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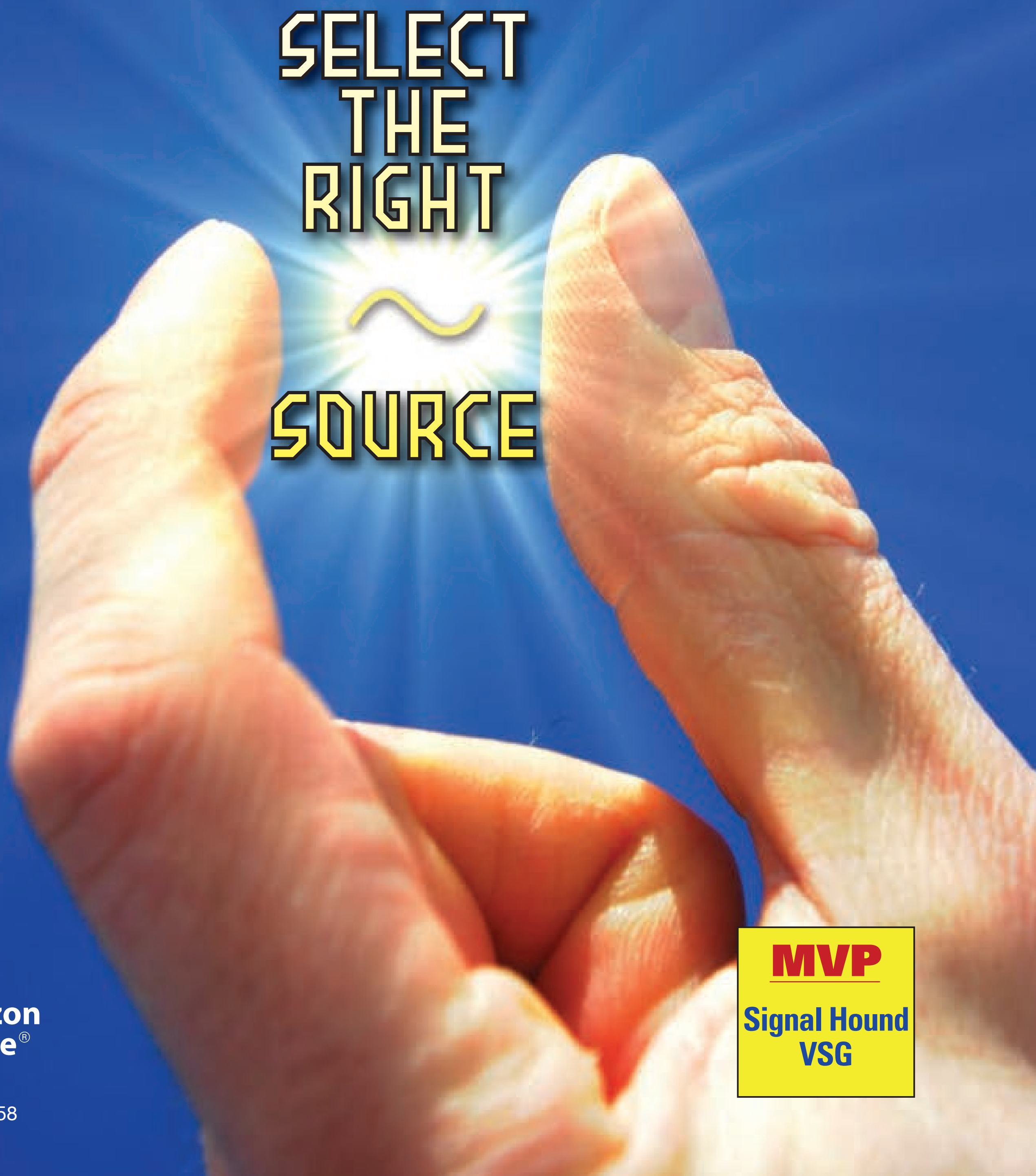

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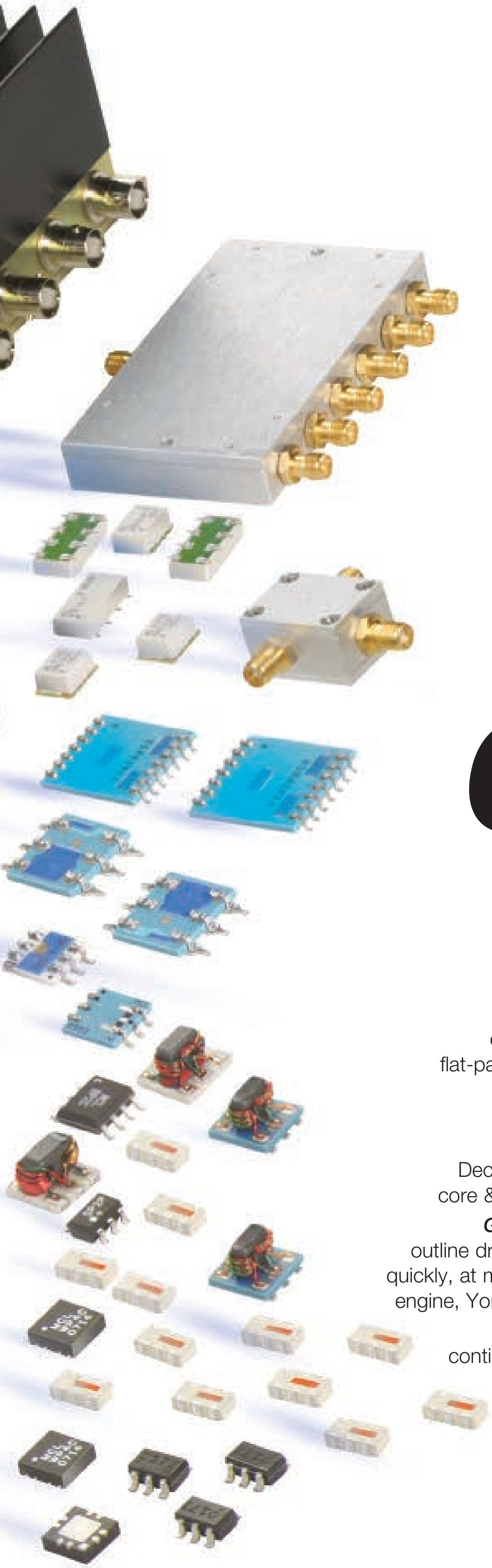

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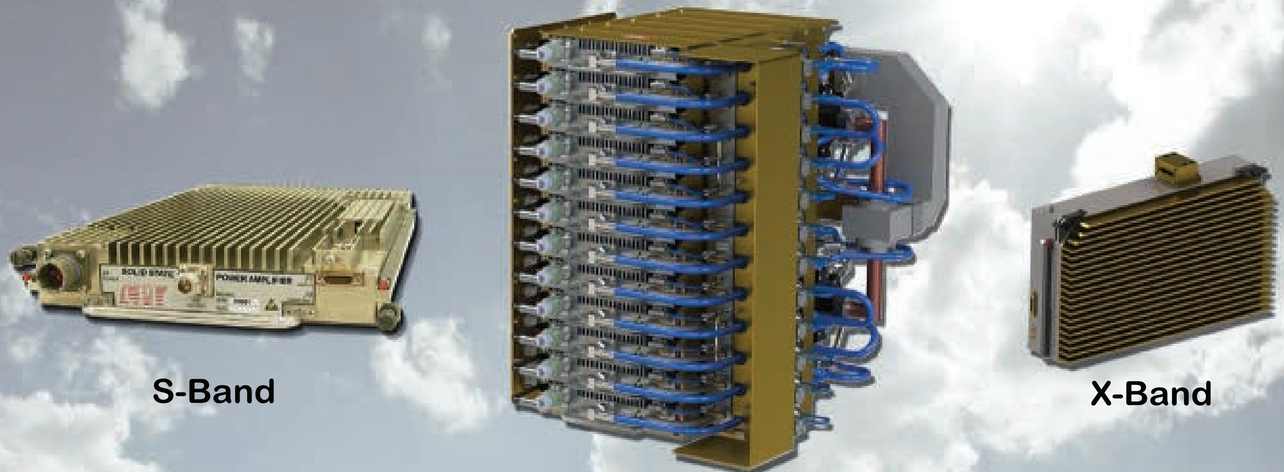

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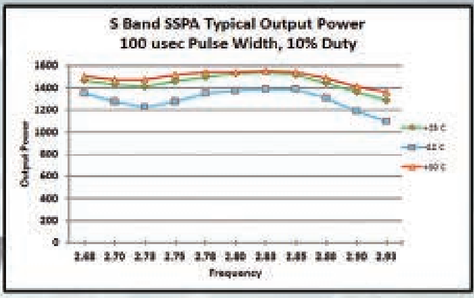

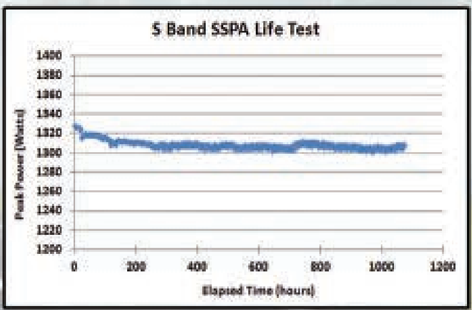

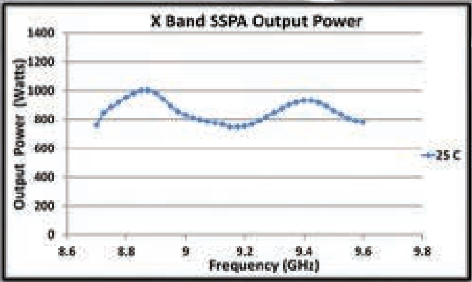

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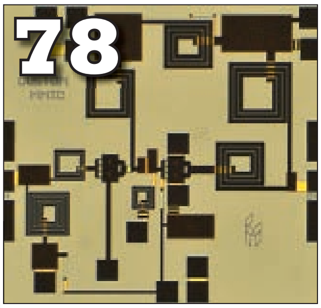

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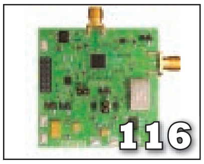

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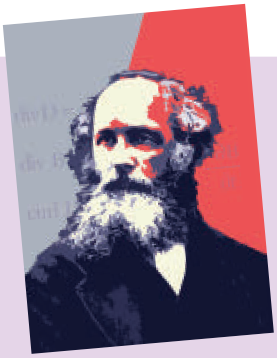

James Clerk Maxwell was a Scottish[1,2] scientist in the field of mathematical physics.[3] His most notable achievement was his formulation of the classical theory of electromagnetic radiation, bringing together electricity, magnetism and light for the first time as manifestations of the same phenomenon. Maxwell's equations for electromagnetism have been called the "second great unification in physics"[4] after the first one realized by Isaac Newton.

His discoveries helped usher in the era of modern physics, laying the foundation for such fields as special relativity and quantum mechanics. Many physicists regard Maxwell as the 19th century scientist having the greatest influence on 20th century physics. His contributions to the science are considered by many to be of the same magnitude as those of Isaac Newton and Albert Einstein.[5] In the millennium poll—a survey of the 100 most prominent physicists—Maxwell was voted the third greatest physicist of all time, behind only Newton and Einstein.[6]

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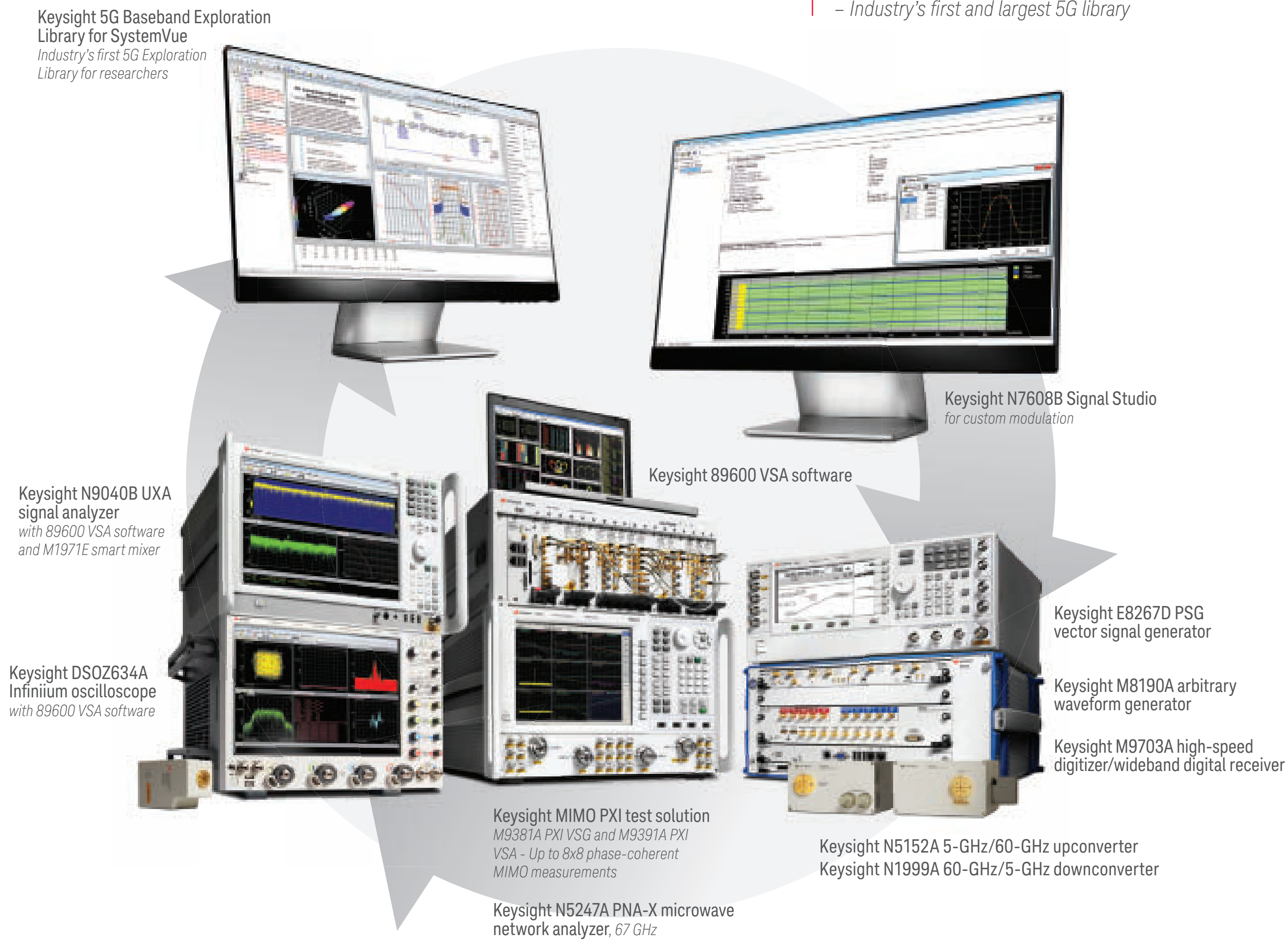

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State of the Art in Microwave VCOs

A.P.S. Khanna
NI Microwave Components, Santa Clara, Calif.

Microwave oscillators are at the heart of all RF and microwave systems from wireless communications, radar and navigation, military and aerospace to vital test equipment. Voltage controlled oscillators (VCO) represent the most common form of oscillators that tune across a band of frequencies specific to applications. VCOs have come a long way from the vacuum tube based components of 85 years ago to present fully integrated ICs. Stand-alone VCOs are commercially available in various SMT packages, hybrid coaxial modules, raw die, as well as part of higher-level mixed-signal ASICs. Improvements in VCO technology have continued throughout that time, yielding ever-smaller sources with enhanced performance. This article will cover basic topology, applications, evolution, specifications and future trends of VCOs based on three terminal devices.

VCO BASICS

A typical block diagram for a basic VCO is shown in ***Figure 1***. A three-terminal active device is the oscillation device that is enabled to oscillate at the desired band of frequencies with the help of a series feedback circuit on one port and a voltage tunable resonator or capacitor on the second port. A matching circuit on the third port is used to extract power typically into 50 ohms.

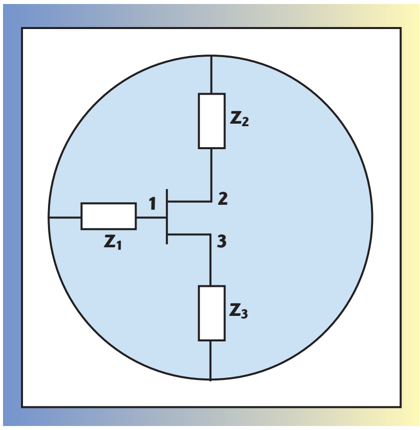


Fig. 1 Block diagram of a VCO.

The large signal oscillation condition for this topology is given by:[1]

$$[S][S'] = [I] \tag{1}$$

where [S] represents an active matrix, and [S'] represents a passive matrix. In simplified form, this condition can be presented as follows:

$$S''_{11}\Gamma_1 = S''_{22}\Gamma_2 = S''_{33}\Gamma_3 = 1 \tag{2}$$

where S''_{11} is the modified reflection coefficient at port 1 with ports 2 and 3 loaded by impedances corresponding to reflection coefficient Γ_2 and Γ_3.

A VCO is a type of oscillator which commonly uses a varactor diode to tune its frequency. The tuning range of VCOs can vary from a tiny 0.1 percent to more than an octave band. Other types of microwave oscillators include dielectric-resonator oscillators (DRO), YIG-tuned oscillators (YTO), surface acoustic-wave (SAW) oscillators, and transmission-line oscillators among others. ***Table 1*** compares these oscillators.

While there are many types of VCOs, it is their application that determines their desired characteristics. VCOs are a key part of test instruments and are used as a basic source of RF energy in signal generators, synthesizers as well as vector network analyzers. In spectrum analyzers and vector signal analyzers, VCOs are used in the generation of wideband local oscillators. In most cases, VCOs are converted to synthesized sources using PLL techniques and a low phase noise reference oscillator.[2] In these applications, phase noise, switching time and compact size are critical requirements.

Another VCO application is transmitter and receiver local oscillator synthesizers for wireless communications, digital radios, satellite terminals and satellites for both down-converter and up-converter application. These systems provide voice, data or video transmissions. VCOs are also an essential part of radars and military electronic systems where, in addition to phase noise, fast-frequency settling characteristics are important requirements. In threat simulator and EW jamming systems, signal responses of sub-microseconds are vital.

VCOs are directly used in FM communication systems where modulation frequency is applied to their tuning ports. In these applications, tuning

TABLE 1 COMPARISON OF COMMON TYPES OF OSCILLATORS							
Type	***Tuning Range***	***10 GHz Phase Noise @100 kHz offset***	***Switching Speed***	***Hysteresis***	***Size inch cube***	***Relative Cost***	***Power Consumption***
VCO	Octave	-110 dBc/Hz	1 µsec	Low	0.001	1	Low
YTO	Decade	-120 dBc/Hz	1 msec	High	1.0	10	High
DRO	1%	-120 dBc/Hz	N/A	N/A	0.5	5	Low

linearity and modulation bandwidth are challenging specifications in the design of the VCO. In a specific requirement of an FMCW radar used in radio altimeters or collision avoidance systems, tuning linearity is directly linked to the accuracy of the measurement.

All modern digital and optical communications systems need a basic clock that is generally a low noise VCO. Clock frequencies have been continuously increasing and are currently in the range of tens of GHz. A clock frequency of more than 40 GHz is used in 40 Gb/s telecommunication systems. These clocks demand very low jitter performance.

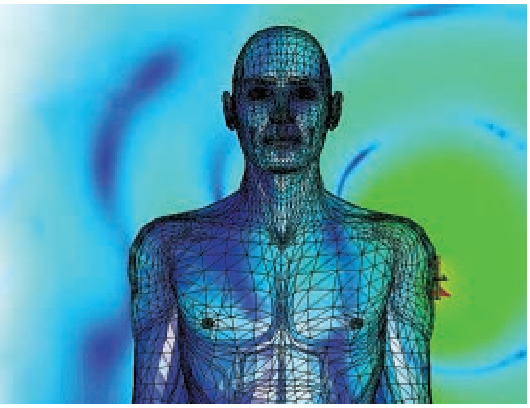
Commercial availability of fundamental stand-alone VCOs are presently limited to K-Band. Higher-frequency sources are generated using frequency multipliers, which add harmonic-related products that require filtering at the output. However there has been rapid technological progress in semiconductor integration of VCO circuitry. The semiconductor industry has demonstrated VCOs with frequencies higher than 200 GHz.[3]

VCO EVOLUTION

Two-terminal VCOs started as early as the 1960s and provided low phase noise tunable signals to over 100 GHz. Nevertheless, because of their size, high power consumption and cold start issues, their applications were limited to high-end uses until three-terminal devices capable of signal generation in microwaves started showing up in the 1970s. Silicon bipolar and GaAs FET devices were the first to be exploited in VCOs. X-Band VCOs were a reality by 1975 using GaAs FETs.[4] Silicon bipolar-based X-Band VCOs were introduced soon after. While silicon bipolar devices had an advantage of lower phase noise, GaAs FETs were able to deliver more power and higher frequencies of oscillations. Silicon bipolar devices ultimately were able to cover VCOs up to Ku-Band[5] and thus became the technology of choice, especially because of good phase noise and low power consumption. Silicon bipolar-based VCOs typically had a close-in phase noise of about 10 dB better than a GaAs FET device in X-Band, for example. GaAs MESFET devices made discrete VCOs up to 40 GHz by the early 1990s. Silicon bipolars with an f_{max} of 35 GHz and oscillation capability to 18 GHz as VCOs and 22 GHz as YTOs were reported.[5,6] f_T of GaAs FET devices continued to increase to beyond 100 GHz.

The availability of frequency-tuning element varactors made a large impact on VCO technology. Note that abrupt-junction varactor diodes were initially used; however, their frequency bandwidth was limited. Hyperabrupt-varactor diodes with higher capacitance variation ratios were made available in the 1970s resulting in wideband VCOs with better linearity. Both silicon bipolar as well as GaAs diodes are now commonly used. GaAs diodes typically have a higher Q but do not necessarily have better phase noise because of up-converted surface noise caused by lack of passivation. The thermal-oxide passivation of silicon varactors provide better 1/f noise and hence better phase noise. Another reason for choosing silicon is the poor frequency stability record of GaAs diodes. Because of the higher thermal resistance of gallium arsenide, GaAs diodes do not settle as fast as silicon diodes in fast VCOs, and the high surface state density in GaAs results in significant long-term drift compared to silicon. GaAs hyperabrupt diodes do offer better tuning ranges at higher frequencies due to their lower capacitances, higher Qs and higher capacitance ratios.

In the 1970s, microwave VCOs used bare die and thin film technology



with chip-and-wire assembly techniques. These VCOs were packaged in metal housings (see ***Figure 2***). Soon, SMT parts were available and VCOs were also made available in SMT packages for direct attachment onto the PCB in the 1980s. MMIC VCOs entered the market in the 1990s and changed the landscape. Using silicon and GaAs technologies, IC VCOs were the only way to meet cost targets of emerging wireless markets. VCO functions quickly integrated into higher level ICs to meet the challenge.

STATE OF THE ART

With time, new semiconductor technologies were introduced for three-terminal active devices and were experimented within their application with VCOs. Some of those technologies, which provided good phase noise, became popular, including SiGe and InGaP HBTs. These devices not only offered higher frequency operation but also very low phase noise, comparable to Si BJTs at lower frequencies.

Commercially available SiGe discrete devices have a f_T of greater than 80 GHz but are available only in SMT form, which limits their use in Ku-Band applications as the SMT packages become parasitic. However, SiGe IC devices have been steadily making strides in high performance VCO functions up to mmWave frequencies. A wideband VCO with 30 percent bandwidth has been reported at 80 GHz using SiGe technology with +12 dBm of power and phase noise of -97 dBc/Hz at 1 MHz offset. Multiple varactors were used in achieving this bandwidth.[7]

GaAs FET and PHEMT devices have proven to be excellent devices for higher power at higher frequencies as wideband amplifiers. However, these devices fall short in phase noise performance due to high 1/f noise. HBT structures on GaAs offer significantly superior 1/f noise due to the vertical current flow. GaAs HBT, InP HBT and more commonly InGaP HBT became the technology of choice in the early part of the century, which were able to combine high frequency potential with low 1/f noise.[8] Technology improvements were able to reduce the base-emitter distance to 0.5 µm and helped increase f_{max} to close to 200 GHz. Using a push-push configuration, an 8 percent tuning range VCO was realized at 77 GHz (see ***Figure 3***) with a decent phase noise of -92 dBc/Hz at 1 MHz offset.[9] It is important to note that InGaP HBT technology has been the technology of choice for low noise discrete VCO MMICs for over a decade. Narrow or wideband VCO MMICs using InGaP HBTs are presently commercially available up to 20 GHz.

The performance of both CMOS and SiGe HBTs, as measured by f_T,

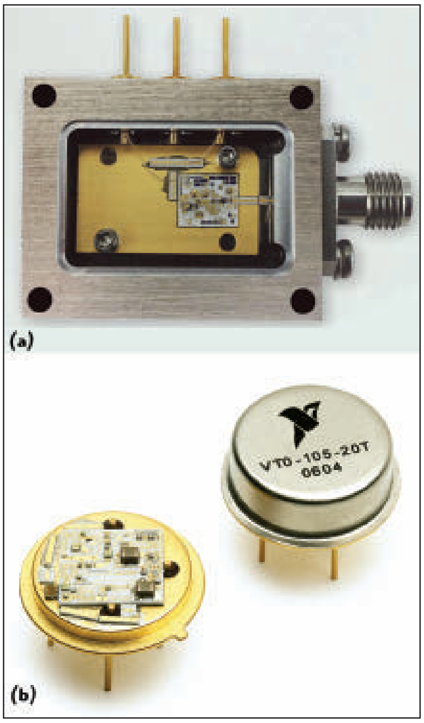


Fig. 2 VCOs in a metal housing (a) and TO-8 cans (b).

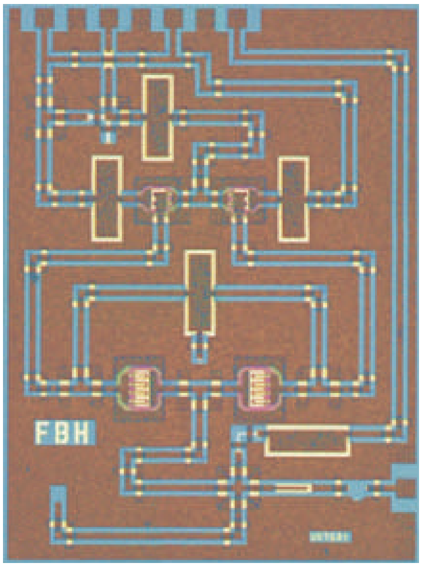
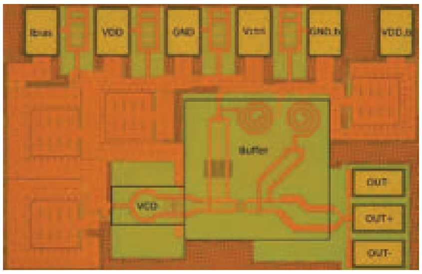


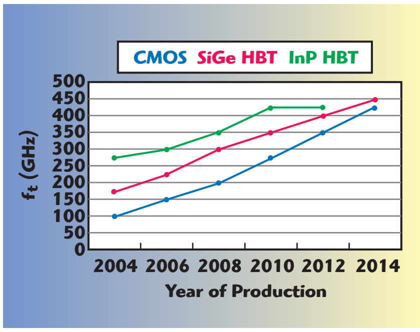
Fig. 3 77 GHz VCO with 8% tuning range and phase noise of -92 dBc/Hz at 1 MHz offset. ©2003 IEEE. Reprinted with permission from IEEE Proceedings, June 2003.

f_{max}, or NF_{min}, has dramatically improved with geometry scaling and technology enhancements. These silicon technologies are able to implement large amounts of digital logic in a given area, enabling the on-chip integration of control logic and digital signal processing. The combination of mm-scale wavelengths, low cost, and the ability to integrate make these technologies an attractive solution for transceiver topologies being implemented on a single die.

CMOS has made significant inroads into microwave and mmWave VCO functions as part of a higher-level mixed-signal IC. CMOS is key to achieve low cost integrated circuits at frequencies approaching 100 GHz and enable the rapidly growing needs of communications and radar applications. A 118 GHz VCO with 8 percent bandwidth and -83 dBc/Hz at 1 MHz phase noise has been reported using CMOS (shown in ***Figure 4***.)[10] Low level oscillations up to 300 GHz have been reported using 65 nm CMOS.[3] CMOS and SiGe technologies are both in use presently, but CMOS is expected to take the lead with the new 0.1 µm technology, which will enable it to perform at the new emerging applications in 5G as well as collision-avoidance radar frequencies covering 30 to 86 GHz.



▲ *Fig. 4 118 GHz VCO with 8% bandwidth and phase noise of -83 dBc/Hz at 1 MHz offset. ©2011 IEEE. Reprinted with permission from IEEE Proceedings, June 2011.*



▲ *Fig. 5 Evolution of f_t for various technologies over the years.*

Figure 5 shows the evolution of f_t for CMOS, InP HBT and SiGe technologies. Conventional CMOS is now rapidly reaching its fundamental limits of silicon performance despite ever decreasing transistor line widths and use of highly complex architectures. It may be noted that for purely RF devices, III-V implementations may turn out to be a lower cost solution under certain conditions when use of existing designs and time-to-market are taken into account. However, as the world moves towards integration of RF with digital and control functions for high volume applications, CMOS has a clear advantage.

Among other emerging technologies, GaN is a promising one for high power and high frequency signal sources. GaN's potential to generate directly multi-watts of RF power at S- and C-Bands is unmatched in the solid-state industry. Almost 50 W of RF power has been realized at 2.45 GHz.[11]

With commercial availability of GaN amplifier MMICs in the mmWave frequencies,[12] oscillators exceeding 100 GHz using GaN are not far behind. A W-Band VCO MMIC has been realized using 0.1 µm AlGaN/GaN HEMT technology. Covering 85.6 to 92.7 GHz, it provided better than +10 dBm power output (see ***Figure 6***). Phase noise of the VCO varied between -80 to -90 dBc/Hz at 1 MHz offset from the carrier.[13]

VCO PERFORMANCE PARAMETERS

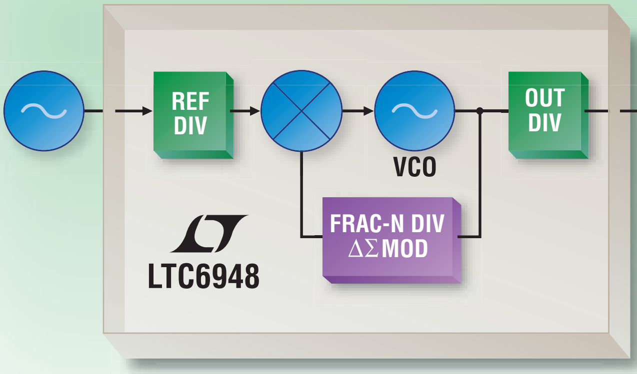
The importance of VCO characteristics depends upon its applications. In addition to basic parameters like frequency range, RF power output, harmonics, spurious and power consumption, there are a number of special parameters that determine the quality of the operation of the system. These include tuning linearity, frequency pushing, load pulling, frequency settling, modulation bandwidth, phase noise and jitter. Some of these parameters are outlined below:

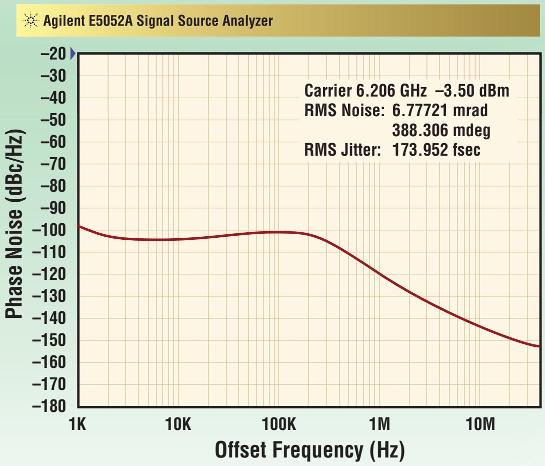
Frequency Range

The output frequency of a VCO can vary over a wide range depending on the tuning varactor, active device and architecture. Frequency bandwidth is defined as:

$$\text{Bandwidth} = (f_{max} - f_{min})/f_{center} \qquad (3)$$

Ultralow Noise Fractional-N Synthesizer





ΔΣ-Based Synthesizer Achieves Integer-N Spurious Performance

Our new ultralow noise fractional-N PLL synthesizers deliver best-in-class phase noise performance, and also provide exceptionally low spurious levels due to an advanced ΔΣ modulator. With modulator spurious levels in the noise, designers can confidently architect a frequency plan without unexpected spurious frequencies in the output spectrum. Predictable spurious performance ensures peace of mind when designing with our fractional-N PLLs.

Features

- Low –226dBc/Hz Normalized In-Band Phase Noise Floor
- –274dBc/Hz Normalized In-Band 1/f Noise
- –157dBc/Hz Wideband Output Phase Noise Floor
- Programmable 1 to 6 Output Divider
- 28-Lead (4mm x 5mm) QFN Package

PLL Family

Part No.	Features	Freq. Range (GHz)
LTC®6945	Integer-N, PLL	0.350 to 6.0
LTC6946	Integer-N, PLL + VCO	0.373 to 6.39
LTC6947	Frac-N, PLL	0.350 to 6.0
LTC6948	Frac-N, PLL + VCO	0.373 to 6.39

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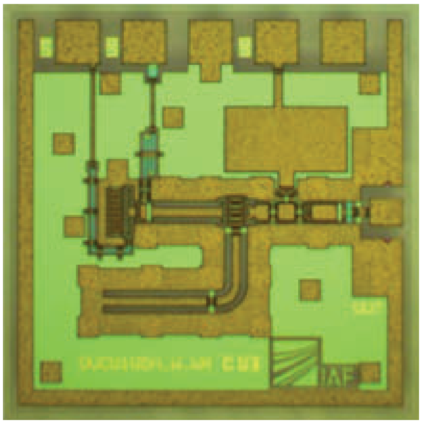
LINEAR TECHNOLOGY



▲ *Fig. 6 W-Band VCO MMIC using AlGaN/GaN HEMT technology with better than +10 dBm power output. ©2014 IEEE. Reprinted with permission from IEEE Proceedings, June 2014.*

In this formula, f_{max} is the maximum tuning frequency, f_{min} is the minimum, and f_{center} is the center of the frequency range. Frequency bandwidths of up to 100 percent have been reported; up to 67 percent (an octave bandwidth) are commercially available up to K-Band.

