

- Gaussian noise is displayed as random groups of samples around each constellation point
- Phase noise appears as points spreading into arcs centered on the origin
- Non-coherent single frequency interference shows as 'donut' circles around each point
- Amplifier compression causes the outer corner points to move towards the center



7. VSWR

$$\text{Return Loss} = -20\log\left[\frac{VSWR-1}{VSWR+1}\right]$$

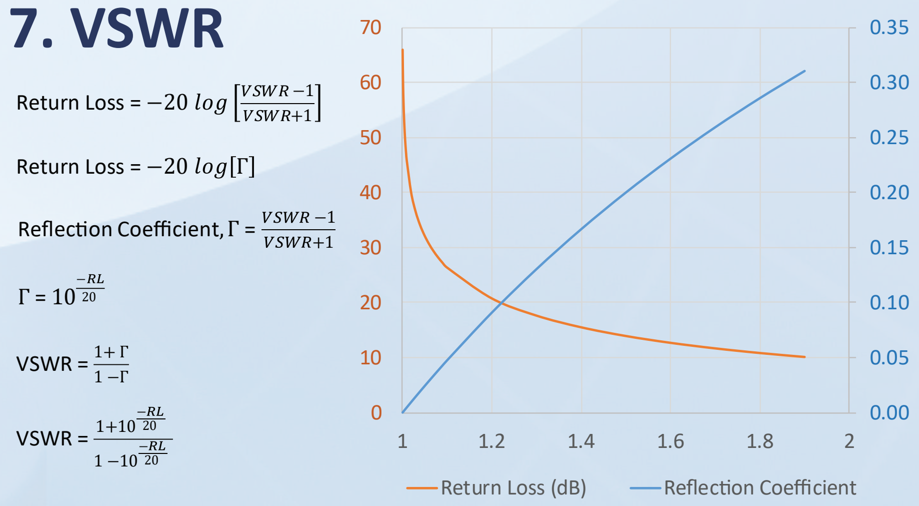
$$\text{Return Loss} = -20\log[\Gamma]$$

$$\text{Reflection Coefficient}, \Gamma = \frac{VSWR-1}{VSWR+1}$$

$$\Gamma = 10^{\frac{-RL}{20}}$$

$$VSWR = \frac{1+\Gamma}{1-\Gamma}$$

$$VSWR = \frac{1+10^{\frac{-RL}{20}}}{1-10^{\frac{-RL}{20}}}$$



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