Output Power

The output power of a fundamental RF VCO can vary from less than 0 dBm for a small low noise device to greater than a watt from a power device. However, since the required RF power can typically be achieved by using amplifiers at the output of VCOs, the VCO design is optimized more for parameters other than power output. Output power flatness in ± dB over the frequency band is another important parameter that reflects the output impedance match of the VCO to the load.

DC Power Efficiency

Since a VCO is a DC-to-AC converter, its DC power efficiency is one of the measured characteristics. It is measured as the ratio of RF power output to DC power input. At microwave frequencies a typical efficiency of about 10 percent is achieved. Load coupling/isolation is one of the factors that impact power efficiency.

Frequency Pushing

Effect of DC bias voltage variation is related to pushing figure. Pushing figure is defined in Hz/V and is measured by varying DC bias in steps of not more than 0.1 V.

$$\text{Frequency Pushing} = \Delta f / \Delta V \qquad (4)$$

In a typical VCO, pushing figure is related to the resonator quality factor and is sometimes used to measure quality of the oscillator. In view of the fact that it is a means to change the frequency, this characteristic has been used for narrowband FM or phase locking for VCOs that present a linear or monotonic relationship between voltage and frequency.

Harmonic Suppression

Harmonic signals represent frequencies that are integer multiples of the fundamental or carrier frequency and are generally measured in dBc with respect to power in fundamental frequency. An oscillator inherently being a nonlinear device will always have harmonics. However, the level of harmonics are generally affected by the design and are commonly rejected by using an external lowpass filter.

Spurious Response

Spurious outputs are the undesired signals in the output of a VCO, which are not harmonically related to the fundamental frequency. One of the causes of close-in spurious is from the ripple in the power supplies, i.e., 60 Hz and its harmonics. It is a low frequency modulation effect produced by the pushing characteristics of the VCO. Another type of spurious is caused by multiple instabilities in the active device causing low-level signals almost anywhere in the useful frequency range of the active device. Careful design can avoid these spurious. It is important to note that spurious performance over temperature can vary due to gain variation of the active device. It is not uncommon to find spurious only at cold temperatures.

Tuning Sensitivity and Linearity

Tuning sensitivity or modulation sensitivity describes the monotonic relationship between the tuning voltage and VCO frequency. Measured as Hz/V, it represents the differential of the tuning voltage curve. Many applications require linear tuning characteristics or constant tuning sensitivity. Linear tuning is affected by the type of varactor diode and oscillator architecture. Hyperabrupt varactor diodes offer better linearity for example. Special profiles for the varactors have been made available for linearity. Another influencing parameter is the VCO circuit itself, which can be opti-

mized for linearity. In certain applications ADC and ROM devices can be used to digitally enhance the linearity of VCO tuning characteristics.

Modulation Bandwidth

Modulation bandwidth is the speed at which a VCO frequency can be changed. In reality, the VCO acts as a frequency modulator where frequency can be modulated using an AC voltage on the tuning port. Higher modulations help with wideband FM systems.

In a VCO, if the amplitude of the modulating signal and modulating frequency (f_m) are proportionally increased, the modulation index and the amplitude of the carrier plus the sideband signals will remain constant up to a point and will start decreasing after that. When the effective deviation of the modulating signal is 0.707 of the initial value, that modulating frequency is known as the 3 dB modulation bandwidth. Modulation bandwidth is a function of the tuning port impedance as well as the modulating source impedance. Generally, high frequency VCOs have higher modulation bandwidths. Typical bandwidths are between 10 and 20 MHz. Using optimized circuits, tuning bandwidths of greater than 100 MHz have been achieved at X-Band as shown in ***Figure 7***.

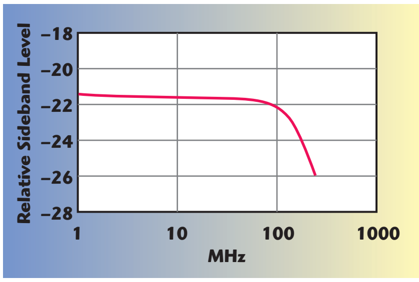
Slew Rate

Slew rate is the rate of change of VCO signal and is of significance in VCOs used as clocks in digital circuits and is presented in V/sec. In a sinusoidal source, it can be estimated by:

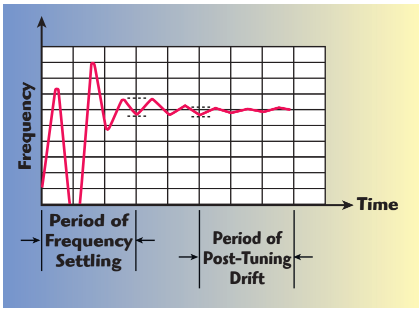
SR = 2 π f Vpk, where Vpk is the peak amplitude of the sine wave clock.

Frequency Settling and Post Tuning Drift

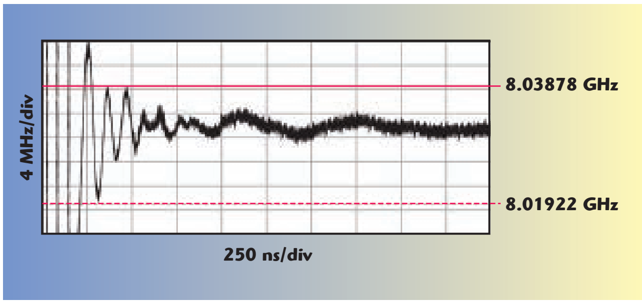
When a VCO frequency is switched from one point to another, it takes a finite amount of time to settle to the new point within the frequency range. Settling time is defined as the interval between the time when the input tuning drive waveform reaches its final value and the time when the VCO frequency falls within a specified tolerance of a stated final value at a particular time. Frequency settling refers to close-in settling (typically up to 1 msec) (see ***Figure 8***). Post tuning drift, on the other hand, represents the frequency settling characteristics between two points in time typically between 1 msec and 1 minute or more. Time references are generally



▲ *Fig. 7 Modulation bandwidth of a 10 GHz VCO.*



▲ *Fig. 8 Frequency settling and post tuning drift diagram.*



▲ *Fig. 9 Frequency settling from 6 to 8 GHz using LeCroy LabMaster 10 Zi 36 GHz/80 Gs/s oscilloscope.*

application specific.

Frequency settling is determined by a number of factors including type of active device, varactor diode, thermal management as well as quality of die attaching. During the interval, when the VCO is being tuned, the junction temperature of both the transistor and the varactor are changing due to changes in RF circuit efficiency and loading. This causes impedance changes that result in frequency shift. The time interval during which this happens is dependent on the thermal impedance of the devices. The varactor used in the VCO is a significant factor for frequency settling caused by the choice of passivation. Ceramic-to-glass passivation is usually superior to thermal oxide or silicon dioxide passivation in terms of post tuning drift. However, devices with thermal oxide passivation usually have more stable settling-time performance over time and temperature. Another parameter affecting frequency settling is chip thickness. In general, thinner is better because of less resistance in series as well as lower thermal resistance. The varactor and the active device are the two components where the most thermal sensitivity occurs and dominates this performance; hence, any long thermal time-constant associated with either of these components can cause pronounced frequency settling effects.

There are a number of measurement methods for frequency settling characteristics. Use of a frequency discriminator at the final frequency or at a down-converted frequency is a common method. With recent advances in technology, new approaches have become possible. Modern digital oscilloscopes are handy tools for making time-domain measurements, and they have recently become available to work at microwave and mmWave frequencies. Newly released high frequency oscilloscopes are already able to analyze signals up to 100 GHz,[14] providing microwave engineers with a tool for time-domain measurements. High frequency scopes make a number of VCO measurements possible including frequency, power output, jitter, modulation bandwidth and frequency settling characteristics. ***Figure 9*** shows a settling time measurement of a 6 to 8 GHz VCO using a silicon bipolar active device and a silicon hyperabrupt varactor. It shows that the VCO frequency settles within ± 4 MHz in less than 750 nanoseconds.

Frequency Load Pulling

VCO frequency also is affected by the load impedance. Variation in load magnitude and phase will change the

frequency of the VCO as a function of the oscillator quality factor. Frequency pulling, generally in MHz, is measured at a frequency by changing the phase of a known return loss through 180 degrees. Typically, a 12 dB return loss or a 6 dB attenuator is used as shown in ***Figure 10***.

Load pulling is also used to test whether the VCO is falling out of oscillations at a given frequency when expected worst-case load return loss is rotated through 180 degrees. In reality, VCOs are rarely used directly in high VSWR loads. Isolation between load and VCO is generally achieved by using an isolator or a buffer amplifier.

Power Load Pulling and Output VSWR

Power load pulling is the variation of VCO power output with the magnitude and phase of a known load return loss. Power load pulling is measured in a way similar to frequency pulling (see Figure 10). Care is taken to place the attenuator after the directional coupler and use a coupler with very good directivity at the frequency of measurement. Peak-to-peak power variation is typically measured into a 6 dB attenuation representing a 12 dB return loss. From the power variation (ΔP) and return loss, output VSWR or return loss of the oscillator can easily be calculated using:

$$\text{VSWR} = (5 \times 10^{\Delta P/20} - 3)/(5 - 3 \times 10^{\Delta P/20})$$

An interactive web flash tool can perform this equation as well.[15]

Hysteresis

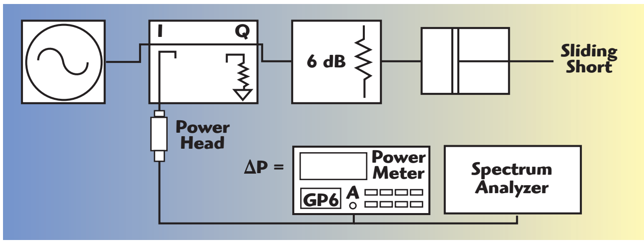
Hysteresis represents the maximum difference in VCO frequency measured at the same tuning voltage when the oscillator is tuned slowly through the specified tuning range from low end to high end and vice versa. Unlike YTOs, VCOs present a very low hysteresis. However, poor thermal management, where slow frequency drift over a long period is present, can result in adverse hysteresis.

Phase Noise and Jitter

Phase noise is an important characteristic of a VCO. It represents short-term stability of the device. Oscillator power is distributed in spectral distributions known as noise sidebands on opposite sides of the carrier. Phase noise can be analyzed as FM phenomenon that describes short-term random frequency fluctuations of a signal. It is measured in dBc/Hz at a particular offset from the carrier. The phase noise of a VCO is determined by a number of factors including resonator quality factor, type of varactor or the active device used, power supply noise, tuning voltage supply noise as well as the circuit design of the oscillator itself. Once DC power supplies are quieted, phase noise depends mainly upon the overall quality factor of the circuit and noise properties of the semiconductor devices. Higher Q means lower bandwidth and vice versa. For better phase noise, therefore, one can combine multiple narrowband VCOs rather than using a single wideband VCO. Regarding semiconductor technologies, silicon bipolar, SiGe HBT and InGaP HBTs are the technologies of choice and are used as demanded by frequency and other features desired.

A graphical representation of phase noise is shown in ***Figure 11***. The vari-

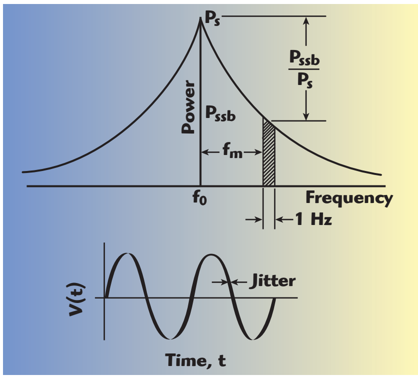
ous noise sources inside and outside the transistor modulate the VCO, resulting in energy or spectral distribution. More noise from various noise sources degrades the phase noise of the VCO. A number of methods are used to measure phase noise. An old trusted method has been the one which uses a frequency discriminator at the final frequency, requiring complex calibration. Automated phase noise measurements are now the norm allowing engineers more time to design and less time measuring. ***Figure 12*** shows a phase noise plot of a 10 GHz narrowband VCO and a wideband VCO using a silicon bipolar transistor.



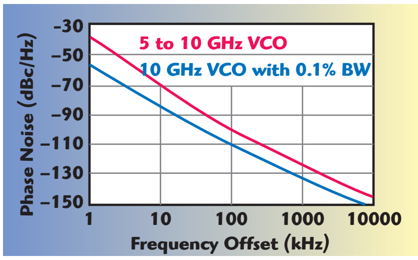
▲ *Fig. 10 Frequency pulling and output VSWR measurement setup.*

Jitter is another measure of short-term stability, which is used more in the digital world. A perfect sinusoidal output of an oscillator would have identical time between subsequently measured zero crossings along the time axis. Any deviation from this time is defined as a phase fluctuation and is known as jitter. Jitter is responsible for causing bit errors. In other words, jitter is a time-based phenomenon in which the edges of waveform transitions arrive early or late with respect to the clock that is latching the signal. If, for instance, the data edge arrives after its companion clock edge, then a bit that was supposed to be latched as high will be latched as low. Wrong edge timing causes incorrect latching which causes bit errors.

A low jitter clock source is an essential requirement for a low bit error rate digital communication system. Jitter in digitizer circuits deteriorates the signal-to-noise ratio. With ever increasing data rates both in the wireless and wired world, digital clocks have entered the microwave and mmWave region. While Gb/s data is entering the wireless world, optical communication systems are knocking at the terabit rate door. These clocks are nothing but microwave VCOs



▲ *Fig. 11 A graphical representation of phase noise.*



▲ *Fig. 12 Phase noise of silicon bipolar VCOs, one narrowband and one octave band.*

with special features. As an example, clock sources need to have differential outputs, achieved in VCOs by using a balun in the output or having a differential output oscillator. Instead of power output and phase noise, clocks are characterized by p-p voltage and jitter. Jitter and phase noise both represent phase fluctuations and are related through simple equations. Jitter is calculated by integrating phase noise over a specified offset range and converting to appropriate units. A simple interactive graphical tool is also available[16] online. Jitter is represented in different ways including radians, degrees, time in seconds as well as unit interval.

CONCLUSION

RF and microwave VCOs have come a long way in the past few decades. Progress in semiconductor IC technology has made these key functions ever so small that they have humbly lost their identity and have merged into a small corner of large mixed-signal ICs. Even when it is hard to see these master functions physically, they continue to provide vital control functions for communication, navigation and radar.

It seems that progress in VCO technology has slowed in the last decade. Technologies of choice for low phase noise, for example, remain silicon-bipolar devices, SiGe HBTs, and InGap HBTs.[17] Gradually, the f_T of these processes is expected to increase to a region where it will be hard to find more applications. Future challenges then will be more focused on cost and volume. Work on CMOS technology in this field will go into high gear. With the promise of low cost and a high level of RF analog and digital-integration capabilities, future consumer electronics applications in microwave and mmWave will see more of this CMOS technology. GaN semiconductor technology is also expected to move into practical use at microwave and mmWave frequencies with necessary cost reduction. Once it reaches high volume production capability, it has the potential to offer a serious challenge to GaAs.

Conventional CMOS may no longer be capable of continuing Moore's law. The ever increasing cost of narrowing line widths with diminishing returns calls for a paradigm shift. A potentially optimal solution is III-V compound semiconductors fully integrated on a silicon platform. Focus is expected to shift to this process in order to exploit the advantageous electronic, optical and power-handling properties of compound semiconductors while continuing to use the scale and cost structure of existing silicon semiconductor fabs. Recently, GaN on silicon was demonstrated on an 8" wafer.[18]

A wide variety of other compound semiconductor combinations could be realized as part of the full array of compound semiconductor on silicon technologies. Mixed-technology ICs are also expected to meet certain custom requirements that were not possible using a single technology. Design libraries will need to be developed in order to enable widespread adoption of these technologies across multiple applications. Improvements in 3D EM simulation software will continue to make the RF designer's job easier with more and more accurate results.

In regards to frequency tuning and

resonator elements new technologies including MEMS and substrate integrated waveguide are expected be used in addition to the standard varactor diode variations. On chip, narrowband but higher Q resonator switching may be used to achieve wider band low phase noise VCOs.

VCOs on MICs will continue to play a vital role in custom, lower volume requirements for defense, instrumentation and higher end communication systems. The speed and cost to develop signal sources with specific optimization of one or more features including power, frequency range, phase noise, settling time and power consumption will continue to count on MIC-based VCOs. Among test equipment, more automation and use of more modular instruments in place of benchtop equipment is expected.[19] High frequency real-time oscilloscopes will start playing a bigger role in characterizing VCOs up to mmWave frequencies. In spite of the slowdown in the rate of innovation, there will be many challenging and interesting opportunities for signal source designers. ■

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Low Cost Vector Signal Generator Features 100 MHz Bandwidth

Signal Hound
La Center, Wash.

As the demand for more bandwidth continues, modulation schemes with higher data rates and wider bandwidths have become prevalent. The test equipment industry has responded with vector signal generators (VSG) featuring higher bandwidth, bigger pattern buffers and more features – along with higher sticker prices.

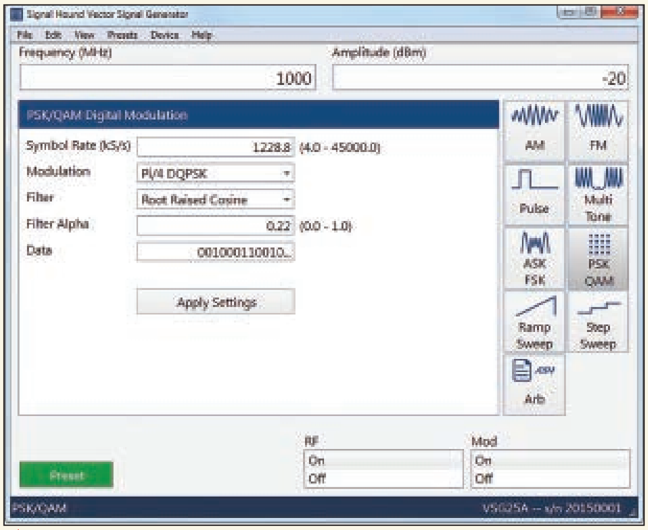
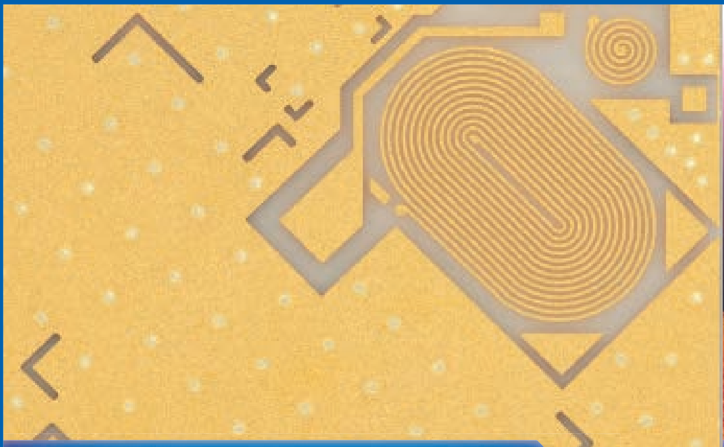


Fig. 1 VSG25A user interface.

Signal Hound takes a different approach. While others strive for unprecedented performance at any cost, the $495 Signal Hound VSG25A vector signal generator delivers good performance at unprecedented value. Featuring a frequency range of 100 MHz to 2.5 GHz, output amplitude from -40 to +10 dBm and 100 MHz of modulation bandwidth, the VSG25A covers most telecom frequencies as well as two major ISM bands (902 to 928 MHz and 2.4 to 2.5 GHz). The low end goes down to 80 MHz with reduced amplitude accuracy, covering the FM broadcast bands. The VSG25A is USB powered, weighs 130 grams and easily fits in a shirt pocket.

FEATURES

The VSG software comes with the expected features and is included in the purchase price. The application programming interface (API) has the exact same functionality as the user interface software, giving the programmer complete access to AM/FM, pulse, multi-tone, ASK, FSK, PSK, QAM and arbitrary waveform functions. A user-friendly API (see ***Figure 1***) makes test automation a straightforward process.



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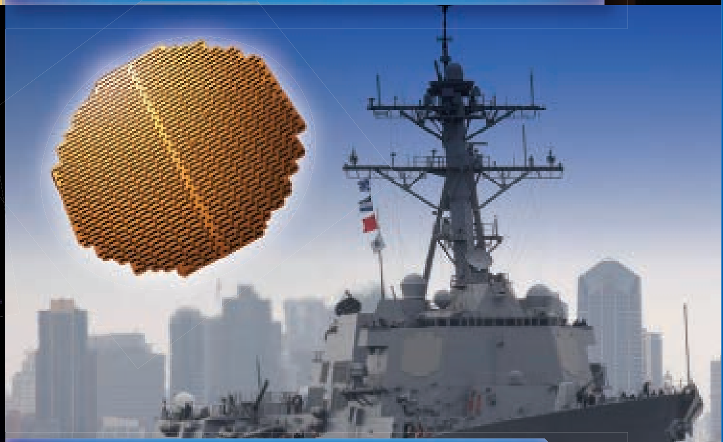

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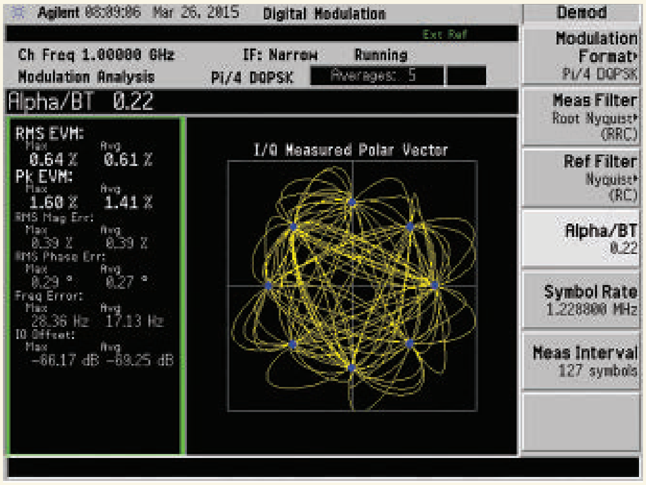
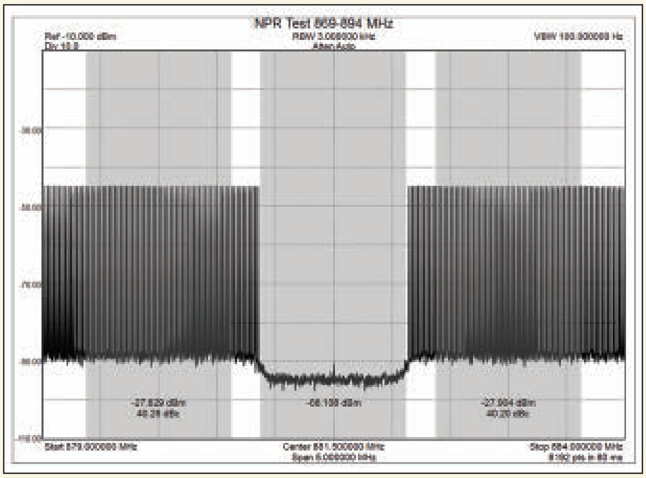


▲ *Fig. 2 Measured EVM of a 1 GHz π/4 DQPSK signal is 0.61% RMS (average).*



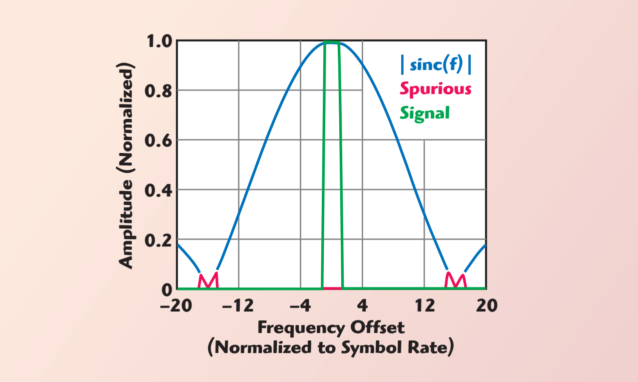
▲ *Fig. 3 Multi-tone NPR signal generated by the VSG.*

The digitally generated AM and FM waveforms are quite accurate. Total harmonic distortion for sine wave modulated FM is typically below 0.02 percent. Pulse modulation features typical rise and fall times of 3.5 and 2.5 ns, respectively (measured at 2450 MHz). Pulse widths can range from 6 ns to 25 ms. Pulse width resolution is typically better than 0.1 percent, even at 6 ns — the VSG25A can produce a 6.01 ns pulse as easily as 6.00 ns. The on/off ratio is typically greater than 50 dB, which is adequate for many applications. Duty cycle may be as low as 0.00025 percent (pulse period ≤ 1.0 s) or as high as 99.9 percent (off time > 6 ns). This is generally sufficient for a broad range of tests.

Digital modulation is built-in. Although specific protocols are not supported, the modulation behind those protocols is, including ASK, FSK, GFSK, OOK, MSK, GMSK, BPSK, DBPSK, QPSK, DQPSK, OQPSK, π/4 DQPSK, 8-PSK, D8PSK, 16-PSK, 16-QAM, 64-QAM and 256-QAM. Symbol rates from 4 kHz to 45 MHz are supported. Raised cosine and root-raised cosine filtering are included, with selectable filter roll-off. Typical error vector magnitude (EVM) for a π/4 DQPSK signal is below 1 percent RMS (see ***Figure 2***). Supported patterns are elementary sequences (01, 0011, 00001111), PN7 and PN9.

The Signal Hound VSG25A's multi-tone generator presents interesting opportunities for intermodulation testing, including noise power ratio (NPR). NPR testing gained a lot of attention in recent years for its ability to better emulate multi-carrier systems than two-tone IP3 (third order intercept point). Traditional NPR testing with additive white Gaussian noise (AWGN) is a fairly old method for testing intermodulation distortion. It uses a noise source with a band reject filter to notch out the middle of the signal. Modern NPR testing uses a synthetic noise technique by generating sets of over 1000 tones, having random phase relationships to each other, combined with the absence of tones in the center of the test pattern. This requires a modern high-bandwidth vector signal generator. A PC driving the Signal Hound VSG25A can accomplish this easily.

Generating 1001 tones with equal spacing and a selectable notch is as simple as entering the total tones, tone spacing and number of notched out tones (see ***Figure 3***). The local oscillator feedthrough can even be tuned out manually.



▲ *Fig. 4 Spurious from DAC aliasing (PN7 shown).*

The phase relationship between tones can be random, for NPR testing, or parabolic, for generating minimum peak-to-average power ratio signals. The user interface has an efficient workflow and can load random phase tone sets as often as every second, to average measurements and reduce uncertainty. When combined with a Signal Hound BB60C spectrum analyzer, 40 dB of effective NPR dynamic range is achieved. To increase the dynamic range to 55 dB, a spectrum analyzer similar to the Keysight PSA series can be used. Synthetic NPR testing is a powerful and flexible approach to multi-carrier intermodulation tests that formerly cost tens of thousands of dollars to set up. Now thorough and efficient NPR testing can be accomplished with the VSG25A and a spectrum analyzer.

The VSG25A can create a modulation signal with a custom or arbitrary waveform. I/Q waveforms can be built using third-party software packages, such as Matlab by MathWorks®, and pasted into a CSV file. The CSV input file, which can be modified with any spreadsheet software, controls the center frequency, amplitude, baseband clock rate, number of samples and signal period, followed by the actual samples. A chirp radar signal file is provided as an example.

Using the VSG25A as a sweeper is somewhat limited. It can sweep in the faster ramp sweep mode or more slowly using the step sweep mode. Ramp sweep time is limited to ≤ 10 ms for a 1 MHz span and ≤ 1 ms for a 10 MHz span. This is not the best product if the primary use is to be a synthesized sweeper.

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SATCOM	DM-HPS-35-101	2.2	2.5	20	40	35%	CW	28	4.0 x 4.00 x 1.00
SATCOM	DM-HPC-60-101	5.5	8.5	50	50	25%	CW	28	2.5 x 2.75 x 0.45
SATCOM	DM-HPX-100-105	9.75	10.25	50	100	30%	CW	28	7.4 x 4.30 x 1.65
SATCOM	DM-HPKU-40-105	13.75	14.5	45	50	20%	CW	24	4.5 x 4.00 x 0.78
SATCOM	DM-HPKU-40-101	14.4	15.5	45	30	15%	CW	28	2.5 x 2.75 x 0.45
SATCOM	DM-HPKA-10-102	29	31	50	12	15%	CW	20	3.1 x 3.00 x 0.78
SATCOM	DM-HPKA-20-102	29	31	50	20	15%	CW	20	3.5 x 4.50 x 0.78
RADAR	DM-HPL-1K-101	1.2	1.4	50	1000	40%	100 µs, 10% d.c.	50	6.0 x 6.00 x 1.50
RADAR	DM-HPS-1K-102	2.9	3.1	45	1300	35%	100 µs, 10% d.c.	32	14.0 x 8.00 x 1.75
RADAR	DM-HPS-1K-103	2.9	3.3	45	1500	35%	100 µs, 10% d.c.	50	9.5 x 9.50 x 1.50
RADAR	DM-HPS-1K-104	3.1	3.5	45	1300	35%	100 µs, 10% d.c.	50	9.5 x 9.50 x 1.50
RADAR	DM-HPC-50-105	5.2	5.8	50	50	35%	100 µs, 10% d.c.	32	3.0 x 3.00 x 0.60
RADAR	DM-HPC-200-101	5.2	5.9	50	200	40%	100 µs, 10% d.c.	50	4.5 x 4.50 x 0.78
RADAR	DM-HPX-140-101	7.8	9.6	50	140	40%	100 µs, 10% d.c.	40	3.6 x 3.40 x 0.67
RADAR	DM-HPX-400-102	8.8	9.8	50	450	35%	100 µs, 10% d.c.	50	7.0 x 4.50 x 1.65
RADAR	DM-HPX-800-102	8.8	9.8	50	900	35%	100 µs, 10% d.c.	50	9.0 x 6.00 x 1.65
RADAR	DM-HPX-250-101	9.4	10.1	50	250	40%	100 µs, 10% d.c.	50	3.6 x 3.40 x 0.67
RADAR	DM-HPX-800-101	9.4	10.1	50	900	35%	100 µs, 10% d.c.	50	9.0 x 6.00 x 1.65
RADAR	DM-HPX-20-101	9.9	10.7	46	20	30%	100 µs, 10% d.c.	32	3.6 x 3.40 x 0.67
RADAR	DM-HPX-50-101	9.9	10.7	50	50	30%	100 µs, 10% d.c.	40	3.6 x 3.40 x 0.67
ELECTRONIC WARFARE	DM-HPMB-10-103	0.1	6	55	10	20%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPLS-50-101	1	3	50	50	30%	CW	45	4.3 x 3.50 x 0.45
ELECTRONIC WARFARE	DM-HPLS-160-101	1	3	16	160	25%	CW	45	6.3 x 6.00 x 0.78
ELECTRONIC WARFARE	DM-HPSC-50-101	2	6	50	50	30%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPSC-80-101	2	6	50	80	25%	CW	28	4.5 x 4.00 x 0.78
ELECTRONIC WARFARE	DM-HPSC-150-101	2	6	60	150	25%	CW	28	6.5 x 6.50 x 0.78
ELECTRONIC WARFARE	DM-HPMB-10-101	2	18	45	10	15%	CW	32	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPMB-40-101	6	18	50	30	15%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPX-25-101	8	11	45	25	30%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPX-50-102	8	11	50	50	30%	CW	28	2.5 x 2.75 x 0.45

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As a low cost vector signal generator, the VSG25A offers a lot of bandwidth for a very low price. With its limited filtering and small pattern buffer, the VSG25A is not for everyone. Yet, at $495, this little gem is likely to become disruptive to the VSG market, putting 100 MHz of arbitrary waveform generation into almost any engineer's or technician's hands without any delays from forecasting capital expenditures. The VSG25A comes with a two-year warranty and a 30-day money back guarantee. Deliveries are off-the-shelf, so orders normally ship within one business day.

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Pushing STEM Onto Our Youth

John Mruz, Sr., Retired Microwave Engineer

For as far back as I can remember, I have always built one gizmo or another, usually from parts I collected from old television sets, radios or with parts that I bought with the money I used to earn on my newspaper route. Back then, in the late '50s, I had an amateur radio operator uncle who worked as a technician for AIL. Through his tutorship, I built my own ham band transceiver and earned my FCC license. I later attended RCA Institutes and got my first job at Technical Research Group (TRG). We built low noise parametric amplifiers for use in the ground stations that received signals from the very early orbiting satellites and a little later in the first geostationary satellites. I finally earned my BSEE degree with my tuition fully paid by TRG (with no groveling required). Yes, those were the days.

Back then, most technical co-workers had related hobbies outside of work. There were the ham operators that later included the Oscar satellite enthusiasts and the microwave moon bounce people. There were the audio buffs with their airtight speakers that incorporated various forms of infinite baffles, and there were even the radio astronomy guys who had the most elaborate antenna arrays and some pretty nifty reflector telescopes right in their backyards. Everybody had at least one room in their house dedicated to some technical hobby and maybe even a complete metal or woodworking shop in their garage. At least once a month, just about everyone would participate in a Friday night "bunny hunt" (for a hidden transmitter) and then meet at some pre-arranged diner. We would tell that evening's war stories associated with that hunt and show off our newest direction finder (DF) construction project. Back in the '60s, technology was more than a hobby. It was a way of life – it was a miracle that marriages survived – and it was a joy to go to work.

As a comparison, let's take today . . . PLEASE take today. We old guys certainly don't want it. What happened to the enthusiasm, what happened to the excitement and what happened to the joy? Want proof? Look at all of the responses that Gary Lerude (*Microwave Journal* technical editor) received from his inquiry about the positive influence today's engineer is contributing to our science, technology, engineering and mathematics (STEM) initiative. In the first two days, he received just mine! Where is everybody? Personally, I'm depressed because I still remember the good old times. For the sake of the technical standing of our country, we have to get those good times back. We sure don't want other countries to have all the future fun by becoming tomorrow's technology leaders, do we?

It is time to get serious and make some changes. How, you ask? Two major areas that should be kept in mind when guiding our youth towards a STEM career are today's political environment and industry's shortcomings in keeping the technical workforce motivated and stable. I have known many excellent engineers who have left the laboratory environment for less technical, yet seemingly more attractive and lucrative positions.

I see the current increase in STEM activity motivated by the U.S. government's fear that we are beginning to technologically lag behind other nations. A similar initiative also existed in the mid '50s through the early '70s. Unfortunately, unlike this earlier period where much of the research and development was government programs, there is very little government funding currently available. We are presently preoccupied with keeping up with our debt payments. Businesses in the private sector have been paying lip service to government R&D requests, while they have actually been placing most of their resources into increasing their profits to keep their stockholders happy. Very little scientific discovery is taking place. Instead, most of today's engineers are working to achieve small incremental improvements in existing technology.

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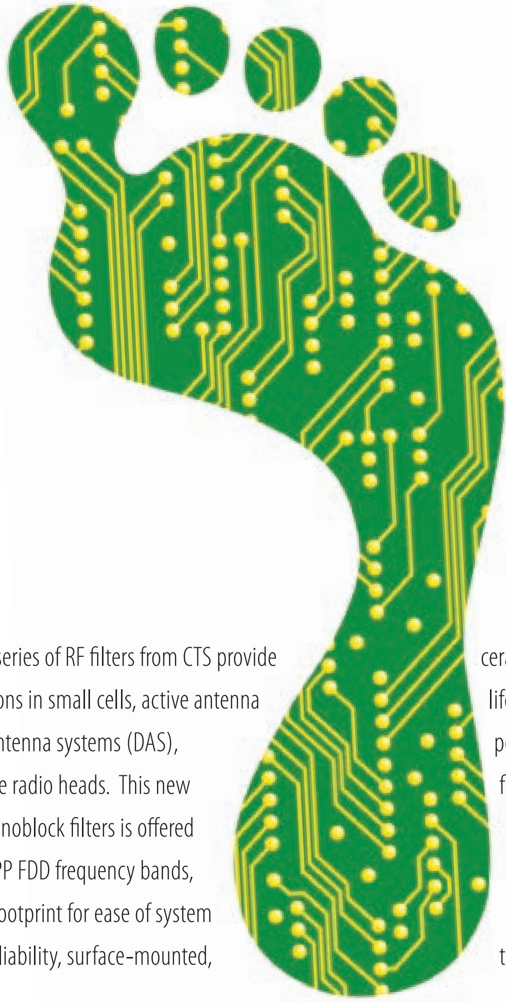

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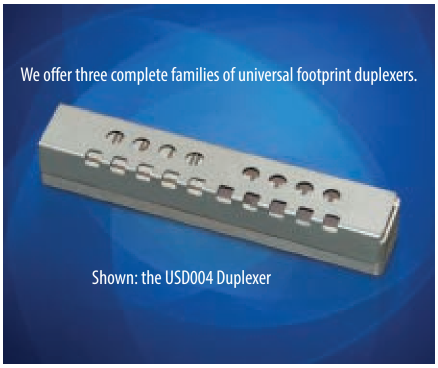

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Input Power Rating	20W Avg 200W Pk	6W Avg 60W Pk	1.5W Avg 15W Pk
Insertion Loss (5MHz AVG)	2.2dB	2.6dB	3.0dB
Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
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* Note: "Difficult" bands may have 2dB lower worst case Rx band isolation.

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Such work is neither very exciting nor mentally challenging. The business environment is also quite competitive, which limits profits and salaries; it certainly is not going to attract our sharpest minds. It is unfortunate that today's environment is considerably less R&D-oriented than it was back in the '50s through '70s.

One additional thought: the IEEE will, of course, fully support the current STEM initiative because its future health is a function of the country's engineering environment. They appear to continually claim that there is an ongoing shortage of engineers. If this were really true, then supply and demand would dictate that engineers would have the highest salaries in any organization. This is certainly not the case. I will have more on this later.

With all this said, I have concerns about those in our industry who are so strongly pushing the STEM and STEAM (STEM + Art) initiatives. We have to be very careful about "selling" a career path like engineering to our impressionable youth, most of whom do not yet realize how that career decision will inevitably affect not only their future lifestyle but also the future lifestyles of their dependents. Honesty dictates that we must share the negatives as well as the positives. Otherwise, what could occur is what happened to one of my personal "career targets" who received an undergraduate degree in engineering from MIT and a master's in engineering from RPI. After a three year stint as a hands-on "lab rat" with a large, reputable company (with its internal politics and meager salary increases), he went back to Harvard, earned his MBA and is now a marketing VP in New York City. He recently shared with me that he still has to put up with company politics, yet at a salary quite a bit greater than twice that of a typical senior engineer. He told me another major motivator in this career change was the piecewise introduction of his four children and his ability now to send them to good schools like the ones he attended. Another of my historical "career targets" left engineering after a few years, attended Wharton and is now a business manager in another industry, for the same reasons given by my first target.

How about a third and fourth example: I am retired today but not because I was able to save all kinds of excess from my typical engineer's salary. Rather, I linked with a very smart financial advisor who, by the way, graduated from Cornell with an engineering degree and quickly learned that he needed a more lucrative means to attain the lifestyle he wanted for himself and his growing family. Incidentally, he initially targeted engineering because his father was a hands-on engineer for Hewlett Packard. As you may have guessed by now, his father soon left the lab and became a manufacturer's representative. My very own first mentor will be the final example that I will share. He was one of the sharpest technical people I have ever known. He soon left engineering – I hope not because of his exposure to me – and became head of the company's human resources (HR) department. Today he is practicing law. While I have numer-

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Dk @ 10 GHz	2.80 - 3.45	3.38, 3.45 & 3.56	3.45*	3.45*	3.00
Df @ 10 GHz	0.0028 - 0.0036	0.0028, 0.0031 & 0.0034	0.0031*	0.0030*	0.0017
CTE Z-axis (50 to 260°C)	2.90%	2.80%	2.80%	2.90%	2.90%
T-260 & T-288	>60	>60	>60	>60	>60
Halogen free	No	No	No	Yes	No
VLP-2 (2 micron Rz copper)	Available	Available	Available	Standard	Standard
Stable Dk & Df over the temperature range	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-55°C to +125°C	-40°C to +140°C
Optimized global constructions for Pb-free assembly	Yes	Yes	Yes	Yes	Yes
Compatible with other Isola products for hybrid designs	For use in double-sided applications	Yes	Yes	Yes	Yes
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ous other examples that I can share, I think I have more than made my point.

In my 47 years working in engineering, I have encountered relatively few people who stayed with the pure technology. Most left the bench within their first 10 years and either entered sales, became hands-off managers or left the industry altogether. In light of this, there is little wonder why so few seasoned, hands-on mentors are left to support and inspire our entry level technologists. It makes little sense expending tremendous effort to attract people into engineering if they will not stay with it for the long term. It makes the current STEM attraction effort nothing more than a big wheel-spinning exercise. It is like polishing the leaves of a plant when its roots are failing. Our immediate focus should be to bring today's engineering careers in line with the competing alternatives, not attracting entry level people into technical jobs that most will prematurely leave. This will not be an easy task, however, when you consider negative issues like competitive outsourcing, where foreign engineers are willing to work for a fraction of the U.S. rate.

While on the negatives, we really should consider the return-on-investment (ROI) on the cost of a good college and historic trends in engineering salaries and related perks. When I initially decided to enter engineering, part of the perks offered to both technicians and engineers by almost all companies was a generous tuition reimbursement policy. Back then, full-time college costs were only a small fraction of what they are today. There was plenty of government-supported and commercial work, and competition among companies was high for good technical people. Annual cost-of-living salary adjustments plus merit reviews were given, and substantial yearly bonuses were the norm. Unfortunately, things are much different today. Recently a senior engineer from a major microwave company told me that his company has not given out yearly increases in almost five years, and health insurance cutbacks have necessitated that the employees now pay a much larger portion of those costs. Last week, during dinner with the HR VP of another prominent Long Island technical company, I was told that yearly cost-of-living plus merit raises were under two percent, and there were also cutbacks in health insurance coverage. In both of these organizations, like many others, layoffs are commonplace. It is little wonder why many parents of our high school students are asking whether or not it actually makes financial sense to enter the engineering profession.

I rest my case.

So, what are we, as today's proponents of engineering, going to do about all this? ■

Editor's Note: John Mruz, Sr. is a retired microwave engineer with six grandchildren who are beginning to ask him about career options. We encourage you to share your experience and thoughts about engineering as a career at our website: www.microwavejournal.com/Stem.

DARPA Shares Its Vision for the Future

DARPA recently released "Breakthrough Technologies for National Security," a biennial report summarizing the agency's historical mission, current and evolving focus areas and recent transitions of DARPA-developed technologies to the military services and other sectors. The report's release coincided with testimony by DARPA director Arati Prabhakar before the Emerging Threats and Capabilities Subcommittee of the House Armed Services Committee, at a hearing entitled "Department of Defense Fiscal Year 2016 Science and Technology Programs: Laying the Groundwork to Maintain Technological Superiority."

"Breakthrough Technologies for National Security" affirms that America is in a strong strategic position today, in large part because of its longstanding technological dominance. But it also notes that a number of challenges threaten that status, including the global spread of ever more powerful and less expensive technologies and the emergence of disruptive non-nation-state actors in addition to ongoing threats from peer adversaries.

"DARPA's mission and philosophy have held steady for decades, but the world around DARPA has changed dramatically," the report says. "Those changes include some remarkable and even astonishing scientific and technological advances that, if wisely and purposefully harnessed, have the potential not only to ensure ongoing U.S. military superiority and security but also catalyze societal and economic advances. At the same time, the world is experiencing some deeply disturbing technical, economic and geopolitical shifts that pose potential threats to U.S. preeminence and stability."

> "DARPA's mission and philosophy have held steady for decades, but the world around DARPA has changed dramatically..."

The report identifies the phenomenon of increasing pace as a central challenge and opportunity—from the need for ever-faster radio-frequency and information-processing systems that work on the scale of nanoseconds, to the need to speed up the development time of major military systems, whose timescales today extend to decades.

DARPA is focusing its strategic investments in four main areas:

- Rethink Complex Military Systems: To help enable faster development and integration of breakthrough military capabilities in today's rapidly shifting landscape, DARPA is working to make weapons systems more modular and easily upgraded and improved; assure superiority in the air, maritime, ground, space and cyber domains; improve position, navigation and timing (PNT) without depending on the satellite-based Global Positioning System; and augment defenses against terrorism.
- Master the Information Explosion: DARPA is developing novel approaches to deriving insights from massive datasets, with powerful big-data tools. The agency is also developing technologies to ensure that the data and systems with which critical decisions are made are trustworthy, such as automated cyber defense capabilities and methods to create fundamentally more secure systems. DARPA is also addressing the growing need to ensure privacy at various levels of need without losing the national security value that comes from appropriate access to networked data.
- Harness Biology as Technology: To leverage recent breakthroughs in neuroscience, immunology, genetics and related fields, DARPA in 2014 created its Biological Technologies office, which has enabled a new level of momentum for the agency's portfolio of innovative, bio-based programs. DARPA's work in this area includes programs to accelerate progress in synthetic biology, outpace the spread of infectious diseases and master new neurotechnologies.
- Expand the Technological Frontier: DARPA's core work has always involved overcoming seemingly insurmountable physics and engineering barriers and, once showing those daunting problems to be tractable after all, applying new capabilities made possible by these breakthroughs directly to national security needs. Maintaining momentum in this essential specialty, DARPA is working to achieve new capabilities by applying deep mathematics; inventing new chemistries, processes and materials; and harnessing quantum physics.

"Breakthrough Technologies for National Security" includes two sections highlighting examples of DARPA technologies that have transitioned to the military or other organizations in support of national interests. One section focuses on technology transitions from recent programs to the Services. A second section, entitled "Success Stories," looks at the long-term impacts of certain DARPA programs over a period of decades—a reminder that the benefits of DARPA research often extend for many years after initial applications get operationalized, sometimes in unexpected ways.

GD to Update MUOS Waveform for U.S. Army AN/PRC-155 MUOS-Manpack Radios

VIEW VIDEO

General Dynamics received a contract from the U.S. Army to support upgrades to the Mobile User Objective System (MUOS) waveform used in the Army's AN/PRC-155 two-channel MUOS-Manpack radios. The waveform is the digital 'dial-tone' needed to connect with the U.S. Navy's new MUOS satellite communications network that will provide U.S. military and government personnel smartphone-like voice clarity and data connectivity. The total potential value of the contract is approximately $13 million and includes waveform integration into the PRC-155 radios, radio/waveform testing, field support and soldier training.

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> MUOS waveform upgrades will enhance voice clarity and cyber security of voice and data communications across the MUOS communications network.

MUOS waveform upgrades will enhance voice clarity and cyber security of voice and data communications across the MUOS communications network. Other waveform enhancements include improved connectivity with other MUOS-Manpack radios, the MUOS ground system and satellites. The MUOS communications network is expected to achieve global communications coverage in 2016.

Raytheon to Demo Technologies That Enable Affordable, Rapidly-Developed Phased Array Systems

DARPA has awarded Raytheon Co. two contract modifications totaling a combined $5 million in support of the Arrays at Commercial Timescales (ACT) program. ACT is focused on developing technology that enables rapidly upgradable and widely deployable radar array architectures. The awards are the result of a competitive down select process after which DARPA chose Raytheon for the next phase of both programs.

"Raytheon shares DARPA's vision of a common digital beamforming architecture platform to enhance affordability and upgradability," said Paul Ferraro, vice president of Advanced Technology Programs for Raytheon's Integrated Defense Systems business.

> This is achieved by creating a building block composed of a digitally-influenced common module and a reconfigurable radiating antenna element that is scalable and customizable.

Raytheon is leveraging its Rapid Array Performance Improvement and Deployment (RAPID) concepts in support of the ACT program. RAPID aims to dramatically shorten the timescales and non-recurring cost associated with phased array development, deployment and performance upgrades. RAPID achieves this by creating a building block, composed of a digitally-influenced common module and a reconfigurable radiating antenna element that is scalable and customizable for each application, without requiring a full redesign for each application space.


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Ericsson Joins Forces With Scania and KTH in Transport Lab

Ericsson is joining forces with Scania and Kungliga Tekniska Högskolan (KTH) – Sweden's Royal Institute of Technology – in their Integrated Transport Research Lab (ITRL) to explore the transport solutions of the future.

The ITRL Lab is set to run until the end of June 2021 and the joint initiative, which will explore areas such as autonomous buses and improved systems for traffic management, forms part of the 5G for Sweden programme that was announced in March. The partnership will feature technology experts from Ericsson, leading scientists from KTH and industry experts from Scania who together will jointly develop ideas and proposals to harness technology to create the transport systems of the future.

"The intention of the research is to validate and evolve technologies and solutions that can benefit transport infrastructure in the future...."

Sara Mazur, Ericsson's head of research, said, "The intention of the research is to validate and evolve technologies and solutions that can benefit transport infrastructure in the future. Our expectation is to develop and introduce new products and new business models in cooperation with Scania for the transport sector, as well as other new markets. We are very proud of our active role in the 5G for Sweden project, which aims to use technology to improve Swedish society. The ITRL project is very much in line with Ericsson's vision of the Networked Society."

EU-Funded Researchers Develop First 5G Radio Channel Model

The EU-funded Mobile and wireless communications Enablers for the 2020 Information Society (METIS) project is a strong example of the serious European investment being made in 5G. The project, which has received €15.9 million in EU funding, used its final meeting in Turin, Italy to herald a significant breakthrough – the delivery of industry-first 5G radio channel models. These models are based on realistic end user scenarios and requirements, and are mapped to a range of options. As 5G will support a broad range of applications, different channel models are likely to be required.

Researchers and developers of new technologies and products will benefit from the proposed 5G radio channel models in several areas, not least in enabling them to characterise the performance of early 5G designs. For example, the models will enable technologists to run laboratory tests to predict how devices will work in real world conditions.

The models will also allow for system performance evaluation, system optimisation, radio interface simulation, R&D testing and final product approval, ensuring that Europe will have a major say in what 5G technology will look like.

...Europe will have a major say in what 5G technology will look like.

Consortium members have also been careful to ensure that the proposed radio channel models address a very wide frequency spectrum, from relatively low frequencies in the current cellular frequency bands to centimetre and millimetre wave frequencies. Some technology firms believe that new channel models will be needed for 5G – in 2020 mobile and wireless traffic volume is expected to increase a thousand-fold over 2010 figures – while it has been acknowledged that limited work has been done on understanding how millimetre wave systems will work in practice.

These models will help speed up development of the next generation of wireless technology, and ensure that European business and know-how are very much in the driving seat.

GSA Confirms 393 LTE Networks Launched

393 operators have commercially launched LTE in 138 countries, according to the data released by the Global mobile Suppliers Association (GSA) in the latest update of the Evolution to LTE report. 107 operators commercially launched LTE service in the past year. 644 operators are investing in LTE across 181 countries. This comprises 607 firm network deployment commitments in 176 countries (of which 393 networks have launched), and 39 pre-commitments trials in a further five countries.GSA raised its year-end forecast to 460 commercially launched LTE networks.

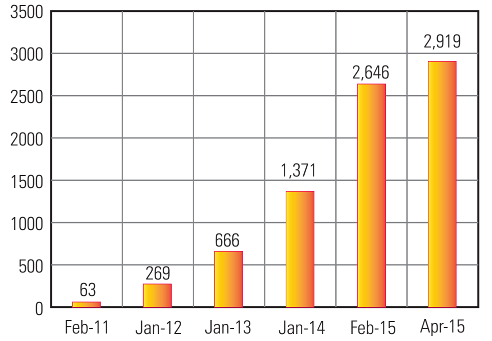
LTE-Advanced deployment continues as a major trend with 116 operators, i.e., around 3 percent investing in carrier aggregation technology. Network capacity, efficiencies and peak speeds are rising dramatically. 64 operators, almost 1 in 6, have commercially launched LTE-Advanced service in 39 countries.

The most widely used spectrum for LTE network deployments continues to be 1800 MHz (3GPP band 3). 176 LTE1800 networks, almost 50 percent higher than a year ago, are commercially launched in 86 countries. 1800 MHz is used today in 45 percent of LTE network deployments and continues to dominate the user devices ecosystem. Over 43 percent of LTE user terminals can operate in the 1800 MHz band. The next most popular contiguous band for LTE deployments is 2.6 GHz (band 7) and is used in almost 25 percent of networks.

For More Information **Visit mwjournal.com for more international news**

While most operators deployed LTE networks in paired spectrum using the FDD mode, the LTE TDD mode (TD-LTE) for operators with unpaired spectrum continues to develop in all regions, and particularly in China. 54 operators, more than one in eight of all LTE operators, have commercially launched LTE service using the TDD mode in 34 countries. Band 40 (2.3 GHz) is the most widely deployed spectrum.

LTE User Devices Growth



LTE Terminals Announcements as Confirmed in GSA Reports up to 20 April 2015

Source: Status of the LTE Ecosystem Reports 2011–2015 Global mobile Suppliers Association (GSA)

Thales to Develop France's CERES Space-Borne Military Intelligence System

The French defence procurement agency (DGA) has selected Thales and Airbus Defence and Space as co-prime contractors for the design and construction of France's future military spaced-based signals intelligence (SIGINT) system, which is due to enter service by 2020.

Capacité de Renseignement Electromagnétique d'origine Spatiale (CERES) will provide the French armed forces with an operational space-based SIGINT capability. Three closely positioned satellites will detect and locate radiocommunications and radars. The system also includes a ground control segment, to be provided by the French space agency CNES, and the user ground segment. Intelligence is one of four priorities identified by the French defence white paper, and funding was earmarked for SIGINT, including the CERES programme, under the 2014-2019 defence spending plan.

"...giving France a capability that few nations possess..."

Pierre Eric Pommellet, Thales executive vice president, Defence Mission Systems stated, "This satellite system will be one of the most sophisticated in the world, giving France a capability that few nations possess. To design and build CERES, we will be drawing on the experience and expertise acquired on the ESSAIM and ELISA demonstrators."

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Cliff Drubin, Associate Technical Editor

New IBM IoT Cloud Services to Drive Insights into Business Operations

VIEW VIDEO

IBM will invest $3 billion over the next four years to establish a new Internet of Things (IoT) unit, which includes creating a cloud-based open platform designed to help clients and ecosystem partners build IoT solutions.

IBM's work in Smarter Planet and Smarter Cities was based on practical applications of IoT in the enterprise and led to a broad set of solutions, ranging from water management to optimizing retail and customer loyalty to alleviating traffic congestion. With new industry-specific cloud data services and developer tools, IBM will build on that expertise to help clients and partners integrate data from an unprecedented number of IoT and traditional sources. These resources will be made available on an open platform to provide manufacturers with the ability to design and produce a new generation of connected devices that are better optimized for the IoT, and help business leaders across industries create systems that better fuse enterprise and IoT data to inform decision-making.

"Our knowledge of the world grows with every connected sensor and device, but too often we are not acting on it, even when we know we can ensure a better result," said Bob Picciano, senior vice president, IBM Analytics. "IBM will enable clients and industry partners apply IoT data to build solutions based on an open platform. This is a major focus of investment for IBM because it's a rich and broad-based opportunity where innovation matters."

"Our knowledge of the world grows with every connected sensor and device, but too often we are not acting on it ..."

IBM estimates that 90 percent of all data generated by devices such as smartphones, tablets, connected vehicles and appliances is never analyzed or acted on. As much as 60 percent of this data begins to lose value within milliseconds of being generated. To address this challenge, IBM is announcing it will offer:

- IBM IoT Cloud Open Platform for Industries: This platform will provide new analytics services that clients, partners and IBM will use to design and deliver vertical industry IoT solutions. For example, IBM will introduce a cloud-based service that helps insurance companies extract insight from connected vehicles. This will enable new, more dynamic pricing models and the delivery of services that can be highly customized to individual drivers.
- IBM Bluemix IoT Zone: New IoT services as part of IBM's Bluemix platform-as-a-service will enable developers to easily integrate IoT data into cloud-based development and deployment of IoT apps. Developers will be able to enrich existing business applications – such as enterprise asset management, facilities management, and software engineering design tools – by infusing more real-time data and embedded analytics to further automate and optimize mission-critical IoT processes.
- IBM IoT Ecosystem: Expansion of its ecosystem of IoT partners – from silicon and device manufacturers to industry-oriented solution providers – such as AT&T, ARM, Semtech and newly announced The Weather Company – to ensure the secure and seamless integration of data services and solutions on IBM's open platform.

IBM's capabilities are illustrated in a recently announced global strategic alliance with The Weather Company through WSI, its global B2B division. WSI's forecasting system ingests and processes data from thousands of sources, resulting in approximately 2.2 billion unique forecast points worldwide, and averages more than 10 billion forecasts a day on active weather days. The IoT and cloud computing allow for collection of data from more than 100,000 weather sensors and aircraft, millions of smartphones, buildings and even moving vehicles. The two companies will help industries utilize their understanding of weather on business outcomes and take action systemically to optimize those parts of their businesses.

Smartphones Fuel Biometrics in Consumer and Enterprise Sectors to $3.1B

ABI Research forecasts $3.1 billion global revenues in 2015 for biometrics in the consumer and enterprise sectors with much of the growth coming from smartphone solutions. Existing smartphone hardware provides a relatively stable foothold for some authentication modalities but rapid advances in the biometrics field will drive further smartphone hardware upgrades. Meanwhile, pioneering algorithm design and cloud computing services are transforming user authentication.

Dimitrios Pavlakis, Digital Security research analyst comments, "Biometry is moving rapidly into the security ecosystem and its adoption by CE devices will jumpstart this phenomenon. Specifically, smartphone biometrics provide not only a secure alternative for authentication, mobile payments and BYOD initiatives but also enhance user experience, navigation, mobility, and versatility."

"Biometry is moving rapidly into the security ecosystem and its adoption by CE devices will jumpstart this phenomenon..."

Market Leaders like Apple and Samsung are setting the new norm for smartphone authentication and mobile payments using biometrics. Other companies like AGNITiO, EyeVerify, ImageWare Systems, KeyLemon and Nok Nok Labs are introducing voice and face biometrics into the

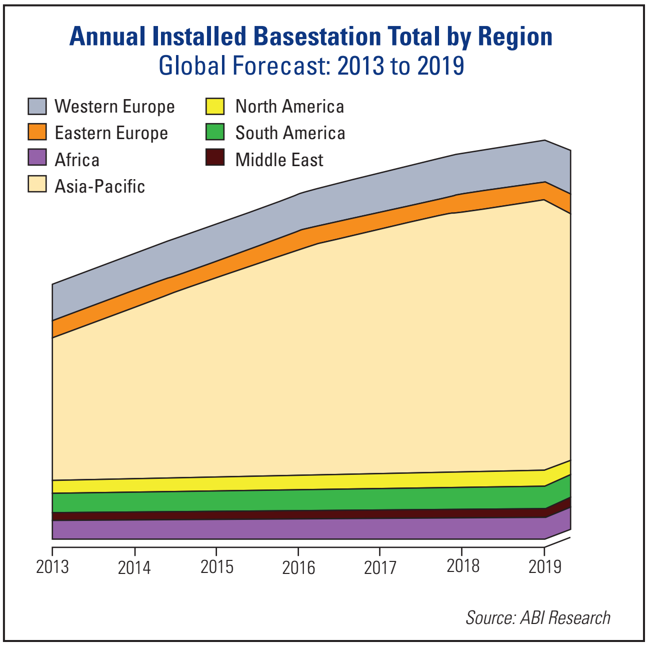
For More Information Visit mwjournal.com for more commercial market news landscape and investigating innovative ways of consumer identity management and implementing improved security features.

Asia-Pacific Drove RAN Market to Double-Digit Growth in 2014

Asia-Pacific regional growth in basestations dominated in 2014 as it continued to account for the majority of worldwide basestation deployments. According to ABI Research, Asia-Pacific is now by far the largest market for LTE, followed by North America and Western Europe, with Asia-Pacific regional installed base growing by double-digits in 2014.

LTE macro RAN spending also set records in 2014 as LTE expenditures accounted for a majority of RAN spending. Ericsson maintained its number one market share rank for 2014 followed by Huawei, Nokia Networks and Alcatel-Lucent all with double-digit shares, according to ABI Research estimates.

One of the main mobile network operators behind this trend is China Mobile—a major proponent of Time-Division LTE or TD-LTE, and one of the three nationwide carriers in China licensed to deploy 4G networks. "After deploying over 700,000 TD-LTE basestations in 2014, China Mobile now plans a massive expansion of an additional 300,000 basestations to reach 1 million by the end of 2015," says Nick Marshall, research director at ABI Research. "The company plans peak CAPEX in 2014 and 2015 to help construct what it claims will be the world's largest 4G network."



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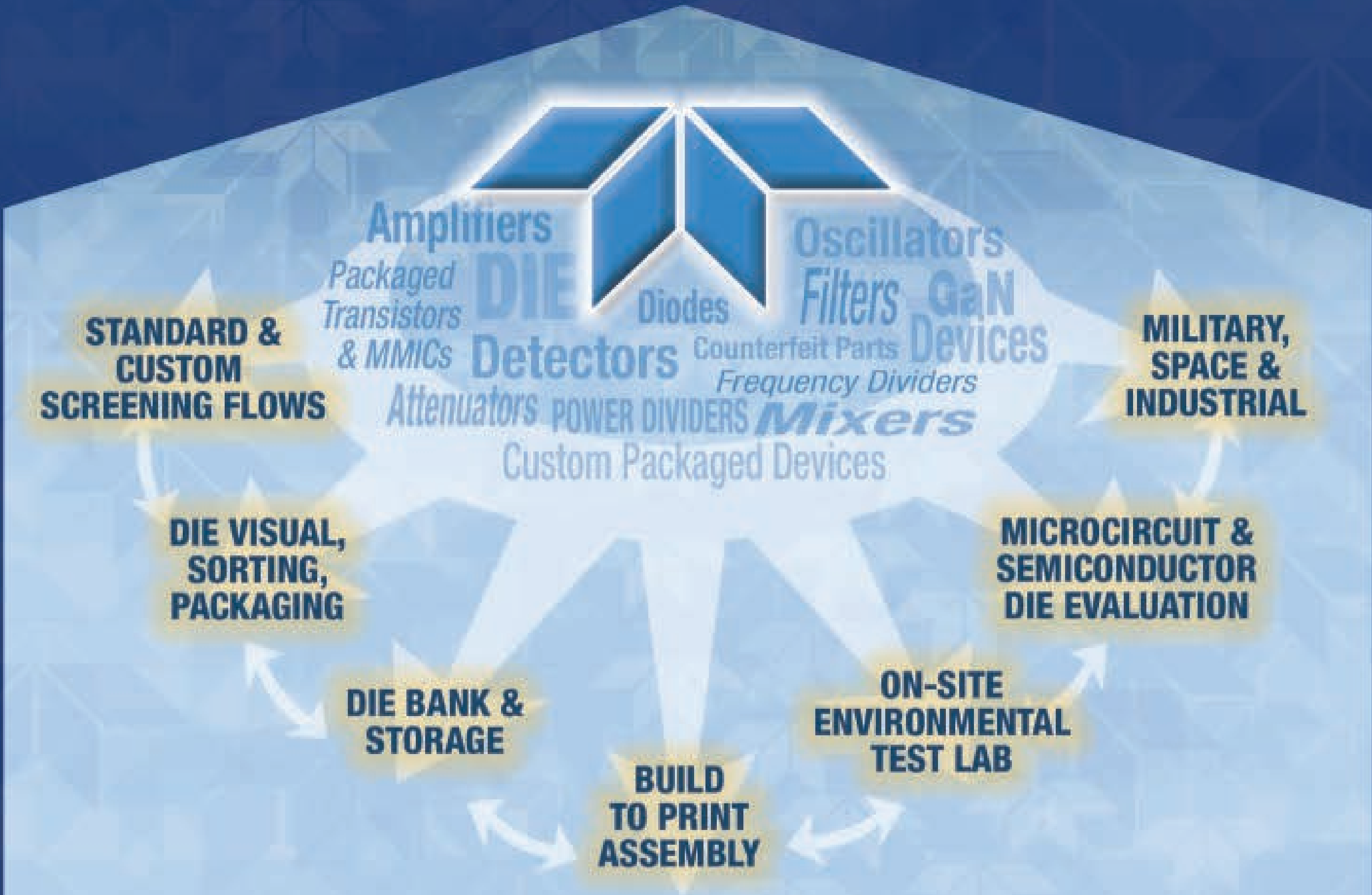

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Axell Wireless has announced that its integration into **Cobham** will be fully completed by July 2015. This follows the acquisition of the company by Cobham in May 2013. Axell Wireless, together with test and measurement company Aeroflex - acquired by Cobham in September last year - will form a new business unit, **Cobham Wireless**. The Cobham Wireless business unit, which will be led by senior vice president Ian Langley, will be a part of Cobham's Communications and Connectivity sector. The completion of the Axell integration enables the former Axell business to take advantage of the combined capabilities in the Cobham portfolio.

Nokia and **Alcatel-Lucent** announced their intention to combine to create an innovation leader in next generation technology and services for an IP connected world. The two companies have entered into a memorandum of understanding under which Nokia will make an offer for all of the equity securities issued by Alcatel-Lucent, through a public exchange offer in France and in the United States, on the basis of 0.55 of a new Nokia share for every Alcatel-Lucent share.

Microsemi Corp., a provider of semiconductor solutions differentiated by power, security, reliability and performance, and **Vitesse Semiconductor Corp.**, jointly announced that Microsemi has entered into a definitive agreement to acquire Vitesse for $5.28 per share through a cash tender offer, representing a premium of 32 percent based on the average closing price of Vitesse's shares of common stock during the 30 trading days ended March 17, 2015. The board of directors of Vitesse unanimously recommended that Vitesse's stockholders tender their shares in the tender offer. The total transaction value is approximately $389 million.

Novatel Wireless Inc., a provider of wireless solutions for the Internet of Things (IoT), and **Feeney Wireless**, a privately held, U.S.-based provider of end-to-end IoT solutions and services, announced that Novatel Wireless completed the acquisition of FW for $25 million in a combination of cash and stock, with up to an additional $25 million in potential earn-out payments over four years based on FW's revenue and gross profit performance. The combined companies will leverage synergies in product development, engineering services, global channels and complementary resources.

COLLABORATIONS

Smart Electronics and **Lark Engineering**, both part of **Secure Technology Co.**, announced they are working together to be a full service components solution provider for the industrial, aerospace and military market segments. Lark Engineering has been a leader in providing commercial and military grade RF and microwave filters for over 25 years, while Smart Electronics excels in using the latest technology to provide contract manufacturing solutions for electronic circuit boards, sub-assemblies, cable/harnesses and modules/box builds. As a value added solutions provider, Smart Electronics and Lark Engineering will maintain a special focus on RFCCA, RF sub-assemblies, special test equipment design, manufacture and use, and technical competence.

NEW STARTS

Supporting the **Microwave Vision Group's** vision to bring all products together under one strong brand, **Satimo Industries**, the manufacturing division of Satimo's multiprobe technology for fast, accurate measurement and visualization of electromagnetic fields, will begin to operate under the new name, **MVG Industries**, effective immediately. There will be no change to existing operations and registration numbers will remain the same. Customers and suppliers will each receive a letter advising them of the name change and highlighting subtle branding changes they will see in all future correspondence.

ACHIEVEMENTS

Reactel Inc. announced it has achieved AS9100 certification. AS9100 is a quality standard for companies that design, develop, or produce aerospace products. Reactel's AS9100 certification is a dual certification, meeting all of the requirements of ISO 9001 as well as the additional requirements specific to the aerospace industry. Prior to receiving AS9100 certification, Reactel had been ISO 9001 certified since 1996. AS9100 certification provides companies with a thorough QMS which is focused on areas impacting the aerospace industries concerns about the reliability and safety of products procured. Companies with AS9100 certification have a QMS which demands control and monitoring from initial design to deliverable product.

Rohde & Schwarz has once again won the highly esteemed GTI Innovation Award in 2015. The company has been singled out for its continuous effort to support the GTI and the entire TD-LTE industry with its broad portfolio of testing solutions for TD-LTE. The testing solutions from Rohde & Schwarz support all parts of the value chain, from chipsets and components, smartphones and other mobile devices to infrastructures and base stations, providing the best performance possible.

Guerrilla RF Inc., a provider of high performance MMICs, announced that the U.S. Patent and Trademark Office has issued Patent No. 8,970,296. The company's first issued patent, expiring in 2033, prevents amplifiers from turning on in the presence of large RF input signals – leading to exceptional isolation and minimal impact to their on-state performance. Guerrilla Armor™ also fits in the same form factor as the company's existing, best-in-class noise figure low noise amplifiers (LNA), requiring no additional components and resulting in substantial cost and size savings.

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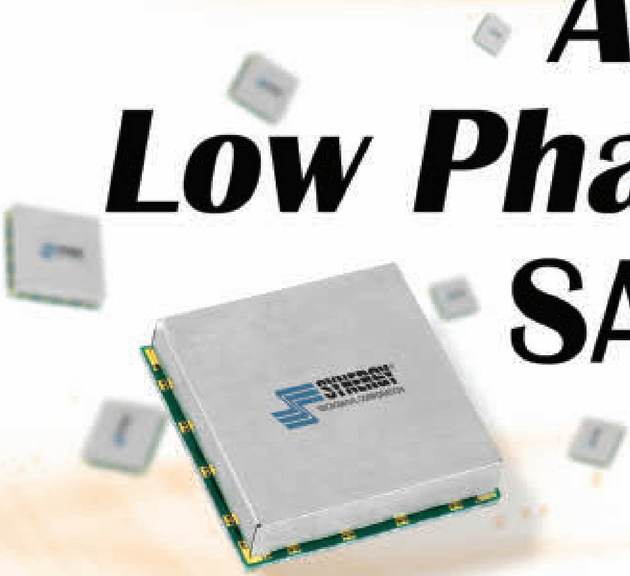

Model	Frequency (MHz)	Tuning Voltage (VDC)	DC Bias VDC @ I [Max.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
HFSO640-5	640	0.5 - 12	+5 @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 @ 30 mA	-146
HFSO914R8-5	914.8	0.5 - 12	+5 @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 @ 35 mA	-141
HFSO1600-5 *	1600	0.5 - 12	+5 @ 100 mA	-137
HFSO2000-5 *	2000	0.5 - 12	+5 @ 100 mA	-137

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Around the **Circuit**

CONTRACTS

Harris Corp. has received a $47 million order for wideband radio systems from a nation in the Middle East as part of its continuing tactical communications modernization program. The Harris systems will be used to support a command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) network used by military and security forces. The system integrates software-defined radios from the Harris Falcon III® RF-7800 family of tactical radios, which includes the RF-7800H Wideband High-Frequency Radio, RF-7800V Combat Net Radio, RF-7800M Multiband Networking Radio and RF-7800I Vehicular Intercom Systems.

Mercury Systems Inc. announced that its **Mercury Defense Systems** subsidiary has received $2 million in follow-on orders to deliver advanced Digital RF Memory (DRFM) jammers to the **U.S. Navy**. The orders were received in the company's fiscal 2015 third quarter and are part of a firm-fixed-price, indefinite delivery/indefinite quantity (IDIQ) time and material contract award issued in 2010. They are expected to be shipped by the end of the company's fiscal 2016 third quarter.

PEOPLE

M/A-COM Technology Solutions Holdings Inc. announced the appointment of **Stephen G. Daly** as an independent director. Daly brings 25 years of experience and leadership in the RF and microwave industry to MACOM's board of directors. Previously, Daly served as chairman of the board and also as president and chief executive officer of Hittite Microwave Corp. Additionally he held various microwave engineering positions at Raytheon's Missile Systems Division and sales management positions at Alpha Industries. Daly received a B.S. in electrical engineering from Northeastern University.

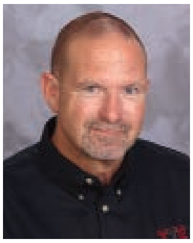
▲ Mark Millhollin

RFMW Ltd. announced that **Mark Millhollin** has joined RFMW as a supplier business manager. Millhollin will be responsible for developing and implementing strategic business plans for various suppliers on the RFMW line card. Prior to joining RFMW, Millhollin's background included corporate supplier manager at Arrow/Richardson RFPD, director of supplier management at Avnet, Americas and sales manager at M/A-COM Eurotech. With his background and relationships, Millhollin will help strengthen RFMW's position within key suppliers and enhance the sales teams' ability to effectively promote and support their products through improved upstream and downstream communications.

Around the **Circuit**

▲ *Mark Reagan*

Delta Electronics Mfg. Corp. welcomes **Mark Reagan** to Delta as the company's director of quality assurance. Reagan has returned to Delta, where he spent over 20 years in both engineering and quality management positions. He returns after enjoying a stint at Safran Aerospace Composites Inc., where he was responsible for AS9100 QMS Audits, Six Sigma Projects as well as calibration and CAPA (Corrective – Preventive Action) system implementation.



▲ *David Zavac*

TTE Filters, a U.S.-based manufacturer of high reliability RF and microwave filters for communication and signal processing applications and an affiliate of **Gowanda Holdings**, announced the hiring of **David Zavac** as sales manager. Zavac worked for TTE for almost 18 years before leaving the company to pursue other opportunities in 2012. TTE Filters has rehired him to oversee the company's sales, customer relations and sales channels.

▲ *Lindy Kretchmer*

Intercept Technology Inc. announced the promotion of **Lindy Kretchmer** as marketing manager. Kretchmer will work closely with Dale Hanzelka, director of sales and marketing, to continue Intercept's marketing and communications efforts going forward. She will be responsible for driving the company's marketing strategy, developing technical communications and designing company messaging. Kretchmer comes to the position with almost 20 years of experience in the EDA industry and has also contracted in the past with such companies as Dish Network, State Farm Insurance, Ciber, Qmatic and others in various marketing and communications positions.

▲ *Antony Harris*

Monroe Electronics and its Digital Alert Systems subsidiary announced that **Antony (Tony) Harris** has been chosen as director of software development. In this newly created position, Harris will work closely with the management team in developing and managing code base for current and future products. Harris comes to Monroe Electronics with a deep understanding of scalable, distributed computing architectures; demonstrated skill in all aspects of software product development; and a record of building successful products, services and teams.

Around the **Circuit**

IN MEMORIAM

▲ *Vincent J. McHenry*

Vincent J. McHenry died peacefully at his home on Thursday, April 2, 2015 at the age of 86. He attended the University of Detroit and subsequently entered the U.S. Army Signal Corp. where he became an instructor during the Korean War. Following military service he joined the **Bendix** corporation. Filled with an entrepreneurial spirit he then co-founded **Omni Spectra**. After briefly retiring in his 40's to spend time with his family he co-founded his most successful venture, **Southwest Microwave** in 1981. In 1997 McHenry won the Pioneer Award for inventing (along with 2 others) the Subminiature Type A (SMA RF) Coax Connector. This technology remained in use for 20+ years and marks a significant achievement in both his career and the field he dedicated his life to.

REP APPOINTMENTS

Custom MMIC, a developer of performance driven monolithic microwave integrated circuits (MMICs), announced the appointment of **Saguaro Technical Sales** as their new representative in Arizona and New Mexico. Saguaro Technical Sales, based in Scottsdale, Ariz., maintains a highly skilled workforce with degreed engineering talent that can target solutions to a broad spectrum of customers. Saguaro will play a pivotal role in Custom MMIC's continued growth over the next several years as they continue to develop their standard product catalog and design services.

Versatile Power Inc., a technology leader in the design and manufacture of commercial power supplies and custom electronic subsystems, announced the addition of **Instrument Engineers**, San Diego, Calif., to its growing list of authorized distributors of Versatile Power's new family of BENCH programmable power supplies.

PLACES

Spectrum announced that it is boosting its sales and support services in the U.S. with the opening of **Spectrum Instrumentation Corp.** Spectrum, headquartered in Grosshansdorf, Germany, is a pioneer in design and manufacturing of PC based test and measurement instrumentation that is used for electronic signal capture, generation and analysis. The new U.S. office provides local sales and technical support and is equipped with demonstration equipment so that customers can test the instruments with their signals. The office is located at 6 Barbara Drive, Warwick, NY 10990.

Towerstream Corp., a fixed wireless fiber alternative provider, announced the opening of a second sales center location in Southern Florida, one of the fastest growing areas of the country. The company has initially hired two sales managers and nine account executives, and plans to increase the number of account executives to approximately twenty by the end of the year.

INVITED PAPER

Low Noise GaN Amplifiers with Inherent Overdrive Protection

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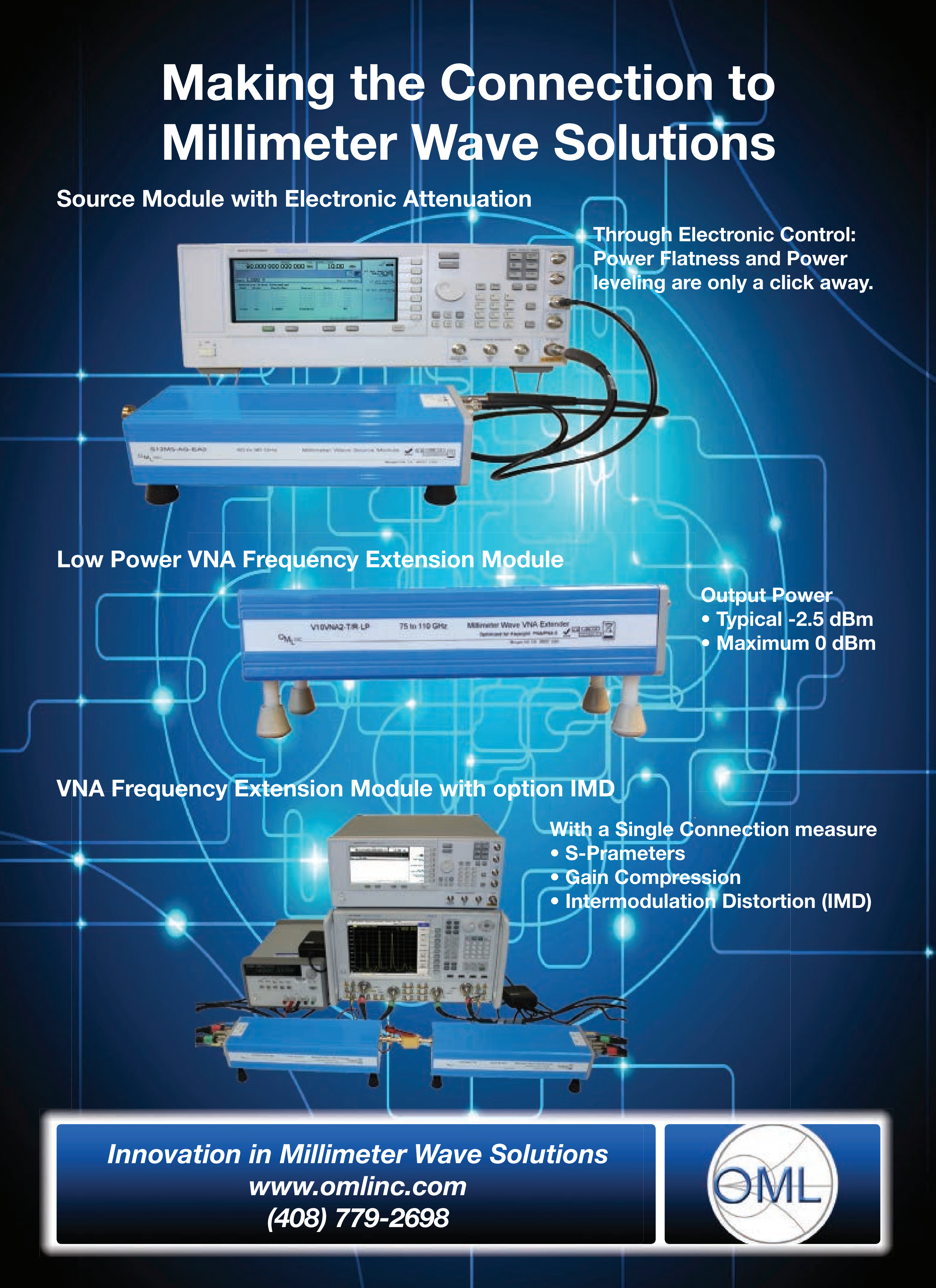
Custom MMIC, Westford, Mass.

When it comes to microwave receivers, the one component that can cause the most headaches is the input low noise amplifier (LNA). Not only must the LNA perform optimally in low-level signal environments, it must also be protected against unwanted high power signals that are well above the amplifier's normal operating range. Consider the case of X-Band satellite receiver systems. While the desired signal levels can be as low as -90 dBm, those unwanted high power hitchhikers, which can include jamming signals or radiation from a nearby antenna, can be as high as 1 to 5 W. To solve this problem, many current microwave receiver systems use a two-pronged approach. First, the LNA is often fabricated in gallium arsenide (GaAs) to take advantage of the semiconductor's inherently good noise properties. Second, a limiter is then placed at the input to the LNA, to protect against the semiconductor's inherently bad power handling properties. The limiter is often a stand-alone component not fabricated as part of the LNA.[1]

In general, this two-pronged approach works well, but at a cost. All limiters have insertion loss, typically 0.5 to 0.7 dB, sometimes as high as 1 dB. This loss directly degrades the system noise figure, since the limiter is in series within the signal path. Over the last 10 years, the use of high electron mobility (HEMT) GaAs transistors has led to a reduction in the noise figure of the LNA, negating some ill effects of the limiter. For example, LNAs operating at X-Band with a noise figure of 0.8 to 1.1 dB have recently been reported.[2] These amplifiers were fabricated using a metamorphic HEMT (MHEMT) semiconductor process, which includes the growth of indium phosphide on top of the GaAs wafer. In terms of robustness in the presence of high power, however, these LNAs require even more protection. The MHEMT devices are much more susceptible to high input power levels than standard GaAs, since MHEMT achieves a lower noise figure in part by reducing the breakdown voltage of the device. Thus, the input limiter takes on an even more critical role within a receiver utilizing MHEMT technology.

The need for a limiter led Custom MMIC to consider an alternate solution to the problem of receiver sensitivity in high power environments. Through a Phase I and Phase II Small Business Innovative Research (SBIR) grant with the United States Air Force, Custom MMIC investigated the use of gallium nitride (GaN) technology for the development of the LNA. When GaN is raised as a topic in conversation, most engineers immediately think of power amplification, since the technology's


Making the Connection to Millimeter Wave Solutions
Source Module with Electronic Attenuation
Through Electronic Control: Power Flatness and Power leveling are only a click away.
Low Power VNA Frequency Extension Module
Output Power
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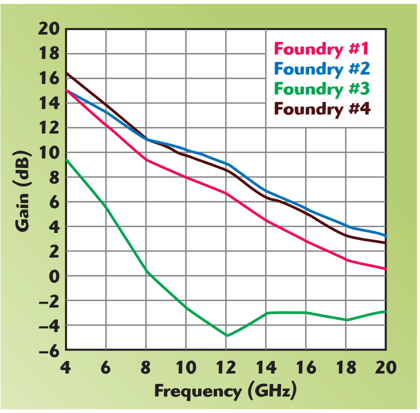
impressive breakdown voltage can be used to generate high power with high efficiency across the microwave spectrum. Such applications are not the only use for GaN. As circuit designers are discovering, GaN, with its high breakdown voltage, offers numerous advantages in other circuit functions, including LNAs.[3-5]

Custom MMIC embarked on an investigation of GaN as a replacement for GaAs LNAs in X and Ku-Band by exploring two key questions: Is the noise figure of a GaN device similar to a GaAs HEMT device? Can a GaN LNA survive incident power levels up to 5 W, thereby negating the need for an external limiter? The answer to both questions is a resounding "yes!"

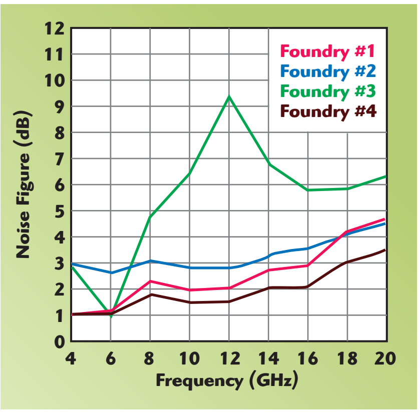
GaN SELECTION AND MODELING

The first step in answering these questions was to identify a commercial GaN foundry with a low noise device that could support the required X to Ku-Band frequency range. Custom MMIC procured devices of roughly the same total periphery from four commercial foundries and measured their inherent gain and noise properties (see ***Figures 1*** and ***2***). For these measurements, all of the devices were measured in a 50 ohm environment, biased with a drain voltage of 10 V and tuned to a current density of 250 mA per mm. Based on these results, Foundry #4 was the best overall choice, since it offered the lowest noise figure while still maintaining adequate gain. This foundry offers a GaN process with a 0.2 µm gate length, two levels of metal interconnects, metal-insulator-metal capacitors, airbridges, backside vias and a substrate thickness of 4 mils.

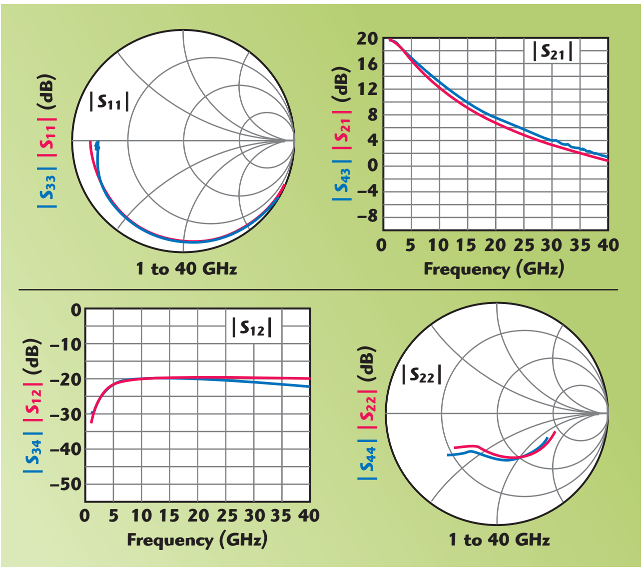
After choosing the foundry, the next step was to develop a scalable, small-signal GaN device model. Custom MMIC accomplished this by first measuring the Y-parameters for different device sizes under a range of bias conditions, then fitting these results to a standard FET circuit model. ***Figure 3*** shows a comparison of the measured



▲ *Fig. 1 GaN devices from four foundries, comparing small-signal gain vs. frequency.*



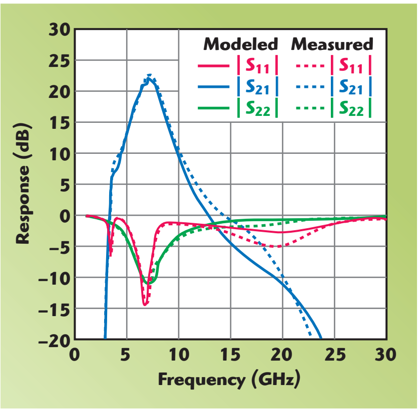
▲ *Fig. 2 GaN devices from four foundries, comparing noise figure vs. frequency.*



▲ *Fig. 3 Comparison of measured (blue) and extracted model (red) S-parameters for a 4 × 100 µm GaN FET from Foundry #4.*

data for a 4 × 100 μm device against the extracted circuit model, where V_{dd} = 10 V and V_{gg} = -2.8 V. Note that the model predicts the gain of the device to within 0.75 dB up through 40 GHz. It achieved a similar level of modeling accuracy across a wide range of device sizes and bias conditions.

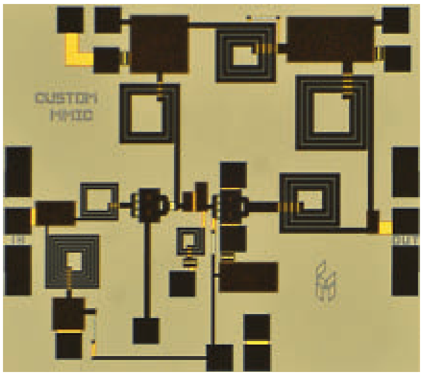
Of course, the device model by itself is not the complete story, the authors are most concerned with accurately simulating the entire LNA. ***Figure 4*** shows a comparison of the measured data with the circuit model for an early iteration X-Band LNA design. This amplifier was designed to operate near 7 GHz with a relatively narrow bandwidth, which makes this circuit ideal for comparing the model and the measured data. The model predicts the S-parameters with very good accuracy, including the resonant nulls in the port return losses. Its device models have been used to design narrowband and wideband amplifiers to 20 GHz, all with the same success as shown in Figure 4.



▲ *Fig. 4 Comparison of the magnitude of the S-parameters vs. frequency, showing the measured (dashed lines) and the circuit model (solid lines) of an earlier, narrow-band version of the X-Band LNA.*

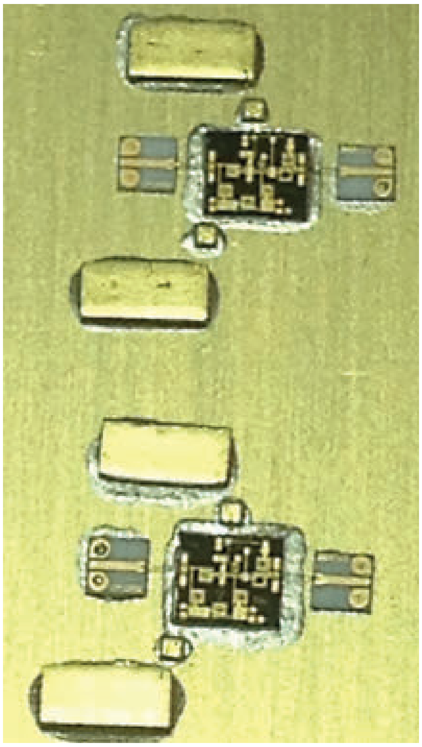
GaN LNA DESIGN

Once Custom MMIC had developed GaN models and examined preliminary designs, they focused on developing an ultra low noise GaN amplifier covering 5 to 9 GHz. They settled on a two-stage topology with highpass matching networks for the input and interstage. Highpass networks tamp down the low frequency gain, ensure unconditional stability and provide a good noise match. ***Figure 5*** is a photograph of the die as manufactured. The input is on the left, the output on the right; drain voltage is applied at the top, gate voltage at the bottom. All grounds are accessed through backside vias. The bright gold traces show the bottom metal layer, the dark traces represent the upper (airbridged) metal layer. This design does not include a front-end limiter.



▲ *Fig. 5 X-Band GaN LNA die fabricated by Foundry #4.*

For testing, Custom MMIC mounted the die to a metal carrier and attached bypass capacitors to the bias ports with bond wires. ***Figure 6*** shows a photograph of the plate assembly. The LNA was biased with a fixed drain voltage (V_{dd}) of 10 V and a variable gate voltage (V_{gg}) between



▲ *Fig. 6 Die plate assembly for testing the GaN LNA with bond wire interconnects.*

-2.4 and -2.8 V, corresponding to a quiescent current between 60 and 150 mA. The bias was connected to the LNA through needle probes to the top plate of the bypass capacitors. The input and output ports were bonded to 50 ohm alumina microstrip lines that were accessed with standard ground-signal-ground wafer probes. All measurements included the presence of bond wires. High performance microwave cables connected the wafer probes to the test equipment. Calibration was performed to the ends of the wafer probes for both vector (S-parameter) and scalar (noise figure) measurements.

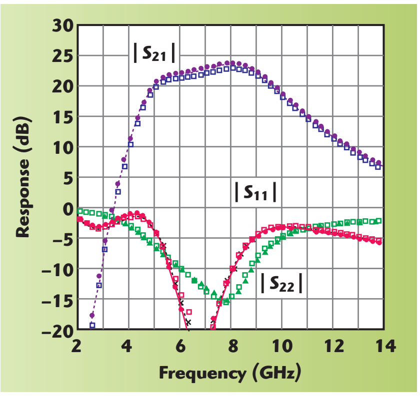
Figure 7 shows the magnitude of the measured S-parameters. The drain voltage was 10 V, and the gate bias varied from -2.4 to -2.8 V. The gain of the LNA was between 20 and 24 dB, with return losses better than -10 dB across 6 to 8 GHz. These parameters are fairly insensitive to the gate bias. ***Figure 8*** shows the noise figure of the LNA under the same bias conditions used for measuring the S-parameters. The noise figure is 1.0 to 1.3 dB across 5 to 9 GHz, with an optimal gate bias, approximately V_{gg} = -2.6 V. The output power at 1 dB compression and third order intercept are plotted in ***Figure 9***. The LNA had a fixed gate bias of V_{gg} = -2.6 V and a drain bias of V_{dd} = 10 V. The LNA delivers a fair amount of power and reaches a peak power-added-efficiency (PAE) of approximately 30 percent under drive. Such efficiency is noticeably better than most typical GaAs LNA designs, which tend to have a PAE on the order of 10 percent.

The noise performance of this GaN LNA is commensurate with a GaAs HEMT design.[6] However, the GaN amplifier delivers much more power with greater efficiency, generating a much wider dynamic range than its GaAs counterpart.

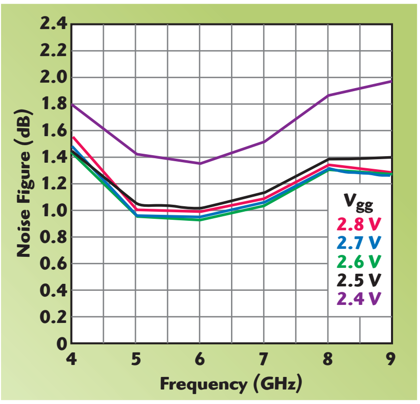
DAMAGE TESTING

The second goal of this effort was to investigate the ability of a GaN LNA to withstand high incident power. Numerous other researchers have considered this problem[3,7] and demonstrated GaN LNA survivability levels at X-Band ranging from +32 to +42 dBm. However, nearly all of the LNAs capable of surviving above +38 dBm have bandwidths much less than the near octave bandwidth of Custom MMIC's design. Therefore, the authors believe their work advances the overall knowledge of GaN LNA robustness.

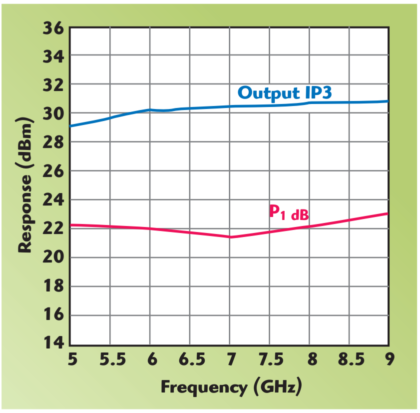
To investigate power handling,



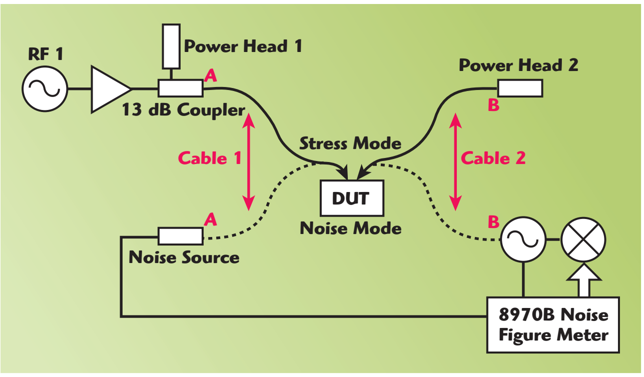
▲ *Fig. 7 Magnitude of the S-parameters of the GaN LNA vs. frequency, biased at gate voltages between –2.8 and –2.4 V with V_{dd} = 10 V.*



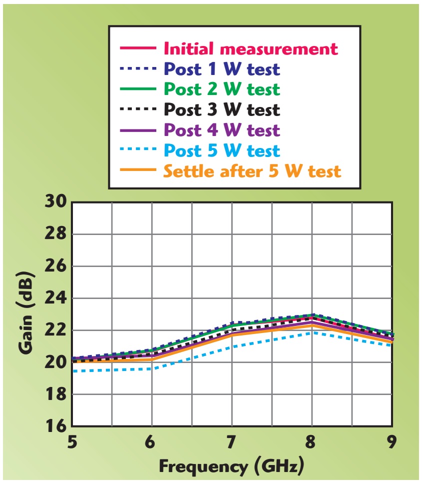
▲ *Fig. 8 Noise figure of the GaN LNA vs. frequency, biased at gate voltages between –2.8 and –2.4 V with V_{dd} = 10 V. The optimal gate bias is –2.6 V.*



▲ *Fig. 9 Output power at 1 dB compression and output IP3 vs. frequency for the GaN LNA biased at V_{dd} = 10 V and V_{gg} = –2.6 V.*



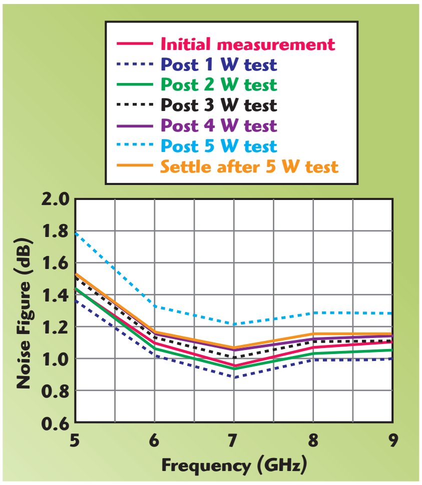
▲ *Fig. 10 Setup for high power stress testing the GaN LNA.*



▲ *Fig. 11 Gain of the GaN LNA before and after stress testing, biased at V_{dd} = 10 V and V_{gg} = –2.6 V.*

they developed a scalar test station (see ***Figure 10***) that stresses the input port of the LNA up to incident power levels of 5 W and then measures the gain and noise figure of the amplifier. In the stress mode, the device-under-test (DUT) was subjected to a high power signal for ten seconds. The power was calibrated using scalar power detectors (power heads 1 and 2 in Figure 10). The test sequence began at 1 W incident power and increased to 5 W, the maximum input power available from the equipment. After each 10 second stressing, the LNA was connected to the measurement path ("noise mode" in Figure 10) and compared to the baseline gain, noise figure and DC current.

Figures 11 and ***12*** show the measured gain and noise figure, respectively, after a number of stress tests. Both parameters remained relatively unchanged until the LNA was subjected to 5 W of incident power, when the gain dropped approximately 0.4 to 1 dB, and the noise figure rose by 0.2 dB. Following this final stress test, the LNA remained biased with no RF drive for five minutes; then the parameters were retested. Both gain and noise figure recovered to within their normal limits after this settling period. Therefore, the authors believe they have demonstrated an LNA that survives incident power levels up to 5 W without suffering long-term damage.



▲ *Fig. 12 Noise figure of the GaN LNA before and after stress testing, biased at V_{dd} = 10 V and V_{gg} = –2.6 V.*

This same power handling investigation was performed on several other X-Band LNA designs with similar noise figure but reduced output power. The lower power was achieved by using smaller GaN devices in the same amplifier topology (two-stage with highpass matching networks), not by varying the bias point of the baseline design. The smaller the device, the less input power the LNA could withstand before damage. For example, an LNA with 50 percent less periphery than the original design could only withstand incident levels up to 2 W; an LNA with 75 percent less periphery could only withstand levels of 1 W.

There does appear to be a direct correlation between GaN device size and inherent overdrive protection.

CONCLUSION

The authors have demonstrated an X-Band LNA fabricated on a commercial GaN process with an ultra-low noise figure of 1.0 to 1.3 dB. This LNA was a two-stage design that utilized highpass matching structures in the input and interstage networks. Without an input limiter, the LNA was able to withstand incident power levels of 5 W for 10 seconds without suffering long-term damage. Survivability in such an environment appears directly related to the device size within the LNA, at least for a fixed topology. ■

ACKNOWLEDGMENTS

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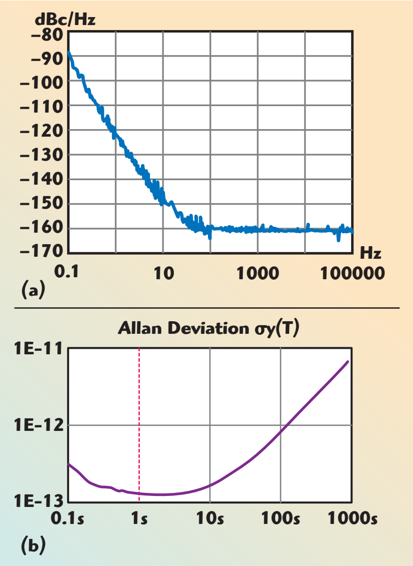
INVITED PAPER

Design Optimization in the Development of Precision Ovenized Quartz Oscillators

Y. Vorokhovsky, A. Nikonov, A. Kotyukov and A. Kamochkin
Morion Inc., Russia

A new precision 10 MHz oven controlled crystal oscillator (OCXO) exhibits low phase noise close to the carrier (-120 dBc/Hz at 1 Hz) and a low noise floor (-160 dBc/Hz at 1 kHz) with very good frequency versus temperature stability.

OCXOs are essential components in modern telecommunication and measurement systems, while requirements for frequency stability versus temperature, thermal hysteresis of frequency, long-term stability, Allan Deviation (ADEV), phase noise and size are becoming more challenging. Meeting these requirements calls for quartz crystal technology improvements and oscillator circuit design optimization.



▲ *Fig. 1 Phase noise (a) and Allan Deviation (b) for a 10 MHz OCXO.*

RESONATOR

The evolution of crystal blank processing and the use of cold welding technology for encapsulation have yielded compact quartz resonators of the highest quality while providing the potential for significant size reduction. To achieve the lowest ADEV, special quartz cleaning methods and a number of additional surface finishing processes are used. This along with circuit optimization to reduce intrinsic noise in the electronics results in the phase noise and ADEV performance shown in ***Figure 1***.

THERMAL DESIGN

For reduced size, a single-oven heating system is used. Although difficult to achieve, design experience and the capabilities of modern analysis and optimization software enable the realization of small single-stage oven-controlled oscillators with high frequency stability versus temperature by ensuring low temperature gradients in a zone occupied by the crystal and other thermosensitive parts.[1]

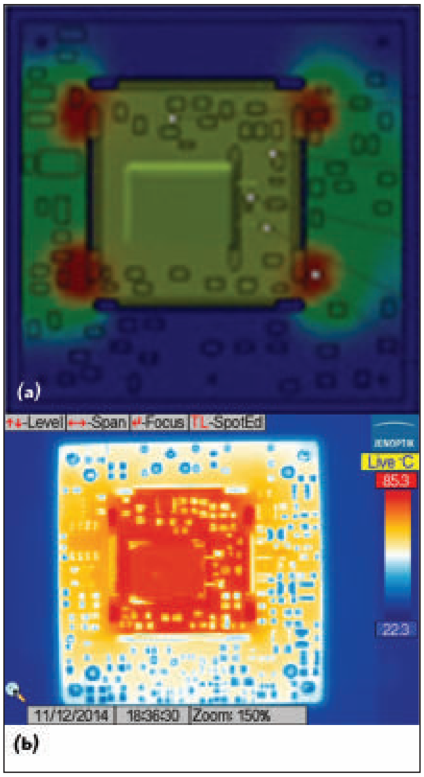
The finite element method is used for thermal modeling. The thermal modeling software takes into account such factors as the individually adjustable thermal conductivity of materials, the area of thermal contact between the material and the heating element, air convection and its influence on the heat transfer, and provides a dynamic thermal map of the design (i.e., during the warming or cooling of the structure). Registration of these factors allows the building of a high fidelity thermal model. ***Figure 2*** illustrates the thermal model of the oscillator and its infrared image. Design optimization achieves such good thermal performance that the influence of temperature on

TABLE 1 B-MODE FREQUENCY CHANGE VS. TEMPERATURE						
	Frequency (MHz)	Temperature Range (°C)	ΔF Oven Off (ppb)	Slope (ppb/°C)	ΔF Operating Oven (ppb)	Accuracy of Temperature Stabilization (°C)
Sample 1	10	-30° to 70°C	2521096	25210.96	3138	0.12
Sample 2	10	-30° to 70°C	2661517	26615.17	4129	0.16

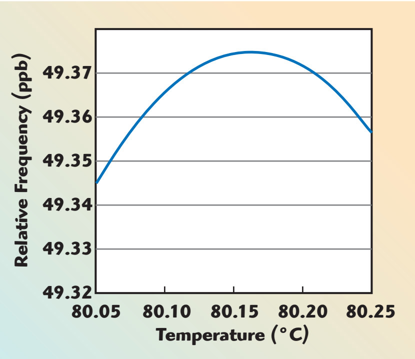
the resonator becomes a negligible contributor to oscillator temperature stability.

The presence of parasitic (B-mode) oscillation for an SC-cut resonator, located above the main frequency by about 10 percent, provides a means to determine the quality of temperature stabilization while in the oven. The B-mode oscillation has an almost linear frequency versus temperature dependence, so the measurement of B-mode frequency versus temperature enables an estimate of temperature stability. Measurement results are shown in ***Table 1***.

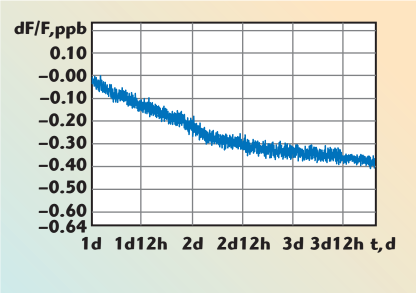
Figure 3 shows the frequency versus temperature characteristic of an



▲ *Fig. 2 Thermal model (a) and infrared image (b).*



▲ *Fig. 3 Frequency behavior of SC-cut resonator close to the lower turnover point.*



▲ *Fig. 4 Continuous frequency measurement of a 10 MHz OCXO.*

SC-cut resonator near the lower turnover point. The data of Table 1 shows that the contribution of the frequency versus temperature dependence of the resonator to the frequency versus temperature dependence of the oscillator is insignificant.

FREQUENCY JUMPS

For some applications, such as timing tasks, the absence of frequency jumps is critical. The nature of this phenomenon is not fully understood; however, on the basis of practical experience we know that two factors are especially important: the cleanliness of the environment in which the resonator is hermetically sealed, and the bonding technology used. Along with additional manufacturing controls, frequency jumps are reduced to a minimum. An example of a continuous frequency measurement during the manufacturing control for frequency jumps is shown in ***Figure 4***.

CONCLUSION

Computer thermal modeling, circuit design optimization and the use of high quality resonators provides a significant improvement in the performance of single-oven oscillators. For a 10 MHz OCXO, frequency stability versus temperature is improved nearly 10 fold (to 4e-10 peak-to-peak from -40° to 85°C), and phase noise close to the carrier is decreased by 10 dB (to -120 dBc/Hz at 1 Hz) along with a low phase noise floor (-160 dBc/Hz at 1 kHz) and a good ADEV (up to 1.5e-13). Final dimensions of the optimized OCXO are 51×51×16 mm. ■

ACKNOWLEDGMENT

The author wishes to acknowledge that this paper was originally presented at the 46th Annual Precise Time and Time Interval Systems and Applications Meeting in Boston, Mass., December 2014. Y. Vorokhovsky, A. Nikonov, A. Kotyukov and A. Kamochkin, "Efficiency of Circuitry and Design Optimization in Development of Precision Ovenised Quartz Oscillators," Proceedings of the 46th Annual Precise Time and Time Interval Systems and Applications Meeting (PTTI), Boston, Mass., December 2014.

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MWJ REVIEW BOARD APPROVED

Characterizing FR-4 Dielectric Constant Using Antenna Resonant Frequency

Pankaj R. Katiyar, M. M. Shafiei and Wan Nor Liza Binti Wan Mahadi
University of Malaya (UM), Kuala Lumpur, Malaysia

The use of antenna resonance for characterizing the dielectric constant of an FR-4 substrate is demonstrated. The maximum error in predicting the resonant frequency of a patch antenna by this method is found to be three percent while minimum error is 0.3 percent. This is within the range of typical impedance control (10 percent) provided by PCB manufacturers. A step-by-step guideline and formula are provided. This approach is inexpensive and involves the straightforward measurement of return loss.

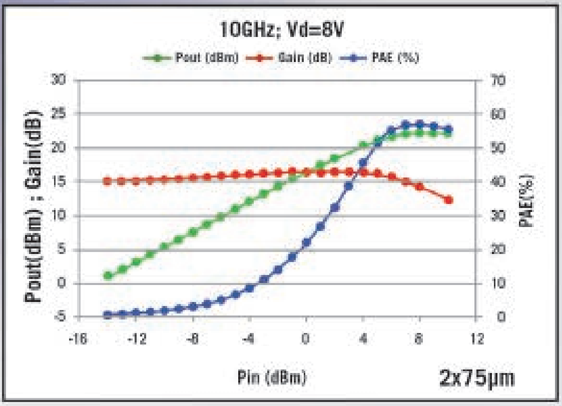
For the design of planar RF and microwave circuits there are many dielectric substrates that can be chosen depending on applications and cost factors. In a commercial environment, cost is a major determinant; hence FR-4 glass epoxy laminate is often used. It is one of the most inexpensive substrate materials and is familiar to many PCB designers. A major issue, however, is the lack of accurate dielectric constant information for FR-4 at RF and microwave frequencies. Datasheets provided by various manufactures provide ε_r at just 1 or 10 MHz, making it necessary for circuit designers to further characterize the material before using it in their designs.

PCB manufactures can control the impedance of specified traces to keep them within desired tolerances; however, impedance control is done using TDR measurements at 1 or 10 MHz. The instrumentation is not capable of performing TDR measurements at higher frequencies such as 2.5 or 5 GHz used for Wi-Fi applications.[1] There are other dielectric characterization methods such as free space transmission/reflection measurement systems,[2] test circuits based on parallel-coupled microstrip resonators,[3] the utilization of transmission information with optimization algorithms,[4] the use of loaded microstrip antennas,[5] ring-resonator techniques,[6] capacitance and S-parameter techniques,[7] and the use of impedance analyzers.[8] Although any of these methods can be used to characterize the permittivity of dielectric substrates at a desired frequency, they all require specialized measurement equipment and, in some cases, a sample of PCB substrate material. The ring-resonator technique described by Rashidian et al.,[6] and the

PP25/-21 0.25μm Power pHEMT

- 0.25μm PHEMT process on 100μm substrates
- Power performance at 8V and 10GHz: >1W/mm, PAE 56%, 14dB Gain

PP25-21 (Class-AB) Tuned for Pout



Gain (dB)	P1dB (dBm)	P1dB (mW/mm)	Psat (dBm)	Psat (mW/mm)	PAE Max(%)
15.0	22.1	1086	22.2	1114	56.8

2x75μm device @8V, 10GHz, 150 mA/mm

Summary of WIN mmWave pHEMT portfolio

	PP25-21	PP15-50/51	PL15-12	PP10-10/11
Gate length	0.25 μm	0.15 μm	0.15 μm	0.1 μm
Max Drain Bias	8 V	6 V	4 V	4 V
Idmax (Vg=0.5V)	490 mA/mm	620 mA/mm	525 mA/mm	760 mA/mm
Peak Gm	410 mS/mm	460 mS/mm	580 mS/mm	725 mS/mm
Vto	-1.15 V	-1.3 V	-0.7 V	-0.95 V
BVGD	20V(18V min)	16V(14V min)	9V(8V min)	10V(8V min)
f_T	65 GHz	90 GHz	100 GHz	130 GHz
f_{max}	190 GHz	185 GHz	150 GHz	180 GHz
Power Density (2x75μm)	1100 mW/mm @ 8V, 10GHz	870 mW/mm @ 6V, 29GHz	580 mW/mm @ 4V, 29GHz	860 mW/mm @ 4V, 29GHz (2x50μm)

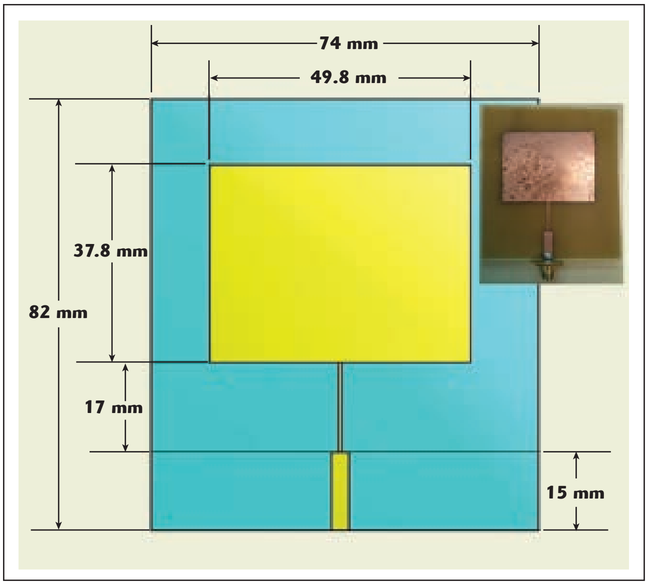


Fig. 1 Simulated dimensions and photograph of the fabricated first-pass antenna.

time-domain method of Fidanboylu et al.,[9] use trial and error to arrive at approximate values, making them more complex to use.

This article describes a simplified method using a step-by-step procedure and formula to derive the dielectric constant from the measured resonant frequency of a patch antenna. The method and formula are experimentally verified. This requires fabrication of a microstrip antenna at the desired operating frequency. We use 3G and Wi-Fi as examples and hence two patch antennas are designed. This is a one-time characterization process and does not require further validation unless a new PCB substrate is used or greater accuracy is desired.

WORKFLOW

The first step is to design a simple microstrip patch antenna on FR-4 substrate using values of dielectric constant and loss tangent provided in the material datasheet (i.e., at 10 MHz). Resonant frequencies of measured and simulated antennas are then compared. Because the fabrication parameters (i.e., dimensions) are the same as the simulated design parameters, the shift in resonant frequency is assumed to be due to differences between the measured and simulated dielectric constants. From this information, a new dielectric constant is determined and used in a second pass of simulation and design. The second pass serves as a validation and an input for determining the dielectric constant at a new frequency.

FR-4 is characterized at 3G and Wi-Fi frequencies, 1.9 and 2.5 GHz, respectively. Two passes of simulation and fabrication are performed. Three data points are then used to extrapolate the value of the dielectric constant over the frequency range.

EXTRACTED PARAMETER CALCULATION

By rearranging the microstrip patch antenna equations,[10] the following is obtained for relative permittivity or dielectric constant.

$$\varepsilon_r = \frac{c^2}{2*(W*f_m)^2} - 1 \tag{1}$$

where W is the width of the patch, f_m is the center frequency and c is the speed of light.

This must be corrected for the fringing effect of the antenna with air above the patch. To remove the fringing effect, Equation 1 is offset by a fringing factor as shown in Equation 2.

$$\varepsilon_r = \frac{c^2}{2*(W*f_m)^2} - \left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} - 1 \tag{2}$$

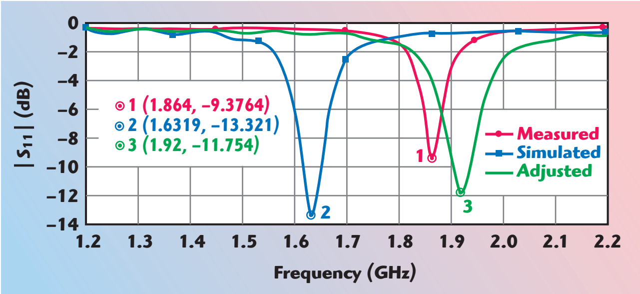
where h is the thickness of the substrate.

ANTENNA SIMULATION AND MEASUREMENT

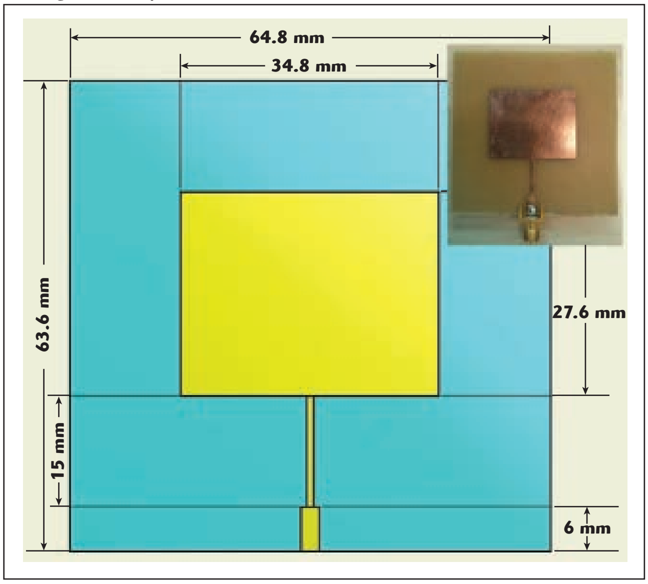
Computer Simulation Technology (CST) software is used for the design and simulation of the patch antenna. The first step is to calculate the antenna length and width using traditional analysis. Simulation is performed to verify the calculated resonant frequency. The microstrip patch antenna is fed by a microstrip line and quarter wavelength matching is used to match the antenna impedance to 50 Ω. Fine tuning is required to perfectly match the antenna impedance and hence some recursive simulation is performed. The simulated model is then

fabricated on FR-4.

Figure 1 shows the simulated dimensions and the fabricated first-pass antenna using a dielectric constant of 4.6 at 10 MHz, per the datasheet. The simulation (see Figure 2) predicts resonance at 1.63 GHz. The difference in resonant frequency between measurement (1.864 GHz) and simulation is clearly apparent. Since all parameters except the dielectric constant are the same, the conclusion is that the resonant frequency difference of 232 MHz is caused by the use of an incorrect dielectric constant in the simulation. Through the application of Equations 1 and 2, the dielectric constant at 1.864 GHz is found to be 3.25.

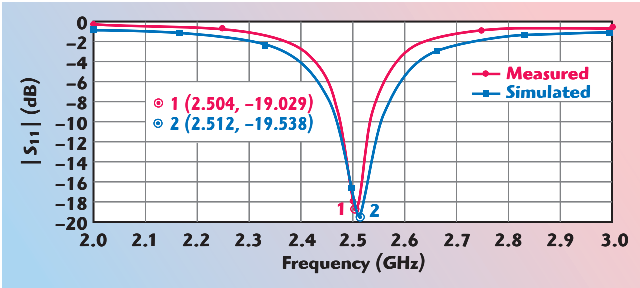


▲ *Fig. 2 First-pass antenna results.*



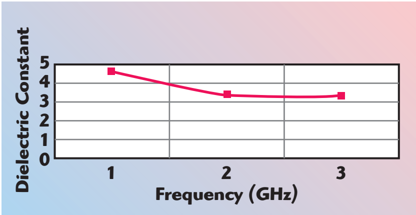
▲ *Fig. 3 Simulated dimensions and photograph of the fabricated second-pass antenna design.*

The adjusted result shown in Figure 2 is determined by repeating the simulation using the same antenna dimensions but with the calculated dielectric constant. The new simulation now predicts resonance at 1.92 GHz (56 MHz higher than measured). This indicates that the dielectric constant of the substrate material is closer to 3.25 than it is to the value 4.6 that is stated within the datasheet.



▲ *Fig. 4 Second-pass antenna results.*

For validation, a second simulation is performed at 2.5 GHz. Using the calculated dielectric constant of 3.25, the patch antenna is redesigned to resonate at 2.5 GHz (see ***Figure 3***). ***Figure 4*** compares measured and simulated results for the second pass. The resonant frequency of the simulated patch antenna is 2.504 GHz, whereas the fabricated antenna resonates at 2.512 GHz – a difference of only 8 MHz.



▲ *Fig. 5 Extrapolation of dielectric constant vs. frequency.*

Using three data points for the dielectric constant, an extrapolation (see ***Figure 5***) provides predicted values derived from measurement over the frequency range of interest.

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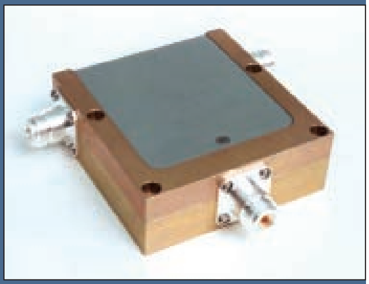
100 MHz to 20 GHz



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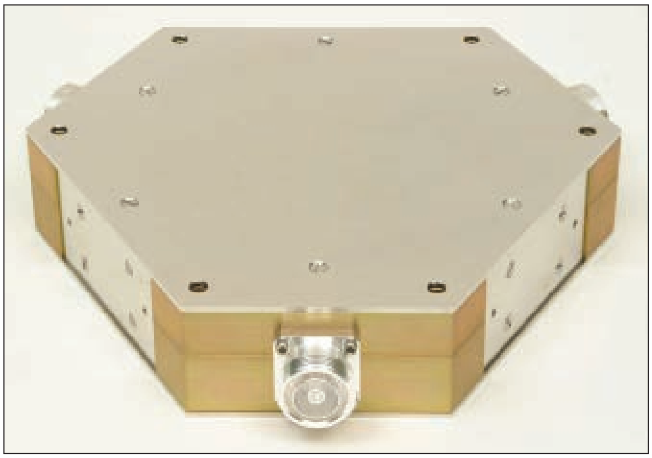

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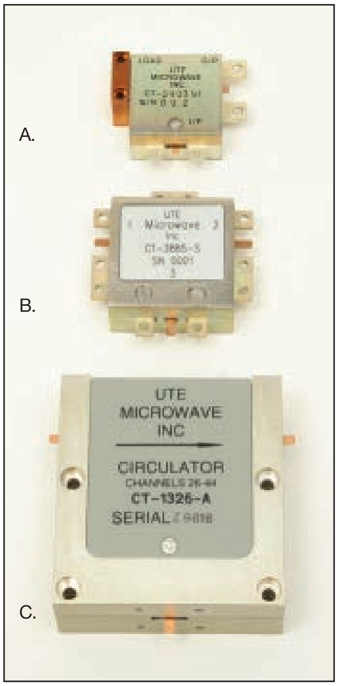

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CT-3877-S	2.5 Kw Pk 250 W Av	"Drop-in"	2.7–3.1 GHz
CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
CT-1645-N	250 W Satcom	N Conn.	240–320 MHz
CT-1739-D	20 Kw Pk 1 Kw Av	DIN 7/16	128 MHz Medical

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CONCLUSION

A resonant frequency method is used to measure the dielectric constant of PCB laminate material. This is useful for characterizing inexpensive FR-4 material, such as 1080 and glass epoxy laminate, at microwave frequencies. The experimental result for a single pass yields a difference of 56 MHz in the resonant frequency between simulation and measurement. This is within three percent of the measured resonant frequency using the calculated dielectric constant of 3.25. For a second pass, the difference is further reduced to within 0.3 percent of the measured resonant frequency. ■

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Phase Noise, Amplitude and TOI Measurement Errors

Bob Stern
Keysight Technologies Inc.
formerly Agilent Technologies electronic measurement business
Santa Rosa, Calif.

Do you rely on accurate measurement of phase noise, amplitude or third order intercept (TOI) as part of your work? Would it surprise you to find out the accuracy of these and other critical measurements may not be what you expected, depending upon how your instruments are calibrated? If you submit your instruments for calibration and just assume good things will happen, your carefully constructed system accuracy budget could be ruined by instruments operating out of specification! Sounds bad – and it is! Unfortunately, what constitutes a proper calibration and the importance to everyday measurement accuracy is seldom taught in electrical engineering classes. This article illustrates how the accuracy of key measurements is directly related to specific calibration deliverables.

State-of-the-art phase noise measurements generally have to be performed with a dedicated phase noise test set. While still the only viable method for truly low noise sources, this technique is time consuming and requires significant technician skill. Fortunately, the local oscillators employed in modern spectrum analyzers frequently have sufficiently low phase noise to allow direct measurement of source phase noise. ***Figure 1*** illustrates the progression of improved phase noise performance in recently introduced spectrum analyzers.

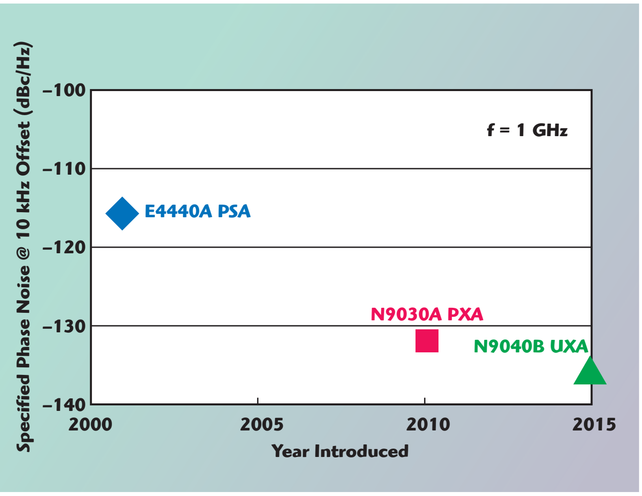
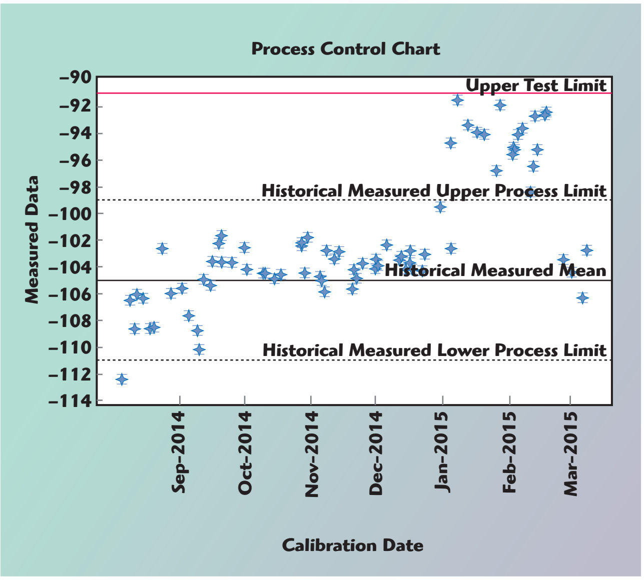


Fig. 1 Trend of signal analyzer phase noise specification.

The phase noise of each of these instruments is tested thoroughly when manufactured. Sometimes you may hear "phase noise performance is an intrinsic design characteristic and doesn't need to be checked during periodic calibration." Certainly, modern instruments do have stable block diagrams. And yes, instruments with synthesized local oscillators connected to 10 MHz external references do not need to be checked for frequency accuracy. However, many other performance characteristics, such as phase noise, may be stable for several years, then degrade without warning and without obvious clues to instrument operation (think instrument heart disease).

Table 1 shows the phase noise specifications for the Keysight E4440A. ***Figure 2*** shows the actual measured phase noise of a series of

TABLE 1 E4440A PSA NOISE SIDEBANDS (dBc/Hz) (20° to 30°C, Center Frequency = 1 GHz)		
Offset	Specification	Typical
100 Hz	-91	-96
1 kHz	-103	-108
10 kHz	-116	-118
30 kHz	-116	-118
100 kHz	-122	-124



▲ *Fig. 2 Process monitoring of phase noise measurements on a signal analyzer calibration station.*

E4440A PSA units measured at the 100 Hz offset point. The test system in this case is one of the signal analyzer calibration stations at Keysight's Roseville service center. Each symbol represents a different customer unit. Of course, the measurement is a combination of the reference source and the receiver performing the measurement. Note the sudden shift of approximately 11 dB beginning in January 2015. Either many units were suddenly not performing within the historical statistical process limits, or something happened with the reference source employed in this system. This service center has several such calibration stations, so experiments were performed with different reference signal sources and multiple measurements of the same test unit on multiple test stations. It was determined that the reference on this station was the source of the 11 dB degradation. As soon as the reference signal generator was replaced, subsequent test units were again measured within the historical process limits.[1] The signal generator in question was in a rack, not moved or otherwise disturbed, prior to this 11 dB shift in performance. The root cause analysis of the failure mechanism had not yet been determined when this article was written.

Suppose the reference signal generator in the example was in one of your test systems. What would be the effect of >11 dB of lost production margin to your yield in a final production test system at your company or a test system used to characterize a new product design for transition from R&D to production? Seemingly stable instrument characteristics need to be periodically checked, just like doctors monitor blood pressure and cholesterol of seemingly healthy patients. Accurate periodic calibration of all the key specifications you count on is essential to ensure your critical measurements are as accurate as your system error analysis assumes.

Every calibration lab has a different level of commitment to maintaining lab standards. Suppose you are relying on the -136 dBc/Hz (@ 10 kHz offset) specification of the new Keysight N9040A UXA signal analyzer. The performance test requires a special reference oscillator. To be sure the current performance of your high end instruments is accurately measured, you should insist on a calibration report that includes both the instruments used and the test results. For any reputable calibration provider, this should

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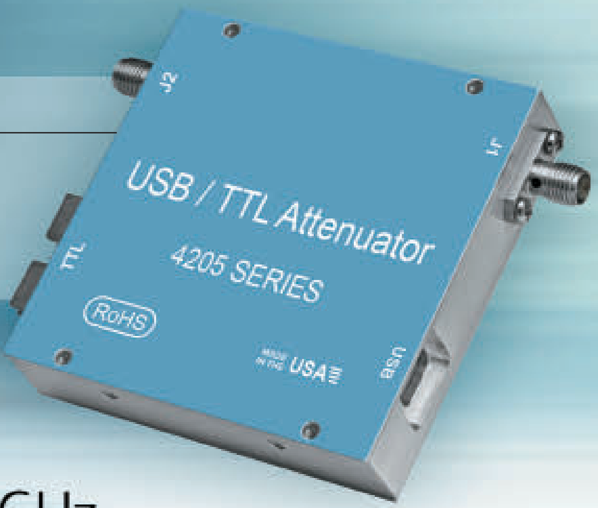

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Figure 3 is an excerpt from the N9040A UXA help file specifying the equipment required for calibration. Hopefully it is obvious that high performance microwave instruments can only be calibrated properly with correspondingly high performance lab standards. For any high performance specifications you count on, you should be checking whether the instruments used to do the calibration are up to the task. You don't have to do this yourself; ask your calibration provider if you have questions.

Phase Noise Performance Test

This test verifies the analyzer Noise Sideband specification. The source can be either a Wenzel Ultra Low Noise source or a E8257D PSG signal generator.

IF the DUT is an N9030A PXA, N9040B UXA, or newer vintage of N9020A MXA (with option EP2), then only the Wenzel Ultra Low Noise source can be used to test Phase Noise. Only the Wenzel source can provide the phase noise performance that is required. If the DUT ia an older vintage N9020A MXA, N9010A EXA, or N9000A CXA, then either source can be used.

Required Test Equipment

Test Equipment	Model Number
Synthesized Signal Source	Recommended model: Wenzel mode l500-13438 Rev D Alternate Model for all X-Series analyzers EXCEPT UXA: Wenzel mode l500-13438 Rev C

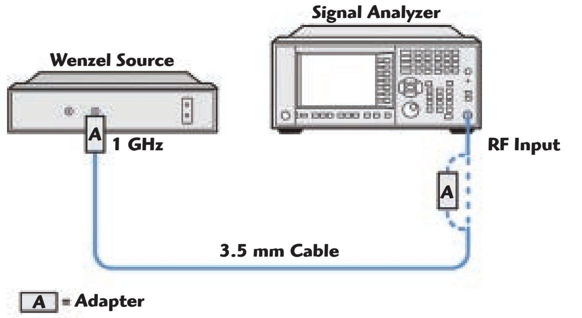


Fig. 3 Excerpt from instructions for calibrating the Keysight X-series signal analyzer.

THIRD ORDER IMD (TOI) MEASUREMENTS

An important specification for amplifiers is TOI performance. The test involves setting up two equal amplitude signals that are fed through a combiner to an amplifier under test (see ***Figure 4***). The level of the signals depends on the amplifier's gain, maximum output level and, of course, TOI performance. Generally, amplifiers are specified for the expected TOI at a given input level. With two input signals, any third order distortion products appear as shown in ***Figure 5***.

If you already make TOI measurements, no doubt you are aware of the importance of isolating the two signal generators to avoid intermodulation via their output level control circuits. However, did you know that signal analyzers can change over time? There are mechanisms that can cause signal analyzer TOI performance to degrade. To illustrate, the video "Out-of-Cal Instruments Cause "Bad" Pass/Fail Decisions"[2], shows a signal analyzer that was apparently functioning perfectly yet had TOI performance more than 5 dB worse than it should have – and was fine after it was repaired. So you may ask yourself, "Can I afford to lose 5 dB or more margin when testing my amplifiers for TOI?" If your answer is "absolutely not," then check the calibration measurement report for your signal analyzer.

Table 2 shows one example of a

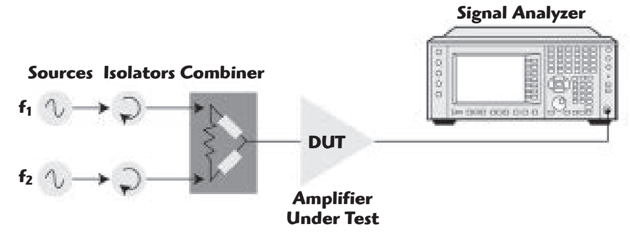


Fig. 4 Test setup for measuring amplifier TOI.

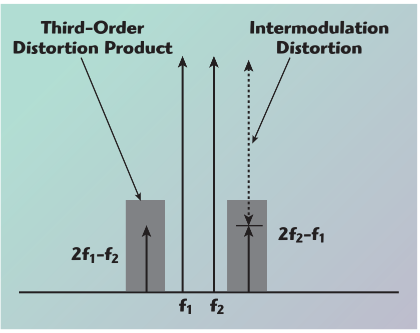


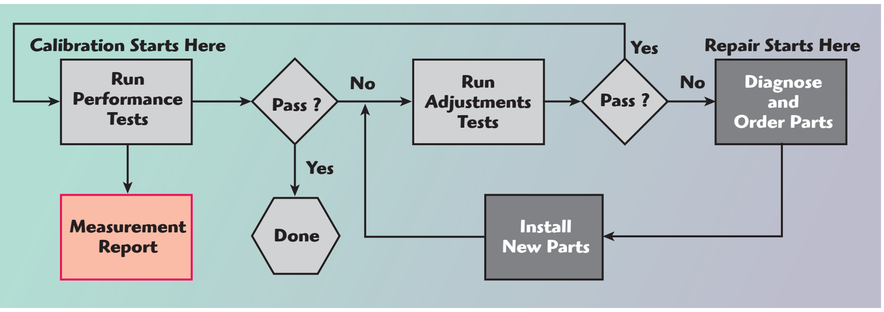
Fig. 5 Spectrum showing third-order intermodulation products.

TABLE 2

THIRD ORDER INTERMODULATION DISTORTION TEST REPORT

Model: N9030A   Serial: US51381234   Test Date: 20-June-2014   Test Result: Pass

Frequency (MHz)	Measured TOI (dBM)	Measured Uncertainty (±dB)	Specification (dBm)	Result
50.01	18.77	0.29	13	Pass
1700.21	23.34	0.47	21	Pass
2800.21	24.28	0.52	21	Pass
5000.21	22.76	0.41	15	Pass
13000.21	23.24	0.40	15	Pass
19500.21	21.90	0.50	10	Pass



▲ *Fig. 6 Work flow for calibration, repair and adjustments.*

TOI report. If your cal provider does not provide a measurement report or if that report doesn't include TOI measurements, then you have no idea of the current TOI performance of your measuring receiver. Just like it takes two people to dance the tango, two microwave signal generators are needed to perform TOI signal analyzer measurements. If the instruments listed in your calibration certificate do not include two microwave signal generators, you know that TOI performance was not measured.

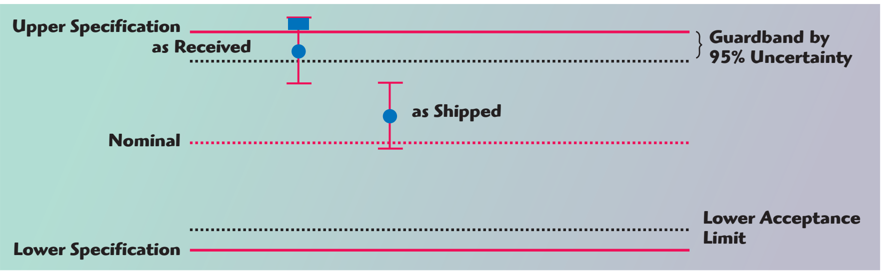
ADJUSTED TO THE MIDDLE?

Many engineers assume that when they submit their instruments for calibration their unit will be adjusted for optimum performance every time. That is not true, not even for the original equipment manufacturer (OEM). What does happen is performance tests establish observed current performance. If the observed measurements are inside the specification limit and considered a "pass," the unit is returned to the customer (see ***Figure 6***). At Keysight, we measure the actual performance for every spec, every time in calibration. If a measurement is out-of-specification, then we perform adjustments. For engineers with long memories, the last adjustable resistor (rheostat) became extinct some 15 to 20 years ago. Since then, instrument manufacturers rely on digital-to-analog converters (DAC). This, with the same accurate external equipment used for measuring performance, allows for automated adjustment routines. These adjustments are often iterative for overall optimum performance. Power level accuracy adjustments in microwave signal generators can be as short as 30 minutes, though most models take two to four hours.

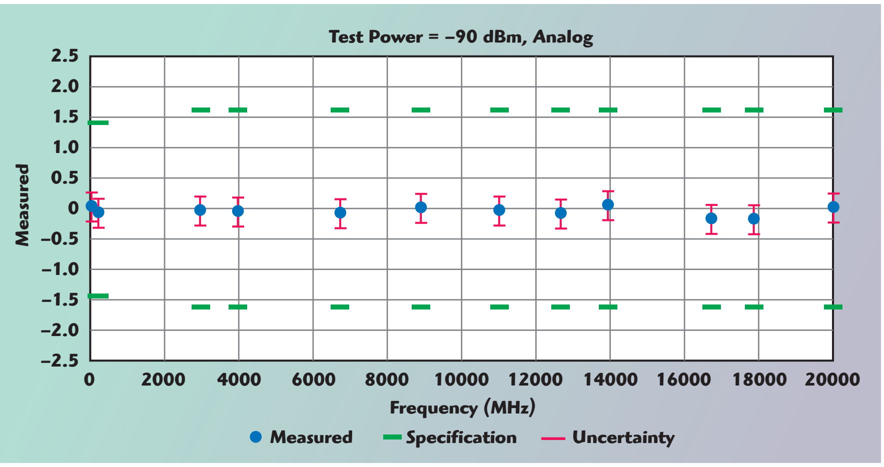
OEMs, including Keysight, do not publish the algorithms of these adjustment procedures. If your unit needs to be adjusted, you need to send it to the OEM. When units are observed out of spec as received, Keysight reports the measured performance so you can determine the impact that instrument may have had on your measurements. Also, if it were necessary to adjust your instrument and re-run the performance tests, you'll receive the "as shipped" measured data so your instrument is fit for use again.

SPECIAL CALIBRATION TO IMPROVE MARGIN

All measurements contain errors. There is no such thing as a perfect measurement. That is why you develop a system error budget for im-



▲ *Fig. 7 Example of the 95 percent confidence range extending outside the instrument specification.*



▲ *Fig. 8 Power level accuracy of a N5183A MXG signal generator.*

portant measurements. Calibration is the same – there are no perfect measurements. In the calibration world, measurement error is referred to as measurement uncertainty (MU). You can think of this as the standard deviation of all the errors combined in an appropriate fashion.[3] For most instruments, if you then draw an interval of ± 2 MU about a measured value, the result is the familiar statistical 95 percent coverage interval.

Figure 7 illustrates a calibration measurement that is in specification. However, a portion of the 95 percent certainty range is outside the specification, meaning there is some risk that the true value is out of specification.[4] On many instruments, Keysight offers a premium calibration service, termed "cal + uncertainties + guardbanding," where adjustments are performed when necessary to ensure the 95 percent certainty region falls within the data sheet specification. Keysight's service adjustments are the same algorithms that are used in production. For specifications that are critical to system error budgets, it is a good idea to request that those instruments receive Keysight's "cal + uncertainties + guardbanding" service. This provides the greatest assurance that the instrument is operating near the nominal specification, with extra yield margin in production test systems.

RECEIVER SENSITIVITY

One of the most important specifications for any RF/microwave receiver is sensitivity. It is generally defined as the minimum signal level at the input which results in a minimum acceptable bit error rate, signal-to-noise ratio or other baseband criteria for minimum acceptable receiver operation. Good receivers have a sensitivity of better than 0.5 µV (-113 dBm). In the region near the specified receiver sensitivity, the acceptable baseband criteria often changes at twice the rate of the incremental change in input level. Thus, it is important to have the power level be as accurate as possible. An example of level accuracy is shown in ***Figure 8***, for the N5183A microwave signal generator. The expanded measurement uncertainty (shown with the red brackets) is quite a bit smaller than the specification. This is due to the excellent performance of the signal generator and because of the digital IF and receiver option of the E4448A measuring receiver used for this test. Calibration labs sometimes use older spectrum analyzers

with analog IF sections (e.g., analog IF filters and log amplifiers). This results in the expanded measurement uncertainty extending well beyond the specifications. Obviously, if the measurement uncertainty extends beyond the specification of the instrument being tested, there's no way to know the actual performance. With large measurement uncertainty, it's also impossible to make accurate adjustments to achieve the power level accuracy shown in Figure 8.

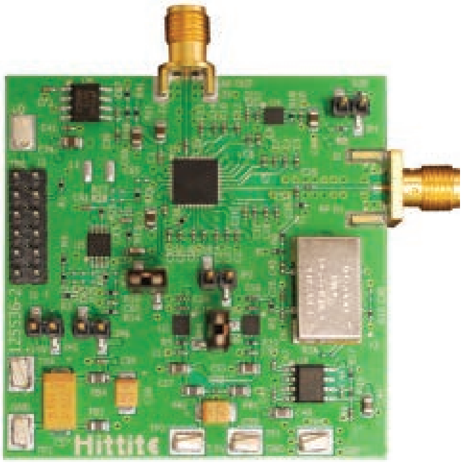
CONCLUSION

With several common, important measurements, the instruments you rely upon may perform out of specification, even though they may not drift evenly from year-to-year. Absent catastrophic failure, you have no way of knowing that performance has changed unless it is caught during periodic calibration. That's the point of periodic calibration: to accurately measure the performance of your instrument and compare that with the original data sheet specifications. For the critical specifications that your organization relies on, review how your instrument performs during calibration. Waiting until one of the instruments is out of tolerance is too long. An instrument barely in tolerance can impact the pass/fail results of the end product. For additional test margin, consider a calibration service that incorporates uncertainties and a guard band. ■

References

1. The chart and associated data is part of the calibration measurement monitoring system (CMMS) as part of Keysight's compliance with Paragraph 5.9.1 of IEC/ISO 17025. More information on CMMS is available at http://literature.cdn.keysight.com/litweb/pdf/5992-0037EN.pdf
2. A series of short videos about calibration and how it relates making accurate measurements is available at www.keysight.com/find/servicevideos
3. ISO/IEC Guide 98-3:2008, The Guide for Expression of Measurement Uncertainty
4. There is a whole field of study to quantify probability density, consumer risk, producer risk, etc.

Bob Stern *graduated from the University of Wisconsin with bachelor's and master's degrees in electrical engineering. Over his career, he has worked for six different divisions at Hewlett Packard, then Agilent, now Keysight Technologies. Stern participates on the National Conference of Standards Laboratories International (NCSLI) committees concerned with calibration standards, he is chair of the NCSLI 174 standards – writing group, and he recently began attending International Laboratory Accreditation Cooperation (ILAC) standards meetings. He is also active in efforts to align Keysight's calibration service deliverables with IEC/ISO 17025, ILAC-G8, ILAC-P14 and ANSI Z540. He has recorded eight YouTube videos on various calibration topics.*



PLL with Integrated VCO Enables Compact Solutions

Analog Devices Inc.
Norwood, Mass.

Radio designers working in cellular/4G, microwave radio, test equipment and military subsystem applications rely on high quality local oscillators (LO) in order to meet system level goals for low bit error rate (BER), low spurious output and low phase noise. RF and microwave communication systems require a clean LO signal source; the higher the capacity of the radio, the more demanding the requirements on the LO signal. There are different architectures in use, but one of the most common methods of generating a stable LO source is to combine a low phase noise voltage controlled oscillator (VCO), with a stable reference and a phase-locked loop (PLL) to form a frequency synthesizer. However, designers seeking the very best LO performance must contend with numerous challenges related to the interaction between the PLL/synthesizer, VCO, charge pump, and loop filter, not to mention issues that arise due to board layout and unwanted power supply noise.

TABLE 1

PERFORMANCE SUMMARY FOR NEW ANALOG DEVICES PLLs FOR COMMUNICATIONS SYSTEMS

Part Number	Frequency Ranges (GHz)	Phase Noise (dBc/Hz) @ 10 MHz Offset, Integer Mode* F_{COMP} = 50 MHz, BW = 100 kHz	Phase Noise (dBc/Hz) @ 1 MHz Offset, Open-Loop VCO	P_{OUT} (dBm)	RMS Jitter Fractional Mode (f_s)	Int. Phase Noise Fractional Mode (° rms)
HMC830LP6GE	0.025 to 3	–114 @ 2 GHz	–141 @ 2 GHz	+5	159	0.114 @ 2 GHz
HMC832LP6GE	0.025 to 3	–114 @ 2 GHz	–139 @ 2 GHz	+7	159	0.114 @ 2 GHz
HMC835LP6GE	0.33 to 4.1	–105 @ 4 GHz	–133 @ 4 GHz	+7	<160	0.23 @ 4 GHz
HMC764LP6CE	7 to 8.2	–102 @ 7.6 GHz	–140 @ 7.6 GHz	+15	196	0.55 @ 7.6 GHz
HMC765LP6CE	7.8 to 8.5	–102 @ 8.2 GHz	–139 @ 8.2 GHz	+13	193	0.58 @ 8.2 GHz

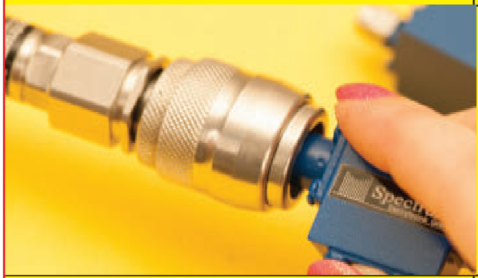
*Figure of merit (FOM) of synthesizer is –221 dBc/Hz/–226 dBc/Hz (fractional/integer).

Procedure for how to use the N, TNC and 7/16 Push-On male. Push-On Connectors mate with any standard female connector of the same connector style.

1. Convert your standard Assembly into a Push-On Assembly using the Nf to Nm Push-On Adapter.

2. Put your fingers firmly onto the knurls of the "Lock Nut".

3. Push "Lock Nut" forward and engage the Push-On end of the Adapter with the mating female. Back nut must be released.

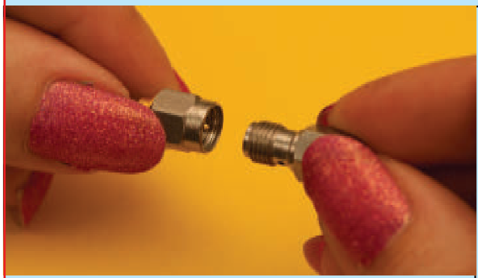


4. The Connection has been completed, easy and fast. The connector has been locked on safely.

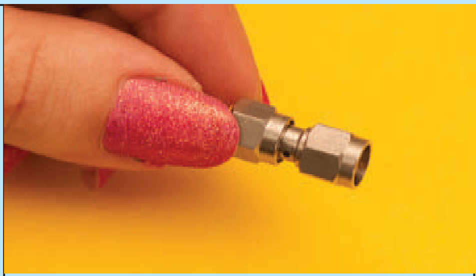
5 . To unlock (when "Back Nut" is in unlocked mode) push the "Lock Nut" forward and stop reverse movement by setting your fingers onto the "Back Nut".

6. Keep fingers on "Back Nut" to ensure that "Lock Nut" cannot slide back and pull the connector off.

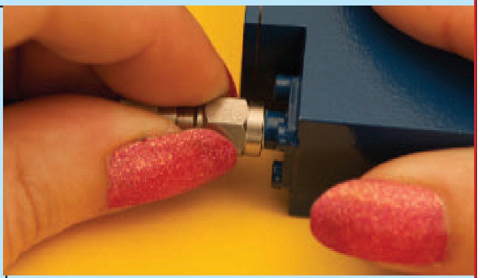
Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.



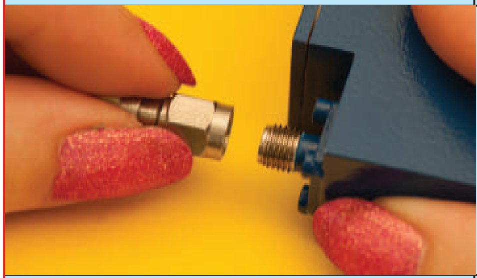
1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted into an SMA male Push-On Assembly.



3. Just slide the Push-On SMA male Connector onto any standard SMA female. The connection is securely completed in seconds.



4. To disconnect, just pull the connector off.

Spectrum
Elektrotechnik GmbH

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Email: sales@spectrum-et.com
Phone: +49-89-3548-040
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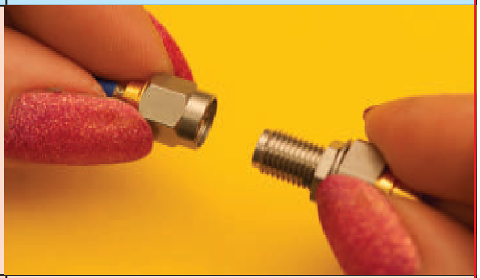
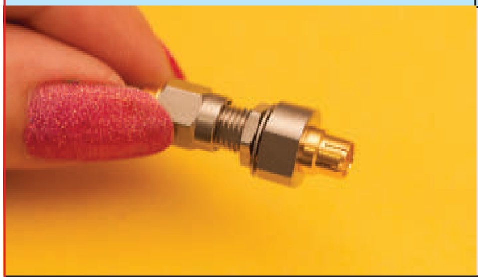
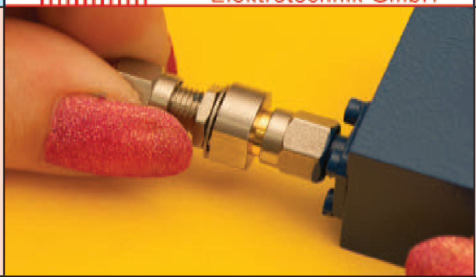


1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted to a Push-On SMA female Cable Assembly.



3. Just slide the Push-On SMA female Connector onto any standard SMA male. The connection is securely done in seconds.

4. To disconnect, just pull the connector off.

TABLE 2

PERFORMANCE SUMMARY FOR NEW ANALOG DEVICES PLLs FOR COMMUNICATIONS SYSTEMS

Part Number	Frequency Ranges (GHz)	Phase Noise (dBc/Hz) @10 kHz Offset*	Phase Noise (dBc/Hz) @ 1 MHz Offset, Open-Loop VCO	P_{OUT} (dBm)	RMS Jitter Fractional Mode (f_s)	Int. Phase Noise Fractional Mode (° rms)
ADF5355	0.05 to 13.6	–90 @ 6.8 GHz	–132 @ 6.8 GHz	–3	150	–221
ADF4355-2	0.05 to 4.4	–95 @ 3.4 GHz	–138 @ 3.4 GHz	+3	150	–221

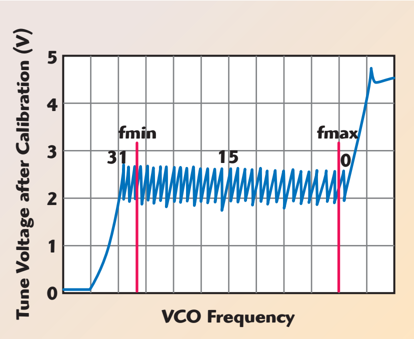
*Integer Mode, F_{COMP} = 61.44 MHz, BW = 20 kHz

Analog Devices has developed a core expertise in frequency generation components such as MMIC VCOs, phase-locked oscillators (PLO), low noise prescalers, phase-frequency detectors (PFD), and a line of dual mode (fractional/integer) PLL/synthesizer ICs with RF input frequencies to 13.6 GHz. Their new PLL with integrated VCO products for communications systems are summarized in ***Tables 1*** and ***2***.

These products implement an advanced fractional-N synthesizer and an ultra low noise VCO in a standard 5 or 6 mm QFN plastic package; this high level of integration minimizes the number of external components. They were designed for ultra low phase noise commercial and military applications and include a very low noise phase frequency detector (PFD), a precision controlled charge pump, and an advanced modulator design that allows ultrafine frequency steps. Ultra low phase noise and low spurious also permit architectures with wider loop bandwidths for faster frequency hopping and low microphonics; spurious outputs are low enough to eliminate the need for costly direct digital synthesis (DDS) references in many applications.

PLLs WITH INTEGRATED VCOs FOR RF MARKET APPLICATIONS

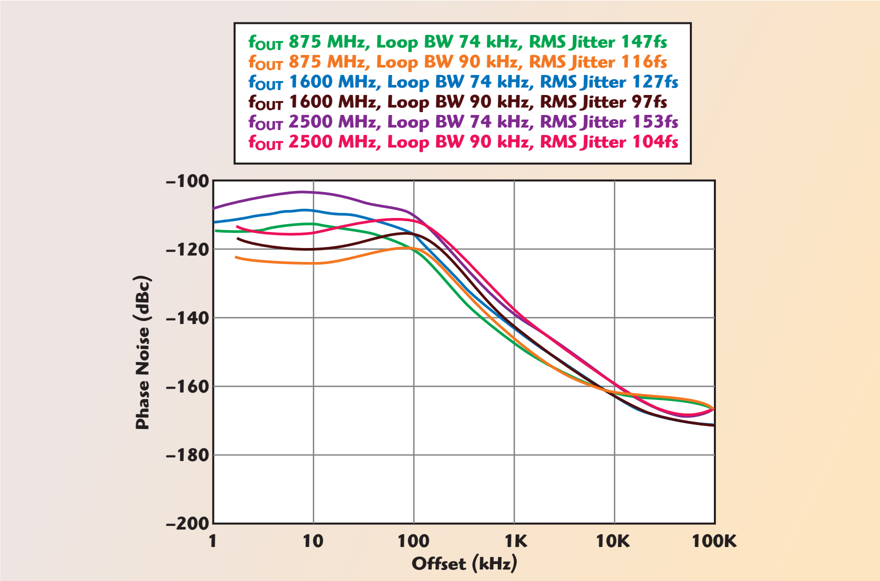
The HMC830LP6GE is one of eight wideband PLL with integrated VCO products which are targeted to cellular/4G, IF of microwave backhaul, and test and measurement applications. Each product within the family combines the functions of a high performance fractional-N PLL/synthesizer with a fully integrated low noise VCO. The architecture of the PLL with integrated VCO for RF applications enables high performance VCOs with sub-five volt tuning (see ***Figure 1***). No op amp is required in the loop filter, saving both cost and board space, while improving performance. The PLL with integrated VCO can be locked at one temperature extreme and then operated over the full temperature range without the need for relocking or recalibration; this capability is required in high reliability applications, but not fully supported by some competing solutions.



▲ *Fig. 1 Tuning voltage vs. frequency for the HMC830LP6GE PLL with integrated VCO.*

As shown in ***Figure 2***, these devices offer excellent phase noise performance that is typically 10 dB better than competing devices both in-band, and at the far out noise floor, all without the need to choose between low spurious or low noise modes. The typical -55 dBc integrated noise from 100 Hz to 1 MHz is equivalent to 0.1° of rms jitter, or 278 fs rms at f_{OUT} = 1 GHz.

As shown in ***Figure 3***, the HMC830LP6GE represents a significant improvement over alternative integrated solutions. For example, it offers approximately 5 dB lower close-in



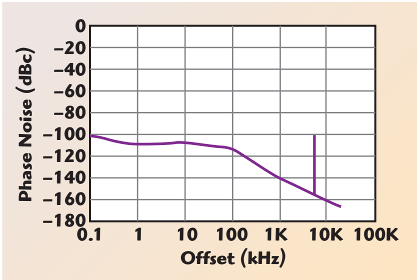
▲ *Fig. 2 SSB phase noise vs. offset frequency for the HMC830LP6GE PLL with integrated VCO.*

phase noise, and a 7 dB lower phase noise floor at offset frequencies greater than 20 MHz, compared to another competing part. The HMC830LP6GE offers better spurious performance, with much lower fractional spurs across the band and a cleaner overall spectral output and provides consistent over temperature performance at the band edges, to ensure no "drop-outs" are experienced.

The ADF5355 PLL with integrated VCO covers 55 MHz to 13.6 GHz, the widest in its class, while the ADF4355-2 covers 55 MHz to 4.4 GHz. Both parts integrate low phase noise VCOs delivering phase noise of -138 dBc/Hz at 1 MHz offset, at 3.4 GHz for the ADF4355-2 while the ADF5355 delivers phase noise of -132 dBc/Hz at 1 MHz offset at 6.8 GHz.

The VCO phase noise performance of the ADF5355 and ADF4355-2 is achieved through unique VCO topologies and architectures that were developed in conjunction with ADI's new advanced SiGe-BiCMOS processes. In ultra-wideband RF and microwave communications applications, this low phase noise has the benefit of improving overall system bit error rates and increasing data throughput while enabling better noise immunity and wider dynamic range.

ADI's new, cost-effective, ultra-wideband PLL synthesizer ICs also feature up to 125 MHz phase comparator frequency and 38-bit resolution, which lowers jitter and allows for very fine step

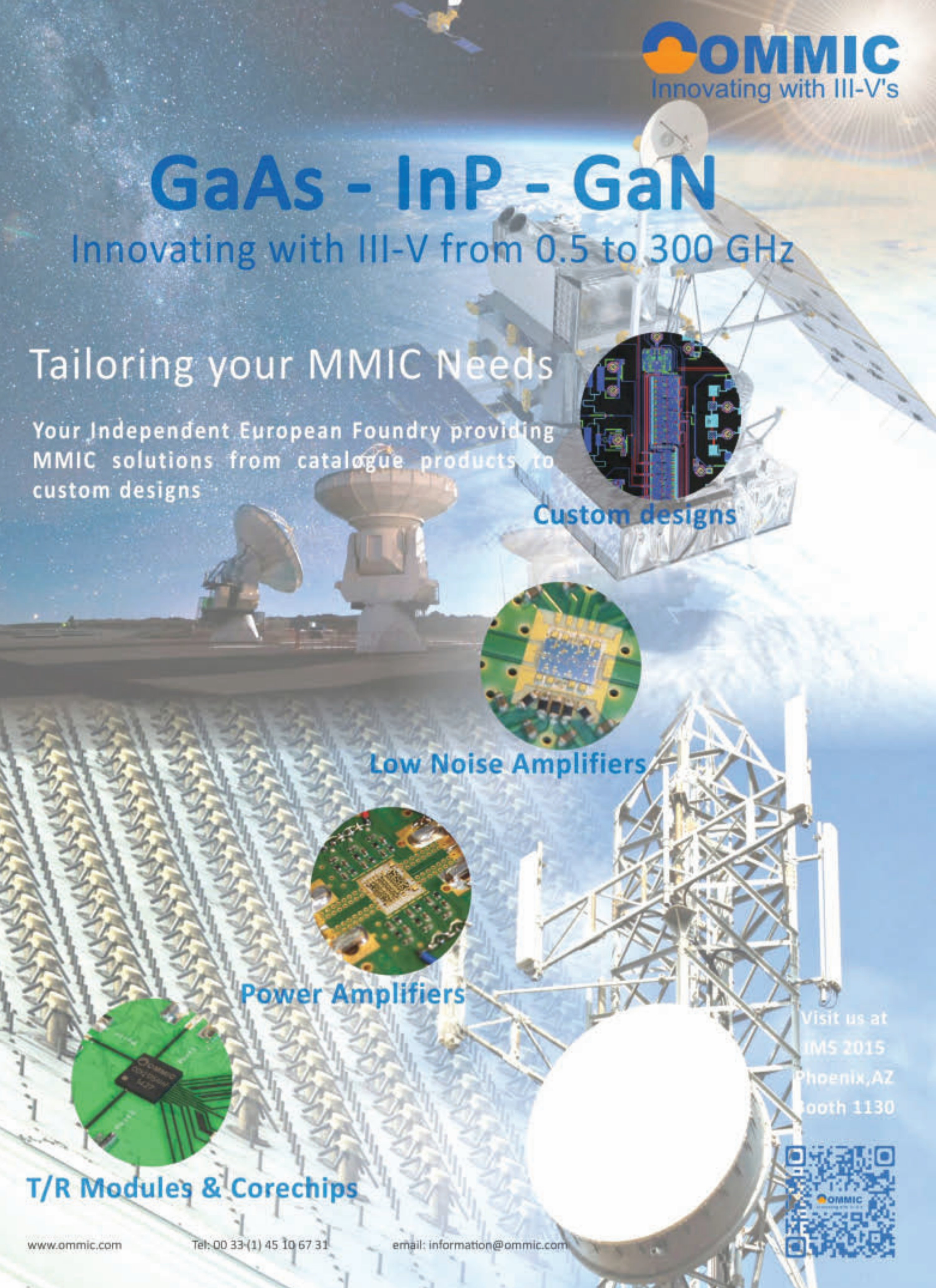


▲ *Fig. 3 Worst spur, fixed 50 MHz reference, output frequency = 2 GHz.*

sizes, while the integrated PLL and VCO are fabricated on an advanced BiCMOS process significantly reducing package size and power consumption compared to discrete GaAs implementations. Furthermore because a single PLL synthesizer can be configured to operate from 55 MHz to 13.6 GHz, designers can more quickly reconfigure their system designs and reduce their parts inventory while still supporting multiple frequency bands.

MICROWAVE MARKET APPLICATIONS

The HMC764LP6CE PLL is optimized for narrow-band but high performance microwave communication applications. These products offer the same exceptional microwave VCO performance which Analog Devices is recognized for, with the added functionality of an advanced, integrated fractional synthesizer. Typical applications include microwave and millimeter-wave radios, industrial/medical test equipment, military communications, electronic warfare (EW), and electron-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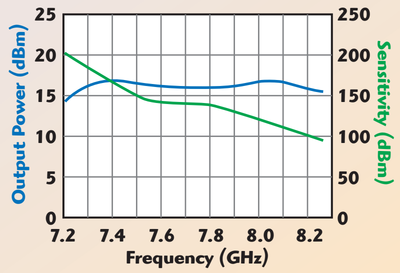
ic countermeasure (ECM) subsystems.

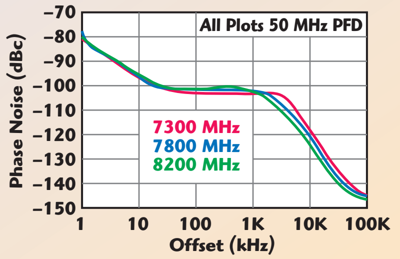
As shown in ***Figure 4***, the HMC764LP6CE exhibits consistent tuning sensitivity and high output power of up to 16 dBm across its bandwidth, making it ideal for directly driving the LO port of many of Analog Devices high linearity, double balanced and I/Q mixer and up and down-conversion products. The single sideband (SSB) phase noise performance vs. offset frequency for the low, mid and high frequency range of the HMC764LP6CE is shown in ***Figure 5***. This data was measured with a reference frequency of 50 MHz, a loop bandwidth of 100 kHz, and in the presence of a comparison frequency of 50 MHz at the PFD. The phase noise performance is consistent over temperature and mechanical shock, due to the monolithic construction. A built-in FSK mode allows the device to be used as a simple, low cost direct FM transmitter source.

Hybrid-based synthesizers typically employ a fiberglass-based substrate material with a discrete VCO, a large resonator, and a stamped metal cover that can present problems in users' systems related to RF grounding as well as unwanted electrical and microphonic coupling effects. Analog Devices PLLs with integrated VCOs have much smaller monolithic resonators and hence offer better microphonic performance compared to larger hybrid designs.

Developing a high performance programmable local oscillator can still require considerable design time. Therefore Analog Devices has developed a PLL with integrated VCO reference designer's kit that enables immediate measurement of the design at hand. The typical evaluation PCB is part of an easy to use, universal evaluation kit which can minimize design time and facilitate rapid prototyping. The reference designer's kit includes an on-board reference oscillator and voltage regulators, and supports universal loop filter configurations. Included software allows the user to program the PLL and access its advanced features. The guide includes a comprehensive discussion of the components used within the evaluation board, and covers advanced topics such as reconfiguring the evaluation board for an external reference, and implementing on-board selectable order passive or active loop filters.



▲ *Fig. 4 Tuning sensitivity and RF output power vs. output frequency for the HMC764LP6CE PLL with integrated VCO.*



▲ *Fig. 5 SSB phase noise vs. offset frequency for the HMC764LP6CE PLL with integrated VCO.*

Each reference designer's kit contains the Analog Devices ADIsimPLL design tool allowing users to tailor the standard evaluation PCB loop filter to their specific application. Comprehensive PC-based PLL control software is provided, with PC-compatible register files to program the PLL via the USB interface. ADI's group of applications engineers is also available to help customers quickly become familiar with this unique product.

Analog Devices PLL with integrated VCO products uniquely combine the attributes of low phase noise, advanced features, and small size, making them ideal for numerous small form factor applications including microwave/millimeter wave radios, test equipment, microwave sensors, fiber optic communications, and military communications and sensors.

VENDORVIEW

Analog Devices Inc.
Norwood, Mass.
www.analog.com

Broadband Up-Conversion Mixer Offers High Linearity and Isolation

Linear Technology Corp.
Milpitas, Calif.

Linear Technology's 3 to 8 GHz wideband mixer is optimized for up-conversion applications. The LTC5576 comprises an active double-balanced mixing core built using an advanced SiGe BiCMOS process. Benefits include low conversion loss – only 2 dB at 8 GHz – excellent port-to-port RF isolation and an outstanding output third-order intercept (OIP3) of +25 dBm. The mixer has an integrated local oscillator (LO) buffer that eliminates the need for external LO amplifiers and an on-chip broadband RF output transformer that allows the mixer to operate over the wide frequency range of 3 to 8 GHz. The device has excellent dynamic range, with a noise floor of -154 dBm/Hz.

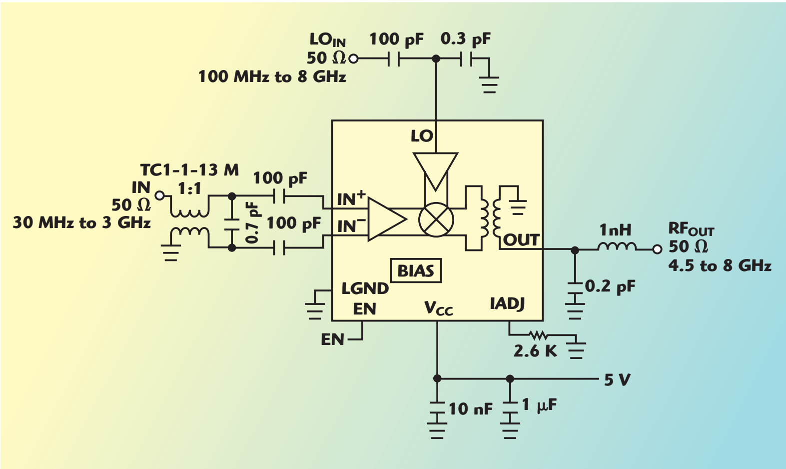


Fig. 1 Wideband up-conversion mixer implementation.

BETTER THAN PASSIVE MIXERS

Compared with traditional microwave mixers, the LTC5576 offers several marked improvements. Most passive microwave mixers utilize GaAs microwave FETs or diode bridge topologies, which typically have 7 to 9 dB of conversion loss. As a result, an external high linearity microwave amplifier is usually needed to increase the signal level to a suitable output for transmitter applications. This requires additional circuitry. The LTC5576 has only 2 dB of conversion loss at 8 GHz, and performance is even better below 5.8 GHz, with only 0.6 dB loss. This new mixer produces higher output signals, reducing the need for additional external amplification. Requiring less gain after the mixer stage, the LTC5576 also improves the overall transmitter noise.

TABLE 1
LTC5576 PERFORMANCE SUMMARY
• 3 to 8 GHz wideband up-conversion mixer
• 25 dBm OIP3 at 8 GHz
• 2 dB conversion loss at 8 GHz
• 0 dBm LO drive
• –28 dBm LO-to-RF leakage
• –154 dBm/Hz output noise floor

LO input level is another area of improvement. Passive mixers typically require moderately high drive level, from +10 to as high as +17 dBm. If the mixer is driven from a relatively modest power PLL/synthesizer, a power amplifier is needed to boost the LO drive. Designing high power RF and microwave amplifiers requires extra caution because the reverse isolation can allow LO power to leak back to the VCO, leading to appreciable VCO frequency pulling. To prevent this, two stages of LO buffer are often used to ensure adequate reverse isolation. The LTC5576's 0 dBm LO drive to its integrated buffer blocks reverse leakage. It also suppresses forward leakage to the RF output, reducing the output RF filtering to meet out-of-band emission requirements. The LTC5576's LO drive does not require tight tolerance. It is much more forgiving compared to passive mixers, delivering good IP3 over a wide variation of LO power.

Having a high power LO signal present on the PC board can be a source of undesirable radiation or coupling to other sensitive parts of the system. This may require extensive RF shielding to enclose the high power circuit and contain the radiation. The LTC5576's lower LO drive power reduces or eliminates the need for external RF shielding, resulting in cost savings.

Most passive mixers are limited in operating frequency, typically supporting 2 to 3 GHz. With a selected baseband balun transformer (see ***Figure 1***), the LTC5576's input is matched to 50 Ω from 30 MHz to 3 GHz. Higher frequency operation to 6 GHz is possible with a 6 GHz balun. On the RF output port, the mixer has an on-chip balun transformer that provides a single-ended interface. With appropriate impedance matching, the RF output operates from 3 to 8 GHz. In the circuit shown in Figure 1, the output is matched to 50 Ω from 4.5 to 8 GHz. The LO input port is also single-ended and matched to 50 Ω from 100 MHz to 8 GHz.

The LTC5576's low conversion loss, wide frequency range, high OIP3 and low LO leakage provide superior transmitter performance in a wide range of microwave radio, wireless communication, radar, avionics and test instrumentation applications (see ***Table 1***). Its unique topology minimizes external circuitry. Housed in a 4 × 4 mm QFN plastic package, it is a compact solution. The mixer can be powered from a single 3.3 or 5 V supply and draws 99 mA. The device is rated for operation from -40° to 105°C case temperature.

VENDORVIEW

Linear Technology Corp.
Milpitas, Calif.
www.linear.com

Controlling EMI with Board Level Shielding and Gasketing

Orbel Corp.
Easton, Pa.

Electromagnetic interference (EMI) can plague even the best RF/microwave designs and requires careful planning to control. Designers working with electromagnetic (EM) fields are constantly faced with the threat of stray EM energy leaking into other parts of a circuit or system. EMI can disrupt the performance of the circuit where it originates as well as nearby circuits and systems. Two approaches can reduce or shield EM emissions from a device or system and improve its immunity. The first is shielding the printed circuit board (PCB) through proper design techniques. The second is placing the device or system in a shielded enclosure.

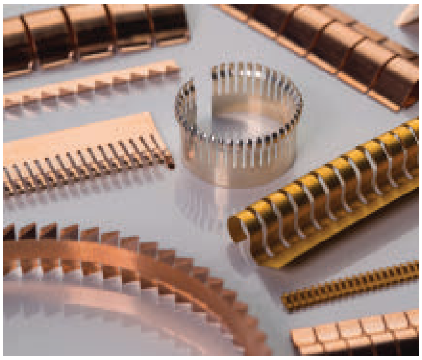
Orbel Corp. produces shielding products for both the printed circuit board (i.e., board-level shielding) and system (i.e., gasketing). Device manufacturers rely on shielding suppliers like Orbel for the technical capabilities and knowledge needed to suppress EMI, since shielding remains challenging.

BOARD-LEVEL SHIELDING

A board-level shield can be viewed as a five-sided can. Available in unlimited sizes, shapes and heights, board-level shielding (BLS) is placed around the component or circuit on the printed circuit board that needs to be shielded. The shield restricts to acceptable levels the electromagnetic energy propagating between the source and a receptor. BLS can be manufactured in one-piece, two-piece, multi-cavity and custom configurations. When designing and manufacturing BLS, consider the following to achieve the most effectiveness:

Near field effects: When the shield is in the near field of the source, shielding performance will be affected by the frequency, field configuration, position of the source and distributed inductances and capacitances. The coupling of the source to the shield, the effect of mutual coupling between elements, shield termination and grounding technique all need to be taken into account.

Layout and hole considerations: The effectiveness of BLS is highly dependent on the proper design of the printed circuit board mounting area. Normally, the sixth side of this “can” will be a ground plane on the board. The number and spacing of traces, vias and holes



▲ *Fig. 1 BeCu gaskets from Orbel provide high EMI shielding effectiveness and are available in a variety of finishes.*

▲ *Fig. 2 Metalized fabric gaskets are manufactured with a polyurethane foam core and nickel-plated copper-conductive fabric.*

running from the shielded area to other board components will determine the effectiveness of BLS.

Resonances: Another issue with higher frequencies is the resonance effect, meaning coupling as a consequence of the self-resonance of various structures. For example, the first-order mode of a 2 × ½-inch enclosure is about 12 GHz. Even weak coupling at these high frequencies can induce strong oscillations that couple to other points in the enclosure.

Thermal management: As devices become faster, they generate more heat. Hence, thermal management is also a design factor. Thermal management can be achieved through the use of thermal pads and heat sinks. Companies like Orbel can assist with design options.

GASKETING

Gasketing maintains shielding effectiveness through proper seam treatment. In general, seams account for most of the leakage in an enclosure design. The shielding effectiveness of a seam depends on materials, contact pressure and surface area. Gaskets maintain conductive contact across mating surfaces. A solution to radiated problems is to make all seams of adjoining metal pieces continuous. If there is no continuity between metal pieces, a radiating aperture for RF is created. This is where gasketing can be used. Chosen based on specific shielding effectiveness requirements, application atmosphere and spatial specifications, both beryllium copper (BeCu) gaskets and metalized fabric gaskets can be used to ensure maximum EMI compliance.

Beryllium copper gaskets: BeCu gaskets (see ***Figure 1***) offer the highest level of attenuation over the widest frequency range and are useable in both compression and shear applications. Solid fingers have greater cross-sectional area, hence higher conductivity. The finger shape has the characteristics of an interconnecting ground plane with a large contact area; therefore, the inductance will be low. The slots between the fingers can create potential problems, depending on the frequency range. At sufficiently high frequencies, these slots begin to permit RF energy transmission through the bounded slot configuration.

Metalized fabric gaskets: These gaskets are made of conductive fabric material over foam (see ***Figure 2***). Conductivity can be very low and hence offer very high attenuation, the amount determined by the level and matrix of the conductive particles and the compression force. Gaskets come in various styles and shapes (e.g., rectangular, square, D, bell, knife) that allow compression ranges down to low values.

Since 1961, Orbel's custom design and manufacturing process has enabled unique engineered solutions for a variety of applications and industries. From conception through delivery, Orbel offers today's most effective EMI/RFI shielding, photo-etched precision metal parts, precision metal stampings and electroplated metal foils. Areas of specialization include RF/microwave, aerospace, telecommunications, electronics, medical, automotive and manufacturing.

Orbel Corp.
Easton, Pa.
www.Orbel.com

Compact Miniature Signal Generator

The ASG miniature signal generator combines exceptional RF performance and versatility of digital interface in a highly compact package – just 21 × 72 × 100 mm and weighing less than 300 g. In addition to the ultra-wide frequency range of 25 to 6000 MHz, tunable in 1 Hz steps, the spearhead of RF performance of these ASG modules is in the spectral purity of their output signal. Phase noise at an output frequency of 1 GHz is better than -106 dBc/Hz at an offset of 100 kHz from the carrier. Spurious are typically lower than -70 dBc and harmonics less than -25 dBc.

The versatile ASG digital interface provides control options which include direct USB with convenient and clearly functional GUI plus input power derivation. Each unit also has the capability of being driven by RS232. Additionally, for both the 6 GHz version and its 3 GHz sibling there is an option of Ethernet control, thereby allowing totally remote and unattended operation in the field, with all of the logistical and cost advantages that provides.

Frequency stability is determined by an internal TCXO with ±1 ppm maximum variation over the -20° to +50°C operating temperature range but the miniature signal generator can also be connected to an external reference of between 10 and 50 MHz where system stability tracking is required.

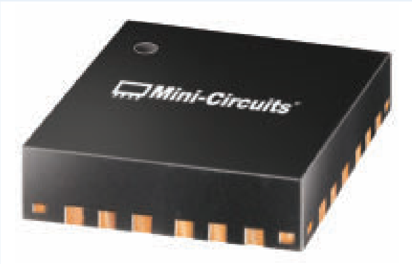
The miniature signal generator is able to generate swept frequency signals and step through a range of frequencies. There are two sweep modes, dwell and duration. Dwell allows the user to set the dwell time at each step, while duration provides a user defined total sweep time. Both modes allow the user to define the start and stop frequencies and the sweep can go from high to low by setting the stop at a lower frequency.

The unit works with Windows XP, Windows 7 and Windows 8, and software upgrades are supplied free of charge. In addition, the ASG has a non-volatile memory that retains all settings. It can have the USB removed and power cycled recalling its last known state.

The clean output signal combined with power levels to +13 dBm, controllable on 0.1 dB steps; make the series suitable for use in most RF theatres of application including test and measurement, communications systems, covert interception and countermeasures.

VENDORVIEW

AtlanTecRF
Braintree, Essex, UK
www.atlantecrf.com



Compact 1.8 to 12.5 GHz Power Splitter/Combiner

Mini-Circuits is offering a new broadband power splitter/combiner covering 1.8 to 12.5 GHz in a compact 4 × 4 mm surface-mount plastic package.

The ports of the EP2C+ are tightly matched, with the typical amplitude imbalance only 0.1 dB from 1.8 to 3.8 GHz, 0.2 dB from 3.8 to 8.5 GHz and 0.7 dB from 8.5 to 12.5 GHz. When used as a power splitter, the two output ports are in phase, with the typical phase imbalance 3, 6 and 11 degrees, respectively, across the 1.8 to 3.8, 3.8 to 8.5 and 8.5 to 12.5 GHz frequency segments. Added insertion loss above the theoretical 3 dB power split is typically 0.8, 1.1 and 1.8 dB across the same frequency bands. Isolation is typically 10 dB at the low end of the frequency range and 17 dB at the upper end. VSWR is low, typically no greater than 1.5:1 at the common port and 1.6:1 at either of the two legs.

As a splitter, the EP2C+ will handle up to 1.85 watts input power and is designed to operate from –40° to +85°C. The RoHS compliant device has a Class 2 human-body model (HBM) ESD rating. Containing no blocking capacitors, the frequency response of the EP2C+ extends to DC, and it will carry up to 400 mA current.

VENDORVIEW

Mini-Circuits
Brooklyn, N.Y.
www.minicircuits.com

Cost-Effective Multi-Demodulator for IP Networks

Teledyne Paradise Datacom has developed a cost-effective solution for satellite point-to-multipoint RF networks using the Internet Protocol (IP). The Q-MultiFlex™ combines an "outbound" modulator with demodulators for up to 16 return carriers within a 72 MHz bandwidth.

The Q-MultiFlex system is scalable to any network size and can handle star, mesh and hybrid point-to-multipoint topologies. Typical applications include cellular backhaul, IP distribution, government, enterprise, and oil and gas networks.

The modulator supports the bandwidth-efficient DVB-S2X standard, with spectral roll-off factors as low as 5 percent. The outbound data rate can be as high as 160 Mbps. The demodulators process FastLink™ low-latency, low density parity check (LDPC) return carriers, with a maximum cumulative data rate of 160 Mbps across all carriers.

The system incorporates three features to optimize the bandwidth, especially important in satellite applications. In addition to DVB-S2X modulation, Paired Carrier™ overlays the transmit and receive carriers to reduce bandwidth by 50 percent. The use of adaptive coding and modulation (ACM) allows unused link margin to be converted into higher throughput.

The Q-MultiFlex has a BNC IF interface, with dual bands covering 50 to 90 and 100 to 180 MHz, and a Type-N L-Band interface covering 950 to 2150 MHz. The data interface is a standard Gigabit Ethernet RJ45 connection.

Teledyne Paradise Datacom
Rancho Cordova, Calif.
www.paradisedata.com

Doubled Lifetime Coaxial Switch for ATE Applications

Dow-Key Microwave has doubled the design life of their 5×5-series DC to 18 GHz multi-position switch from 1 to 2 million cycles. The switch is ideal for ATE applications where many DUTs repeatedly need to undergo testing. The break-before-make coaxial switch comes in SP3T, SP4T and SP6T configurations and are normally open until actuation. Insertion loss is less than 0.5 dB at 18 GHz, with isolation at least 60 dB and VSWR no greater than 1.5:1. As expected, loss, isolation and VSWR are better at lower frequencies: 0.2 dB, 70 dB and 1.2:1, respectively, at 4 GHz. Switching time is 20 msec maximum.

The switches are available with various options such as TTL or non-TTL control, and offered with standard coil voltages 12 or 28 V. Other voltages can be selected upon request. SMA-type connectors provide the input and output RF interface. The operating temperature range is -25° to +65°C. The 2 million cycles switch has a small footprint with the size of only 1.755" × 1.755" × 1.97". The standard solution is RoHS compliant but can be designed without RoHS materials if needed.

VENDORVIEW

Dow-Key Microwave
Ventura, Calif.
www.dowkey.com

IEEE COMCAS 2015

International Conference on Microwaves, Communications, Antennas and Electronic Systems

David Intercontinental Hotel ■ 2-4 November 2015 ■ Tel Aviv, Israel

IEEE COMCAS 2015 continues the COMCAS tradition as a multidisciplinary forum for the exchange of ideas, research results, and industry experience in the areas of microwave/RF/mm-wave engineering, communications, antennas, electromagnetic compatibility, solid state circuits, electronic devices, engineering in medicine, radar, sonar and electronic systems. The technical program includes invited talks by international experts and contributed papers and will be complemented by a large industrial exhibition.

Important Dates

Submission of summary:
30 May 2015

Notification of acceptance:
15 July 2015

Submission of final paper:
20 September 2015

For more information visit:

www.comcas.org

Email: comcas@ieee.org

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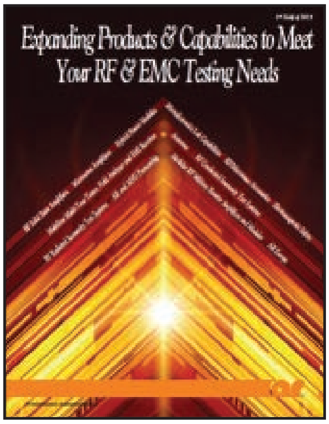
For author's instructions and further information, see www.comcas.org.

CatalogUpdate

EMC & RF Testing Product Catalog

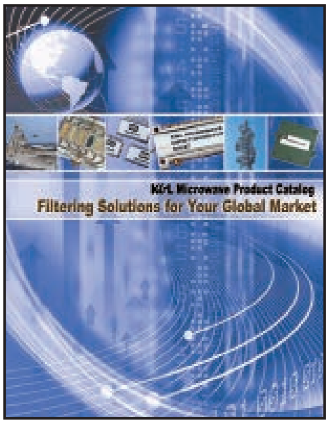
VENDORVIEW



A brand new edition (1st half of 2015) of AR's complete full line product catalog is now available. "Expanding Products & Capabilities to Meet Your RF and EMC Testing Needs," features new products, including the new line of electromagnetic safety products, refreshed page layouts, details on the company's new partnership with MVG and more. Please contact your local AR sales associate for a hard copy or visit AR's website at www.arworld.us/html/catalogRequest.asp for a free download, in full or by section.

AR RF/Microwave Instrumentation
www.arworld.us

2015 Product Catalog



K&L designs and manufactures a full line of RF and microwave filters, duplexers and subassemblies, including ceramic, lumped element, cavity, waveguide and tunable filters. The catalog shows filter responses, loss calculations and standard packages for all products. K&L supplies many of today's most significant military and homeland security electronics programs. Applications include space flight, radar, communications, guidance systems, mobile radio base stations as well as air traffic control and communications. Visit www.klmicrowave.com to download the complete catalog.

K&L Microwave
www.klmicrowave.com

Power of Wireless

VENDORVIEW

The new Keysight Technologies application note, "Solutions for Testing Data Throughput Performance in LTE-A User Equipment" provides insight into simplified, real-world functional and RF test of LTE-A user equipment (UE) performance using a fast, flexible and future-ready one-box tester. It is the newest in the series of Keysight's Power of Wireless application notes designed to provide a better understanding into the intricacies of the continuously evolving wireless industry and help users accelerate development of their products.

Keysight Technologies Inc.
www.keysight.com/find/powerofwireless

Custom Rack Mount Test Equipment Guide

VENDORVIEW

Mini-Circuits' Custom Rack Mount Test Equipment Guide is a 52-page, full color brochure showcasing a wide selection of custom test solutions ranging from DC to 18 GHz including amplifiers, signal generators, routing and distribution systems, and more. The brochure highlights Mini-Circuits' ability to deliver affordable, reliable custom test solutions with turnaround times as fast as two weeks as well as the company's user-friendly control software, programming support and test accessories. To request a copy, email sales@minicircuits.com.

Mini-Circuits
www.minicircuits.com

Air Traffic Control Rotary Joints

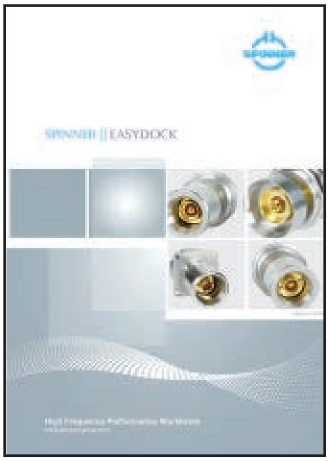
VENDORVIEW

The new second edition of SPINNER's Air Traffic Control Rotary Joints catalogue covers all rotary joints for civil and military ATC radars. This edition reflects the latest developments for this demanding market with high reliability. Starting from 3 channels up to 9 channels, S and L-Band solutions are available from Europe's leading system house of rotary joints. Customized solutions used for ATC radar applications can be made available on short notice.

SPINNER GmbH
www.spinner-group.com

SPINNER EasyDock

VENDORVIEW



The SPINNER EasyDock is a spring-mounted measurement adapter that guarantees perfect contact and reliable operation even when the axes of the test device and the adapter are not perfectly aligned. It tolerates deviations in all planes and directions and the conical intake ensures that the adapter and the test device slide together reliably even if they are not centered and aligned. Moreover, the precision of the measurement process is totally unaffected by mechanical tolerances.

SPINNER GmbH
www.spinner-group.com

Components

Public Safety Filter

VENDORVIEW

3H Communication Systems designs and manufactures a complete line of public safety filters and multiplexers for first responders for land, mobile, marine and aeronautical markets. The filter products are suited for VHF, UHF, 700, 800, 900 MHz and tetra bands. 3H filter products offer low insertion loss and >60 dB co-channel isolation. Filters can be designed for high power. Additional frequency bands and power options are available. For more information contact: sales@3hcomm.com.

3H Communications Systems

www.3hcomm.com

50 W Conduction Cooled Termination

Model series 552-308-050 is a 50 W of RF power (average) rated conduction cooled termination that has been deployed in commercial and military applications.

This 50 Ohm device has an operating frequency range of DC to 4 GHz and features maximum VSWR of 1.35:1. The RF connector is N male. Additional heat sinking is required for safe operation of this device at 50 W (case temperature must be maintained at +100°C or less).

BroadWave Technologies Inc.

www.broadwavetech.com

8-Way Ku-Band Iso-Divider

VENDORVIEW

Crane Aerospace & Electronics Microwave Solutions launched the 8-way Ku-Band Iso-divider designed for use in satellite applications. The Iso-divider combines the functions of high performance power dividers with ferrite isolators to provide a high isolation power divider solution, making the external isolators redundant for satellite receiver applications without introducing complex switch-based solutions. Integration of the two functions into a single package provides enhanced product reliability due to fewer external components, interconnects and transitions.

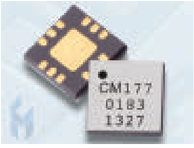
Crane Aerospace & Electronics Microwave Solutions

www.craneae.com

6 to 14 GHz Fundamental Mixer

VENDORVIEW

Custom MMIC announced the release of the CMD177C3, a packaged 6 to 14 GHz double-balanced mixer, to its growing standard product library. The CMD177C3 has a low conversion loss of 6.5 dB, high LO to RF isolation of



45 dBc, and a high input IP3 of +18 dBm across the 6 to 14 GHz bandwidth. The minimum LO drive requirement is +9 dBm, with saturation reach to levels above +13 dBm.

Custom MMIC

www.custommmic.com

Space Qualified Isolator

VENDORVIEW

DiTom Microwave released a new K-Band (18 to 22 GHz) space qualified isolator. The DS1015 is manufactured to meet or exceed environmental space-level reliability including thermal shock, sine and random vibration, temperature cycling, and thermal vacuum survivability over a specified qualification and acceptance test plan. DiTom's current space level manufacturing process allows for delivery in as quickly as four weeks depending on the test requirements. For more information contact (559) 225-7042 or email: space@ditom.com.

DiTom Microwave

www.ditom.com

Two-Way Power Divider

ET Industries, a designer of high frequency, wideband power dividers, introduced Model D-1050-2. This model is a two-way power divider that operates in a frequency range from 10 to 50 GHz. The maximum insertion loss is less than 1.80 dB. Amplitude balance is 0.5 dB maximum and phase balance is 5 degrees maximum. The minimum isolation is 16 dB and VSWR is 1.70:1 maximum. Connectors are 2.4 mm female. Housing size is 1.15" × 1.06" × 0.5".

ET Industries

www.etiworld.com

Elliptic Function Highpass Filter

Integrated Microwave Corp. offers a high frequency elliptic function highpass filter. This small-profile filter offers a passband insertion loss of 0.7 dBa from 5.2 to 13 GHz, with a -3 dBc cutoff at 5.15 GHz. The filter provides superior rejection: -20 dBc at 4.9 GHz and -40 dBc DC to 4.8 GHz. Performance is comparable to a suspended substrate, but at one-quarter the size and cost.

Integrated Microwave Corp.

www.imcsd.com

Low PIM 10 W Terminations

VENDORVIEW

MECA now offers a new line of 10 W terminations, with industry leading PIM performance of -175 dBc typical to <-165 dBc (2×5 W), -165 dBc Typical to <-155 dBc (2×20 W tones, additional heat sink required), while handling full rated power to +85°C. All terminations cover frequencies of 380 MHz to 2.700 GHz, VSWR=1.10:1 Typ./1.20:1 max. (0.698 to 2.700 GHz) & VSWR=1.15:1 Typ./1.25:1 Max. (0.380 to 0.698 GHz) with 7/16 DIN, Type N & 4.1/9.5 connectors. Made in USA and 36-month warranty.

MECA Electronics Inc.

www.e-meca.com

Coaxial Limiters

GG77317-04 and GG77317-05 are 100 W and 60 W broadband coaxial limiters that provide CW power handling capability from 10 MHz to

4 GHz and from 10 MHz to 6 GHz respectively, and are ideal for receiver protection in ECM, EW, radar and test equipment applications. These PIN-diode based limiters feature SMA female connectors and are designed to meet or exceed the MIL-STD-883 environmental conditions without damage. For product sales or technical information, contact RFMWMOD@microsemi.com.

Microsemi

www.microsemi.com

Power Splitter/Combiner

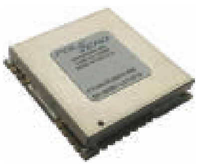
VENDORVIEW

Mini-Circuits' coaxial power splitter/combiner has an operating and storage temperature of -55° to 100°C. It features DC to 10,000 MHz wideband, 2 deg. typical phase unbalance and 0.2 dB typical amplitude unbalance. Applications include laboratory and test set-ups.

Mini-Circuits

www.mini-circuits.com

Bandpass Filters



Pole/Zero released its new line of NANO-ER™ tunable bandpass filters covering the entire military tactical radio band of 30 to 520 MHz while fitting in a low-profile package measuring 1.1" × 1.1" × 0.216" (28 × 28 × 5.5 mm). These low cost bandpass filters are commonly used in applications where small size, low power and high performance are needed such as military handheld radios, radar systems, SATCOM, test and measurement systems and additional commercial applications.

POLE/ZERO

www.polezero.com

Drop-In Circulator

VENDORVIEW

For X-Band radar systems, Renaissance has developed a low inser-

GVA AMPLIFIERS

NOW DC* to 12 GHz   up to 1W Output Power   from 94¢ ea. (qty. 1000)

GVA amplifiers now offer more options and more capabilities to support your needs. The new **GVA-123+** provides ultra-wideband performance with flat gain from 0.01 to 12 GHz, and new model **GVA-91+** delivers output power up to 1W with power added efficiency up to 47%! These new MMIC amplifiers are perfect solutions for many applications from cellular to satellite and more! The GVA series now covers bands from DC to 12 GHz with various combinations of gain, P1dB, IP3, and noise figure to fit your application. Based on high-performance InGaP HBT technology, these amplifiers are unconditionally stable and designed for a single 5V supply in tiny SOT-89 packages. All models are in stock for immediate delivery! Visit minicircuits.com for detailed specs, performance data, export info, **free X-parameters**, and everything you need to choose your GVA today!

US patent 6,943,629

**Low frequency cut-off determined by coupling cap.*
For GVA-60+, GVA-62+, GVA-63+, and GVA-123+ low cut off at 10 MHz.
For GVA-91+, low cut off at 869 MHz.

NOTE: GVA-62+ may be used as a replacement for RFMD SBB-4089Z
GVA-63+ may be used as a replacement for RFMD SBB-5089Z
See model datasheets for details

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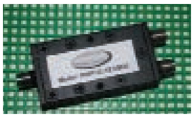
458 rev P

NewProducts

tion and return loss circulator operating between 9 and 10 GHz in a compact 0.5" × 0.5" × 0.18" package.

Renaissance Electronics & Communications LLC
www.rec-usa.com

Two-way Power Divider



Response Microwave Inc. announced the availability of its new multi-octave band power dividers for use in ATE and production applications. The new RMPD2.2-18Sf covers the 2 to 18 GHz band offering typical electrical performance of 0.8 dB insertion loss, VSWR of 1.50:1 and isolation of 20 dB. Power handling is 25 W and the unit is operational over the -35° to +85°C range. Mechanical package is 1.85" × 0.95" × 0.39", plus SMA female connectors. Unit configurations are currently available in two-way, four-way, six-way and eight-way splits.

Response Microwave Inc.
www.responsemicrowave.com

DC RF Switch

VENDORVIEW

Richardson RFPD Inc. announced the availability and full design support capabilities for a new UltraCMOS true DC RF switch from Peregrine Semiconductor Corp. The PE42020 is a

HaRP™ technology-enhanced SPDT true DC RF switch that operates from DC up to 8 GHz with integrated RF, analog and digital functions. It can be configured as a 50 ohm absorptive or open reflective switch and offers power handling of +30 dBm at 0 Hz and +36 dBm at 8 GHz.

Richardson RFPD Inc.
www.richardsonrfpd.com

High Power Splitter

RLC Electronics recently added a high power capability to its power divider product line. These reactive splitters are offered in two-, three- and four-way splits and have excellent input VSWR (1.3:1 max), high power ratings (500 W CW), low PIM (-125 dBc) and low loss (usually less than 0.2 dB). Frequency capability extends from 250 to 4000 MHz, and connector options include N and 7/16 connector types. These power dividers are designed to evenly split high power cellular signals with minimal reflection.

RLC Electronics Inc.
www.rlcelectronics.com

High Power Circulator

Model CT-1872-S is rated at 60 kW peak and 600 W average power at 325 MHz. The unit

provides 20 dB min. Isolation at 0.2 dB insertion loss and 1.20 max VSWR. The extremely compact design has flange to flange insertion length of only 6 ¾" and a height of 5 ¼". For use in radar applications, it has 1 ⅝" EIA connectors. It is also available at other UHF frequencies and connector types.

UTE Microwave
www.utemicrowave.com

Cables & Connectors

Phase Stable Cable Assemblies

D-COAX Inc. has introduced ≤ 1 ps skew matched and phase stable high performance flexible coaxial cable assemblies through 65 GHz. The standard assemblies deliver excellent return loss and low insertion loss. Cable pairs are ideal for signal integrity, channel modeling, jitter measurements, BERT and differential measurements.

D-COAX Inc.
www.d-coax.com

75 Ohm Test Cables

VENDORVIEW

Pasternack, a manufacturer and supplier of RF, microwave and millimeter wave products, announced the release of its line of 75 ohm test cables with operation up to 3 GHz. These rugged cable assemblies

are specially designed to withstand the rigors of test lab use and applications in 75 ohm communications systems. Technicians commonly rely on these high frequency test cables in technologies such as cable TV, MoCA 2.0 and MoCA 1.1 (Media over Coax Alliance) and DOCSIS (Data over Cable Service Interface Specifications).

Pasternack
www.pasternack.com

Coax to Waveguide Transitions

QuinStar Technology introduced a new line (Series QWA) of 1 mm coax to waveguide transitions (adapters) for full waveguide band operation in V, E and W-Bands. Both in-line and right-angle versions are available with male and female connectors. VSWR over the full band is 1.43:1 max. (return loss > 15 dB) with less than 0.8 dB insertion loss. Most models are available immediately from stock.

QuinStar Technology
www.quinstar.com

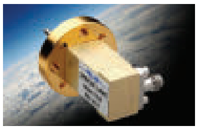
Right Angle Adapters

SGMC Microwave's SMA to SMM right angle (Between-Series adapters) features a frequency range of DC to 26.5 GHz. They also feature low VSWR and insertion loss, internally swept right angle design, corrosion resistant 303 stainless steel (passivated) and ruggedized construction for repeatability and reliability.

SGMC Microwave
www.sgmcmicrowave.com

NewProducts

E-Band Adapter



Spacek Labs model T79-W is one of the E-Band models in its series of waveguide to coaxial transitions or adapters. The T79-W covers the available commercial E-Band spectrum from 71 to 86 GHz with a typical insertion loss of 0.6 dB (typical). The maximum VSWR is 1.30:1. This transition can be used to adapt a component or system from WR-12 (UG387/U) waveguide to the 1 mm coaxial connector. This transition is also available covering the entire 60 to 90 GHz waveguide band.

Spacek Labs Inc.
www.spaceklabs.com

Amplifiers

TWT Amplifier

VENDOR**VIEW**

AR's new 250T6G18 TWT amplifier provides 250 W CW power from 6 to 18 GHz for EMC and microwave testing applications. Standard features include a built-in IEEE-488 (GPIB) interface, 0 dBm input, VSWR protection, gain control, RF output sample ports, plus monitoring various TWT voltages and currents.

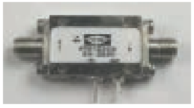
AR RF/Microwave Instrumentation
www.arww-rfmicro.com

Broadband RF Amplifiers

Fairview Microwave Inc. announced the release of its expanded broadband RF amplifiers operating in octave bands between 0.5 and 40 GHz with noise figures ranging from 2.5 to 6 dB across the entire frequency range. Fairview Microwave's new broadband amplifier portfolio consists of 18 part numbers to choose from that are commonly employed in a wide spectrum of military and commercial applications including wireless communications, telecom infrastructure, radar, electronic warfare, sensors, test instrumentation and microwave backhaul.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Wideband Amplifier

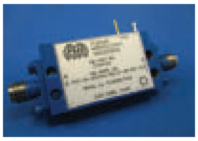


Herotek offers a multi-octave ultra wideband amplifier with excellent gain flatness and low power consumption. Model AF00120243A operates from 0.01 to 20 GHz. It has 24 dB gain with maximum gain variation of ±1.5 dB, noise figure of 3 dB, P1dB output of +8 dBm, and current draw of 90 mA at +5 V bias. This amplifier comes in a hermetically sealed package with removable connectors for drop-in assembly and is designed for both military and commercial applications.

Herotek Inc.
www.herotek.com

Low Noise Amplifier

VENDOR**VIEW**

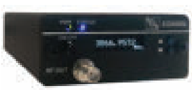


PMI Model No. PEC-30-2R04R0-1R5-21-8V-SFF-HS is a 2 to 4 GHz, low noise amplifier designed for military and industrial applications. This amplifier is supplied in PMI's EMI shielded, hermetically sealed housing with SMA(F) connectors. It provides > 30 dB of gain with a typical noise figure of 1.5 dB and a minimum OP1dB of +21 dB. This amplifier operates on +8 VDC and has a maximum current draw of 380 mA.

Planar Monolithics Industries
www.pmi-rf.com

Sources

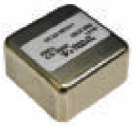
Compact RF Signal Generator



DS Instruments introduced the SG6000L, a small, compact but full featured RF signal generator that covers the 25 MHz to 6 GHz band. An optional doubler extends coverage to 12 GHz. The SG6000 maximum output level is above +6 dBm across all its bands. The SG6000L is fully synthesized to a 10 MHz reference using modern fractional N methods. External or internal 10 MHz reference is supported. The SG functions of frequency and level can be programmed over the USB port using industry standard SCPI commands.

DS Instruments
www.dsinstruments.com.

Low Profile Precision OCXO



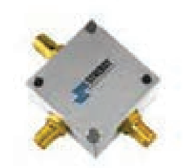
Morion's low profile precision OCXO MV317 is available with a frequency range from 80 to 122.88 MHz. With a package size of 25 × 25 × 10.3 mm, it guarantees stability level vs. operating temperature range up to 5E-8 and aging up to 1E-7/year. The MV317 offers highly improved phase noise

NewProducts

levels better than: -135 dB/Hz at 100 Hz, -162 dB/Hz at 1 kHz, and -176 dB/Hz at 100 kHz for 100 MHz output. It is available with SIN output, 12 V voltage supply and sub-harmonics < -40 dBc.

Morion US LLC
www.morion-us.com

C-Band Connectorized VCO



KDCO615712-5 is an optimized fundamental frequency planar resonator oscillator designed to operate in the C-Band frequency range of 6150 to 7120 MHz with just 0.5 to 12 V of tuning. The 5 V supply voltage (Vcc) draws only a maximum current of 22 mA and 0.11 W, while achieving a superb typical low phase noise of -106 dBc/Hz at 100 kHz offset. The output power is -5 dBm minimum with excellent harmonic suppression of 25 dB typical.

Synergy Microwave Corp.
www.synergymwave.com

Software

PAM-4 Analysis Software

VENDORVIEW

Keysight Technologies Inc. introduced measurement software designed to help engineers quickly and accurately characterize PAM-4 (pulse amplitude modulation with four amplitude levels) signals using the Keysight V-Series, Z-Series, and S-Series real time oscilloscope platforms. The Keysight N8827A PAM-4 analysis software (for V- and Z-Series oscilloscopes) and N8827B PAM-4 analysis software (for S-Series oscilloscopes) provides comprehensive analysis of electrical PAM-4 signals. Mobile computing applications are demanding more of the underlying computer Internet infrastructure. To enable increases in Internet and server-farm performance, higher-speed connectivity among server systems is required.

Keysight Technologies Inc.
www.keysight.com

Test Equipment

YIG Tuning Current Supply

Black Box Instruments has introduced a low noise precision current supply specifically tailored for tuning YIG devices. The instrument outperforms any of the legacy instruments that are no longer available today. The instrument is a “black box” in the sense it is solely controlled via a USB interface. Multiple “front panels” are realized through a PC controller. The instrument comes with free LabView programs to get the user started.

Black Box Instruments
www. blackboxinst.com

V-Band Frequency Extender

VENDORVIEW

Model STE-KF415-14-S1 is a bench-top V-Band frequency extender, which extends the input frequency 12.5 to 18.75 GHz to full waveguide bandwidth, 50 to 75 GHz, operation. The frequency extender combines high performance millimeter passive/active multipliers, amplifiers, filters and Faraday isolator to extend the low frequency sweeper or synthesizer to V-Band frequency band. The required input power is +3 dBm and resultant output power is +14 dBm typically. The DC input is +8 to 12 VDC/550 mA.

SAGE Millimeter Inc.
www.sagemillimeter.com

MICRO-ADS

White Space Communication Technologies

Nuno Borges Carvalho, Alessandro Cidronali and Roberto Gómez-García

The term "white space" refers to chunks of frequency spectrum that are licensed for certain services, yet aren't being used. For example, a frequency band licensed nationally for a TV channel may not be used in certain geographic regions. Rather than let these frequencies go unused when the demand for bandwidth seems insatiable, other services could use the spectrum if they don't interfere. This is the concept of white space communication. Moving from the idea to successfully deployed systems requires "cognitive" radios that sense spectrum usage in real-time and adapt their transmissions to the white spaces.

"White Space Communication Technologies" addresses the analog and digital radio technologies required to enable cognitive radios. The book begins with the regulations in Europe and the U.S. that allow the use of white spaces and presents various applications that could utilize the capability. These include mobile communications, smart metering of utilities and broadband services in rural areas. This first section discusses how to determine spectrum usage and availability – the crux of ensuring that transmissions don't interfere with existing licensees and services. The section concludes with the features and challenges for a radio to be cognitive (i.e., wide bandwidth, frequency agility, high dynamic range, high linearity, high efficiency and spectrum sensing) and describes the resulting approaches and trade-offs for the receiver front-end of the radio.

Having set the stage, the second and third parts of the book delve into the details of adaptive receivers and transceivers. Receiver topics include reconfigurable RF front-ends, filtering and subsampling. Chapters in the transceiver section cover FPGA-based, all-digital transmitters and highly efficient transmitter architectures.

The editors of "White Space Communication Technologies" are professors at universities in Portugal, Italy and Spain. Adding to their own perspectives, they recruited 21 experts from academia and industry (Analog Devices and Intel) to ensure a comprehensive treatment of the topic.

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- Aperture Design
- Signal Processing for Arrays
- Array Measurements
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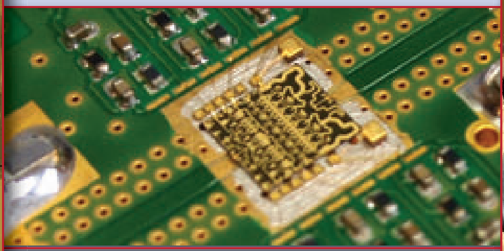

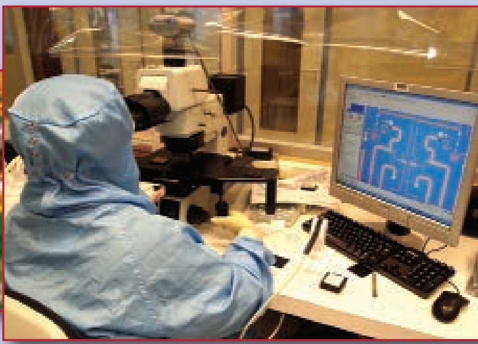

Based close to open countryside on the outskirts of Paris, conversations at OMMIC are undertaken in French but for 35 years the company has endeavoured to speak its customers' language and use its background in III-V materials, design and processing to provide innovative solutions.

Founded in January 2000 by Philips, OMMIC is an independent SME that supplies MMIC circuits, foundry services and epitaxial wafers based on III-V (GaAs, GaN and InP) materials for telecommunication, space and defense applications.

OMMIC's portfolio of MMICs, includes LNAs from 5 to 160 GHz and power amplifiers from 8 to 46 GHz as well as corechips and control functions. Corechips are based on the integration in a single die of digital phase shifters, digital attenuators, LNAs, MPAs and switches for phased array antenna applications.

In 2015 OMMIC began providing fully plastic QFN corechips in C-Band to large radar companies and at the end of the year will release X-Band corechips packaged in plastic QFN offering better integration. The company also proposes a full solution for 94 GHz radar and passive imaging including a matched zero bias diode detector RTID.

OMMIC supplies InP, GaN and GaAs based MMIC circuits and services to the telecom, space and defense markets and MOCVD based epitaxial wafers to the commercial market. On-site epitaxy serves high-performance low-cost PHEMT, MHEMT and HBT epitaxial wafer supply to large volume GaAs fabs.

The company has three principal HEMT processes in full production and has been introducing other processes including MHEMT and HBT. These services enable cut-off frequencies as high as 400 GHz via the MHEMT technology. The latest processes include 100 nm GaN-on-silicon. Another newly released process is D025PHS which is a 250 nm PHEMT D mode, enabling high power from C to X-Band (12 W at 10 GHz).

OMMIC also supplies epitaxial wafers to the commercial market in 3, 4 and 6-inch formats using production MOVPE. This activity includes PHEMT containing up to 25 percent Indium in the GaInAs layer as well as HBT structures.

The company has an aggressive roadmap to develop and introduce advanced technologies based on III-V compounds. This means moving to shorter gate lengths, optimizing the channel Indium content for the PHEMT and MHEMT processes, smaller emitters and using antimonides for the InP DHBT.

The short gate length technologies include 70 nm 70 percent In MHEMTs, soon to be followed by 40 nm with the D004IH process. With the 100 nm GaN/Si and D025PHS process OMMIC is targeting power applications from X to E-Band. The roadmap will lead to the development of sub 60 and 40 nm GaN/Si(C) to target greater power at W-Band and higher frequencies.

Currently, the company has started first runs of D01GH 100 nm GaN on Si and the first pizza mask (MPW) will be launched in June 2015. This process is not only dedicated to Ku to E-Band power amplifier design but also for robust LNAs. At the end of 2015 a Satcom HPA (27 to 32 GHz Psat>8 W) will be released using this 3.3 W/mm GaN process.

Clearly, OMMIC's activities are impressive in any language.

2015
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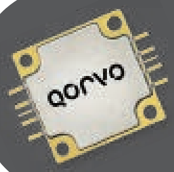
Qorvo Delivers Breakthrough Performance with Broadband GaN Solutions



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TGA2573-2 2-18GHz 8W	2-18GHz	2-18GHz 120W
TGA2590-CP 6-12GHz 30W	6-12GHz	6-12GHz 450W
TGA2574 6-18GHz 20W	6-18GHz	6-18GHz 300W
	32-38GHz	32-38GHz 100W

Qorvo offers the combined Gallium Nitride (GaN) portfolio and expertise from TriQuint and RFMD – two industry leaders in GaN technology. Qorvo is a **Manufacturing Readiness Level (MRL) 9** GaN manufacturer and a **DoD accredited "Microelectronics Trusted Source"** with platforms deployed in ground and airborne environments for electronic warfare, communications, radar and metrology applications. A broad portfolio of GaN processes and long-established expertise with GaN and GaAs power solutions enables Qorvo to offer many world-class / high-performance "off the shelf" power amplifier MMICs.

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Images Courtesy of Jamie Hunter / Aviacom & Northrop Grumman

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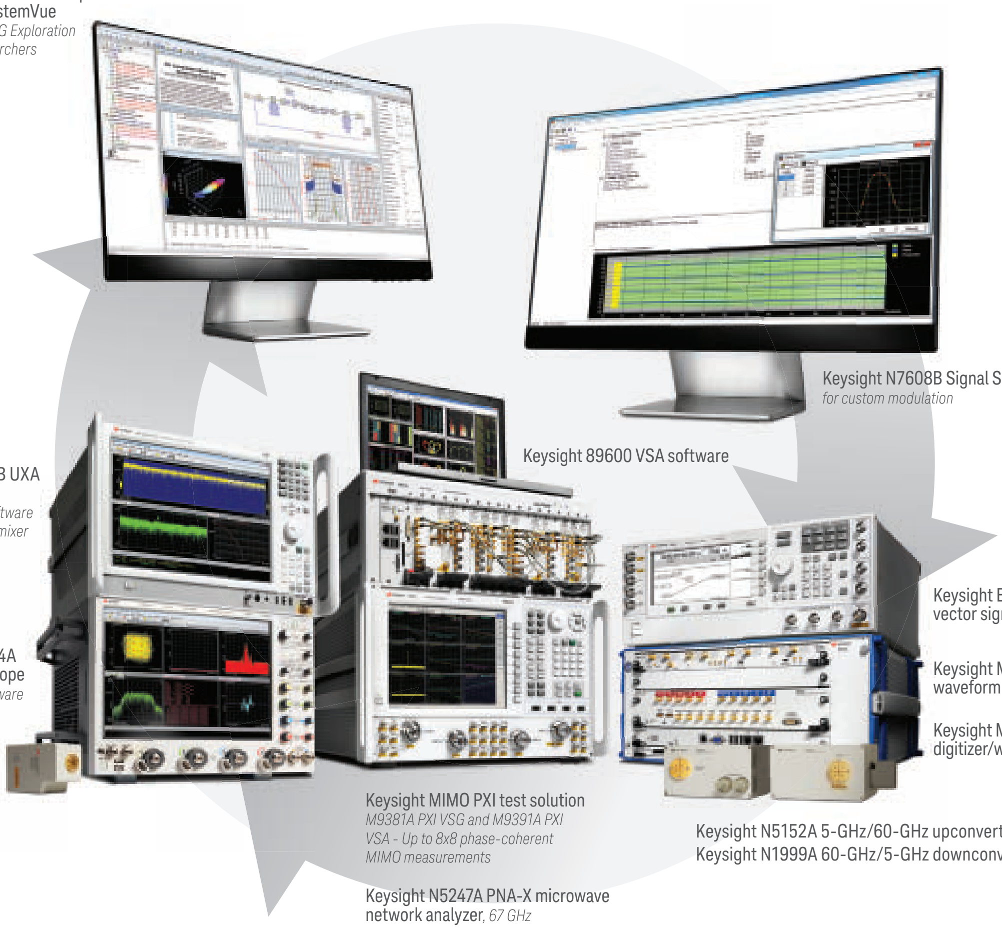

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Early Returns: U.S. Export Control Reform Positive

Gary Lerude
Microwave Journal ***Technical Editor***

For decades, U.S. export control regulations have been a target of frustration for industry and government, both within and outside the country. The frustration led to episodic discussions by presidential administrations of reforming the system, followed by little action. Those whose careers have taken them to foreign shores to sell U.S. electronics have encountered exasperated if not furious customers promising never to buy another component requiring a U.S. export license. Others who have engaged the Departments of State or Commerce seeking a license — often beginning with the question of which agency had jurisdiction for a product — can likely tell stories of Kafkaesque experiences with ITAR, commodity jurisdictions, EAR99, end use and dual use.

Those who have experienced this history might find the "export control reform" that ushered in 2015 hard to believe, even miraculous. Yet, teams from the Departments of Defense, State and Commerce have patiently and steadfastly fashioned a major and encouraging reform.

GENESIS

April 20, 2010. U.S. Secretary of Defense Robert Gates stood before the 400-member Business Executives for National Security (BENS) and outlined his vision for export control reform,[1] one piece of his broader mission to "adapt and reform America's national security apparatus." Gates wasn't acting alone. The prior August, President Barack Obama made export control reform one of the initiatives of his administration.

Saying that the U.S. had one of the most stringent export control regimes in the world, Gates added "stringent is not the same as effective." He said that what was being controlled with the existing policy was too broad, quoting Frederick the Great that "he who defends everything defends nothing." The multi-agency bureaucracy for export control that was created to provide checks and balances was inefficient. Which agency had the authority and jurisdiction for a particular license was often confusing, both to exporters and government officials. Perhaps the worst issue was the friction the system caused with U.S. allies. "Finally, the current export control regime impedes the effectiveness of our closest military allies, tests their patience and goodwill, and hinders their ability to cooperate with U.S. Forces," Gates said.

He was preaching to the choir. The audience knew the issues. They wanted to hear what he would do to fix the problems. The solution the Secretary of Defense outlined had been agreed upon by his counterparts at State, Commerce and Homeland Security as well as the Director of National Intelligence and the National Security Advisor. Although it would also require congressional action, presumably the heads of these agencies could make it happen — unlike

the initiatives under previous administrations.

The ultimate export control reform objective articulated by Secretary Gates that day had four elements: creating a single export control list, using a single information technology (IT) system, issuing licenses through a single agency and coordinating enforcement through a single agency. In Gates' view, "A single export control list will make it clear to U.S. companies which items require licenses for export and which do not." He added that the single licensing agency "which will have jurisdiction over both munitions and dual-use items and technologies, will streamline the review process and ensure that export decisions are consistent and made on the real capabilities of the technology. This single entity would also reduce exporters' current confusion over where and how to submit export license applications, as well as which technologies and items are likely to be approved."

Gates said the process of export control reform would occur in three phases. Acting within its existing authority, the Executive branch would begin the transition to a single control list and licensing agency. Completing the effort would require legislation by Congress, which would be the third phase. The middle step would implement the single IT system to support the unified export control list and licensing system. While the vision of a single list and agency is not yet reality, significant change is occurring within the existing structure.

EXPORT 101

Prior to reform, a company wishing to export a product (or service or technical data) first classified it as either 1) defense or 2) commercial or "dual-use." The defense category captured products designed or modified for a military system or application, like the F-35 fighter. These "defense articles" were identified on the United States Munitions List (USML). The second category encompassed products developed for purely commercial markets, such as mobile phones, or products that could be used in either military or commercial applications (dual-use). A transistor is one example of a dual-use product.

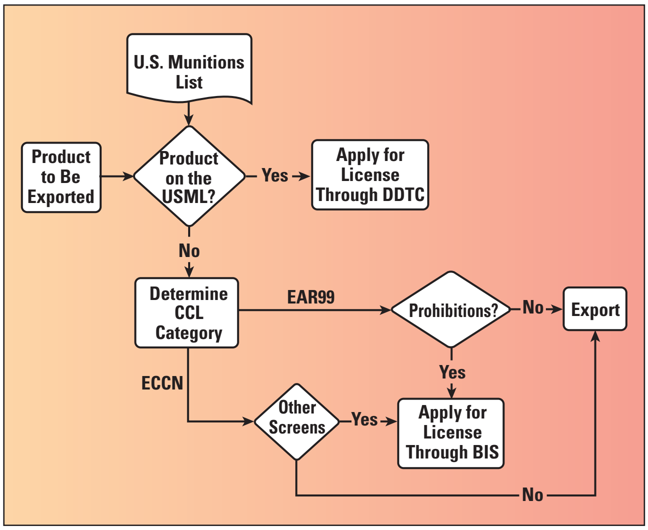

Fig. 1 Export license decision tree, prior to export reform.

The export of defense articles required a license issued by the Directorate of Defense Trade Controls (DDTC) of the Department of State and governed by the International Traffic in Arms Regulations (ITAR). The export of commercial and dual-use products was governed by the Bureau of Industry and Security (BIS), part of the Department of Commerce, per the Export Administration Regulations (EAR). BIS maintained a Commerce Control List (CCL) of products that, along with the purchaser and destination country, determined if the product could be exported and, if so, whether an export license was required.

Figure 1 shows the process a company would follow to determine whether a license was required to export a product. Confused? If so, companies could request a Commodity Jurisdiction (CJ) from the DDTC, which would determine if the product fell on the USML and was subject to ITAR. After ruling out the USML, a company could request a commodity classification from BIS, which would determine whether the product was governed by the EAR and then its Export Control Classification Number (ECCN). However, BIS could not say whether an item was on the USML.

More frustrating than the uncertainty of which agency had jurisdiction for a product was the inflexibility of the ITAR. The regulations treated the components of a system the same as the system. Exporting a bolt designed for a fighter was controlled essentially the same as the fighter. While the likelihood of getting an export license for a bolt would presumably be greater, the process was the same. This flood of licenses clogged the system, consuming resources that should have been focused on licenses truly important to national defense.

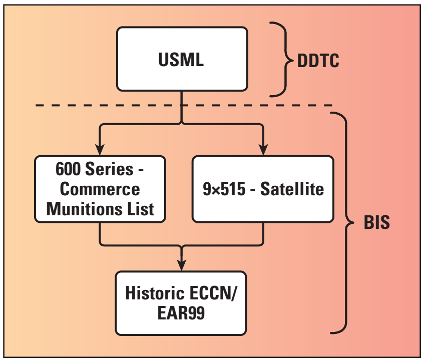

Fig. 2 Export license decision hierarchy following export reform.

The first step to reform the export licensing system has been to pare the USML to only the defense articles that are deemed most important to U.S. national security. DDTC retains responsibility for issuing the export licenses for these items. Not-as-critical defense items have been transferred to BIS and categorized on a newly created group of export control numbers called the "600 series" on the CCL (and 9×515 for satellite items). BIS is responsible for issuing licenses for these transferred items. ***Figure 2*** illustrates the control hierarchy post reform.

The USML comprises 21 categories, spanning ammunition to ships, directed energy weapons to toxicological agents.[2] By the end of last year, 15 of the 21 had been revised to move the not-as-critical items to the CCL. Two of the categories on the USML are relevant to the RF/microwave industry, and both have been updated: military electronics (category XI) and spacecraft and related articles (cat-


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egory XV). In paring the USML to just the defense articles that provide the United States with a critical military or intelligence advantage, the lists contain specific products and avoid, with some exceptions, "catch all" phrases.

The revised military electronics category identifies systems such as radar; electronic combat; command, control and communications; direction finding equipment; and equipment specially designed to test these systems. Below the system level, the USML logically captures application specific integrated circuits (ASIC) and programmable logic devices (PLD) that are programmed for these systems as well as printed circuit boards and multi-chip modules where the layout is "specially designed" for the system.

The list also identifies a few RF components as defense articles:

- Circulators where the isolation is greater than 30 dB and any dimension is a quarter-wavelength or smaller at the highest operating frequency
- Transmit or transmit/receive (T/R) modules that incorporate monolithic microwave integrated circuits (MMIC) or discrete RF power transistors, have electronically variable phase and a size small enough to enable a phased array
- Digital radio frequency memory (DRFM) with better than 400 MHz instantaneous bandwidth and four bits or greater resolution
- Certain vacuum electronics devices with multiple or sheet electron beams or cross-field amplifiers.

The revision includes a provision that "developmental electronic equipment or systems funded by the Department of Defense" will be on the USML beginning July 1, 2015. There are a couple of exceptions to this: if the contract identifies the product as "being developed for both civil and military applications" or a CJ determines that the EAR governs the product.

In category XV, pertaining to satellites and spacecraft, only two space-qualified components remain on the USML:

- Certain MMICs that integrate a T/R module on a single die and
- Low phase noise oscillators for space-based radar.

MMICs AND DISCRETE MICROWAVE TRANSISTORS

Exporting MMIC power amplifiers and microwave power transistors has long been a concern to the Department of Defense (DoD). In the 1980s and '90s, the DoD funded the early development of GaAs MMICs as an enabling technology for active phased array radar. DoD also invested in gallium nitride (GaN) to achieve even higher power than available with GaAs. Active phased arrays have revolutionized radar; they provide a strategic military advantage, and, understandably, the DoD wants to retain U.S. technology leadership. Restricting exports has been a bulwark of their strategy. U.S. industry and the DoD have long debated the best way to protect national security interests while not hindering the industry's competitiveness in global commercial markets. Commercial markets for MMICs dwarf military applications, and GaAs and GaN process technology are found worldwide, in Europe, Japan, Taiwan and mainland China. Where to draw that line has been an interesting eddy in the wider current of export control reform.

To govern commercial and dual-use products, the EAR has categories for "microwave monolithic integrated circuits" (3A001.b.2) and "discrete microwave transistors" (3A001.b.3). Historically, the requirement for an export license from BIS was determined by the operating frequency and average output power. Average power proved to be confusing, as the application (e.g., pulsed or continuous wave) really determined the average power, not the device.

During 2012 and 2013, BIS solicited industry feedback on a proposal to change from average to "peak saturated power." They also subdivided the prior frequency range into more bands covering 2.7 to above 90 GHz. These revisions were proposed to the Wassenaar Arrangement, a consortium of 41 nations that harmonize export controls.[3] In December 2013, the Wassenaar Arrangement formally adopted and incorporated these changes to their list of dual-use goods and technologies.

As the same changes were working their way through the U.S. bureaucracy to be incorporated in the EAR, a multi-agency team was developing the criteria for the new 600 series control for military electronics – ECCN 3A611 – that would result from revisions to the USML. The team added efficiency to the usual parameters of power, frequency and bandwidth to define which devices would fall on the Commerce munitions list. Assuming military applications demand higher efficiency, efficiency would be a clear differentiator to protect critical technology. The proposed thresholds for MMICs (ECCN 3A611.c) and microwave power transistors (3A611.d) were issued on July 1, 2014 and scheduled for implementation on December 30, 2014.

The 3A611 proposal was viewed with alarm by several MMIC suppliers and at least one commercial telecommunications system manufacturer. In response, representatives from several U.S. companies gathered in Washington to meet with government officials from BIS, DDTC, the Defense Technology Security Administration (DTSA), and other DoD organizations on August 15, 2014. The forum hosted by BIS allowed industry to provide feedback on the proposed 3A611 criteria. The industry group said that the efficiency requirements of commercial applications are often as great — even greater — than those of military systems. Further, they explained that efficiency is a nebulous specification, with multiple definitions and values that vary with how the device is biased and driven. If the new 3A611 guidelines were implemented, industry argued that exports for bona fide civil applications would be required to follow the more stringent licensing requirements. Cellular and WiMAX base stations, point-to-point radio for backhaul, satellite ground terminals, test equipment for communications and civilian radar were cited as markets that would be adversely impacted. One semiconductor company said that 39 products that previously did not require a license (i.e., classified as EAR99) would require licenses. All 39 of the products were sold internationally to commercial customers, some for more than a de-

cade. The system manufacturer said the lack of a de minimis provision in 3A611 would force a redesign to use non U.S. MMIC suppliers. The government team asked each company to provide data on the specific products and associated revenue that would be affected, allowing them to understand the economic impact.

On December 23, just a week before the 3A611 categories for MMICs and microwave power transistors were to become effective, BIS published a final rule in the Federal Register that eliminated 3A611.c and .d. The ruling stated "BIS did not adopt changes to the control based on fractional bandwidth, peak saturated power output, and/or power added efficiency because the agency found that attempting to designate some MMIC power amplifiers and discrete microwave transistors as civil and others as military based on those characteristics is impractical, and any resulting classification would not accurately reflect real world applications for those devices."

However, the final rule added "national security" and "regional stability" controls to the existing 3A001.b.2 and b.3 ECCNs, except for civil telecommunications applications. This restricts the license exceptions for MMICs and discrete microwave transistors that are being exported for applications other than civil telecommunications. As explained in the ruling "These actions will allow the U.S. Government to examine in advance the exports and reexports of MMIC power amplifiers and discrete microwave transistors that pose the greatest risk of diversion or enhancement of potential adversaries' military capabilities without imposing unnecessary licensing requirements on low risk transactions."

Table 1 summarizes the performance thresholds for MMICs that require an export license (ECCN 3A001.b.2). ***Table 2*** contains the same information for discrete microwave transistors (ECCN 3A001.b.3). Both tables are taken from the CCL as of December 30, 2014.

TABLE 1

3A001.b.2 MMIC OUTPUT POWER AND BANDWIDTH THRESHOLDS

Frequency Band (GHz)	*Peak Saturated Output Power Greater Than*	*Fractional Bandwidth Greater Than (%)*
2.7 to 2.9	75 W	15
2.9 to 3.2	55 W	15
3.2 to 3.7	40 W	15
3.7 to 6.8	20 W	15
6.8 to 8.5	10 W	10
8.5 to 16	5 W	10
16 to 31.8	3 W	10
31.8 to 37	0.1 nW	
37 to 43.5	1 W	10
43.5 to 75	31.62 mW	10
75 to 90	10 mW	5
Above 90	0.1 nW	

FRIENDLY LICENSING OFFICERS

Kevin Wolf is the Assistant Secretary of Commerce for Export Administration (see ***Figure 3***). He joined the Obama administration after spending 17 years with a Washington law firm that focused on export cases. Sworn in two months before Robert Gates spoke at the BENS conference, Wolf became the regulator and the export control reform champion at BIS.

As he has done dozens of times since 2010, Wolf rattles off the list of benefits spawned by export reform. "Commerce allows license exceptions," he begins, the biggest being provisions associated with the 36 strategic trade authorization (STA) countries. These include replacement parts, limited value shipments and temporary exports. Unlike ITAR, the EAR has a de minimis provision that allows exports where the value of the product is less than 25 percent of the total value of the end equipment, so long as the ultimate end use is not in an embargoed country. BIS doesn't require separate licenses for manufacturing, technical assistance agreements or proposals. Congressional reporting, registration and import are all simpler, and BIS doesn't charge for licenses. He concludes that Commerce is very flexible, meaning they can tailor licenses, and adds "we have very friendly licensing officers."

Although it's early in the process, Wolf is pleased with the initial results. DDTC is seeing a significant reduction in license applications and CJs, "especially for lower-level items." That's the

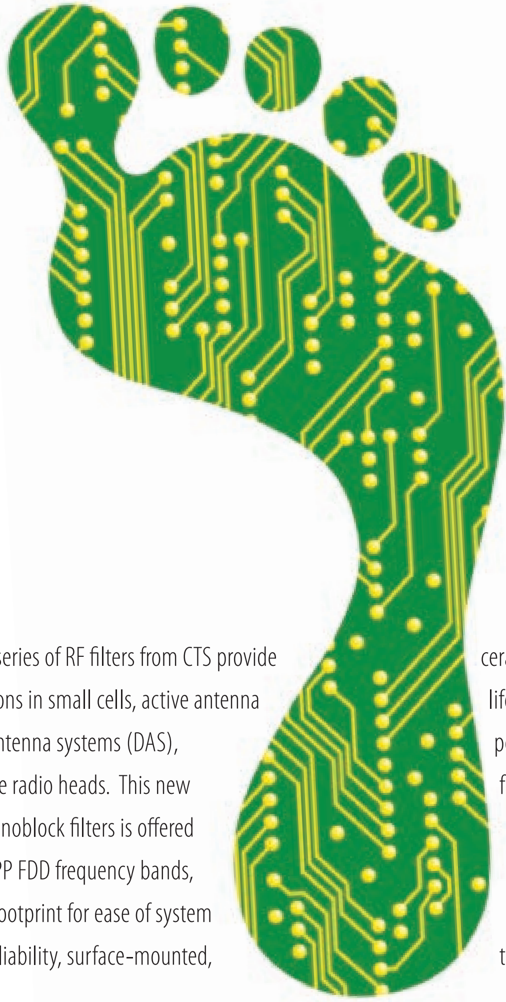
TABLE 2

3A001.b.3 DISCRETE MICROWAVE TRANSISTOR OUTPUT POWER THRESHOLDS

Frequency Band (GHz)	*Peak Saturated Output Power Greater Than*
2.7 to 2.9	400 W
2.9 to 3.2	205 W
3.2 to 3.7	115 W
3.7 to 6.8	60 W
6.8 to 8.5	50 W
8.5 to 12	15 W
12 to 16	40 W
16 to 31.8	7 W
31.8 to 37	0.5 W
37 to 43.5	1 W
Above 43.5	0.1 nW

▲ *Fig. 3 Kevin Wolf, Assistant Secretary of Commerce for Export Administration.*

Universal Footprint RF Duplexers



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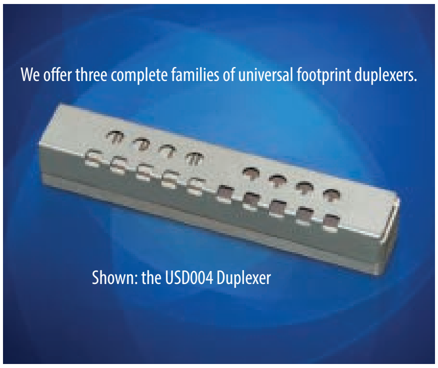

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Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
Operating Temp Range	-40 to +85°C	-40 to +85°C	-40 to +85°C

* Note: "Difficult" bands may have 2dB lower worst case Rx band isolation.

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intent. Although they hoped to have purely objective criteria for each of the products, it wasn't possible with MMICs. They recognized that efficiency was not an effective discriminator between commercial and military so adopted an end-use definition, carving out civil telecommunications to minimize the adverse impact on industry. Even so, Wolf is "very grateful for the clarity," which is better than before.

The view from industry is similar to Kevin Wolf's. James Klein (see ***Figure 4***) is president of the Infrastructure and Defense Products (IDP) business of Qorvo, the combination of TriQuint's IDP business unit and RFMD's Multi-Market Products Group (MPG). Qorvo is likely the largest RF/microwave semiconductor supplier with a portfolio in both defense and commercial markets.

▲ *Fig. 4 James Klein, president of the Infrastructure and Defense Products business at Qorvo.*

TriQuint's Richardson, Texas facility is a "trusted source," first accredited by DoD in 2008, and the company's GaN technology has been developed with significant R&D funding from DoD. Qorvo is also a major supplier of MMICs for base station, point-to-point radio and optical markets.

Export control reform has been positive, according to Klein, although the change just occurred at the beginning of 2015. They saw 37 products move from the 3A001 classification to EAR99, due to the change from average to peak power; a few moved the other way. They are still learning about the Commerce licensing process for products that are not classified as civil telecommunications, such as automotive radar. He feels it's premature to judge whether the changes will increase their international defense business. "It's too early to tell." If he has a concern, it's that the initial rollout has been a little conservative, meaning the export thresholds don't recognize the fast-moving trends in the commercial markets that push frequencies and power levels higher. As examples he notes LTE-Advanced and 5G, the latter moving to adopt millimeter wave spectrum for very high data rate links.

Klein sees Qorvo's responsibility as helping government officials keep up to date with the market and international suppliers. "Qorvo has a broad portfolio of products, serving a wide range of commercial and defense-related markets. The new export regulations have been positive for products that are applicable to the civil tele-


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communications industry, which is a very important market for us. We will continue to work with the Department of Commerce to understand how the new rules are applied for defense and aerospace, and we are hopeful that we will see improvements in licensing speed and availability for that market segment going forward."

Speaking unofficially, because he was not authorized to speak for his company, an executive with a manufacturer of vacuum electronics products sees the changes in export control as "overall positive." Their non-classified defense products have moved from the USML to the 600 series category governed by BIS. "ITAR was a hazy, gray area subject to interpretation. It's more predictable now, and I'm feeling much more comfortable." The change has opened up their sales process, since they can submit most proposals under a license exception. "I'm loving that aspect of it," he says. However he is concerned with the stipulation in the USML that products developed with government funding could be ITAR controlled. That may cause them to avoid some government development programs.

Everyone agrees that it's too early to judge the success of the changes, despite the initial positive signs. In another year companies and government regulators will have considerable experience to judge what is working well, where the bottlenecks lie and further changes that are warranted. Kevin Wolf says the government's mantra with export control reform has been "flexibility, adaptability and transparency," and he encourages industry to communicate with the agencies.

Speaking at the annual BIS export conference held in July 2014, Wolf reflected on the progress since the administration committed to export reform. "This is all moving us closer to one of my personal goals for the limited time I have in government, which is that the export control agencies think of themselves as part of one system, one administration, bound by the rules, but willing and able to change those rules in a transparent, regularized process as foreign policy and national security considerations change, and as technology evolves."[5] ■

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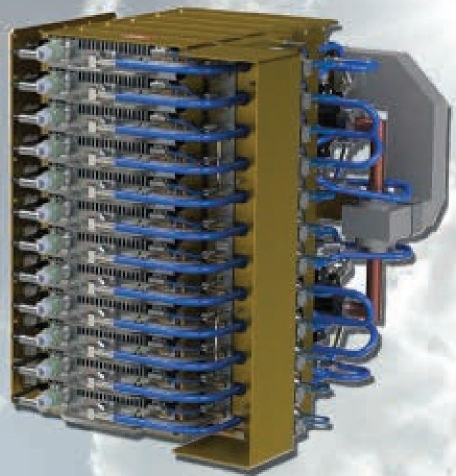
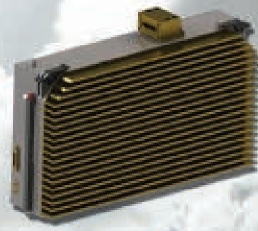
Editor's Note: Share your experiences with export control reform. You may leave comments at the online version of the article, www.microwavejournal.com/exportcontrolreform.

Solid State Power Amplifiers

S-Band





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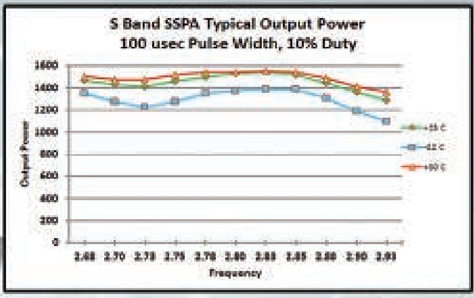

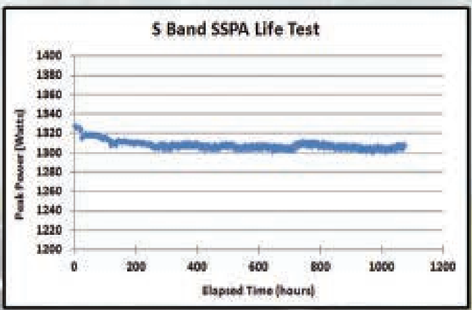

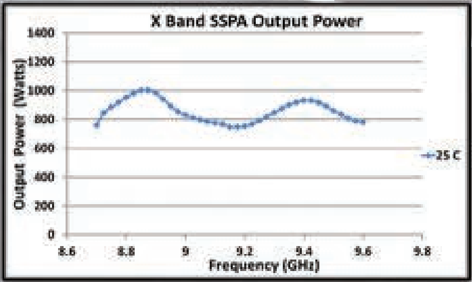

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INVITED PAPER

A&D Test & Measurement Trends

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With shrinking defense budgets and smaller military forces relying on greater technological capabilities, the push is stronger than ever to do more with less while at the same time meeting unprecedented performance and reliability requirements. In response to these pressures, test tools must provide greater ease of use, lower test costs and perhaps most importantly, cutting edge performance.

The aerospace and defense (A&D) environment can be broken up in several ways. When discussing test and measurement equipment it is best to divide it into separate functional areas as shown in ***Figure 1***. Common technologies include, but aren't limited to, array antennas, multi-function systems, mixed-signal processing and mmWave.

ADVANCED CAPABILITIES NEEDED FROM TEST EQUIPMENT

The development of new and advanced EW, radar and communications systems drives requirements for performance and usability of signal simulation and analysis equipment. Test systems must employ wider bandwidth signals and move acquired or stored RF signal data from one instrument or storage element to another in a real time environment. Data transfer rates on the order of 10 GB/s (equivalent to about 2 GHz RF bandwidth) are required. High speed (to real time) reduction and analysis of massive data streams within the instrument is a common need. This must be accomplished in the FPGA, DSP or GPU; the instrument controller can no longer be relied upon. Operations include digital up- and down-conversion, simultaneous high resolution time and frequency display and real time signal generation from acquired raw data or data generated algorithmically for playback.

Many technologies including radar, EW and SIGINT are moving to multiple distributed apertures for higher performance and more capability. Multi-aperture, multi-function systems require multiple, coherent RF channels for signal generation and analysis.

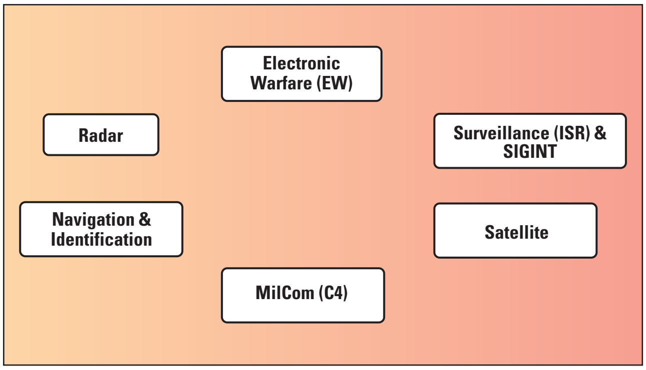
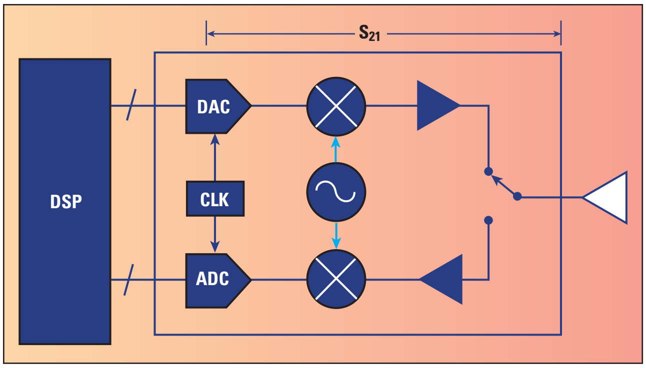


Fig. 1 A&D applications for test and measurement.

TESTING ARRAY ANTENNAS AND TRANSMIT/RECEIVE MODULES (TRM)

In radar and EW systems the use of active electronically scanned array (AESA) antennas has become nearly ubiquitous for their many advantages. They enable operation in multiple modes to engage several targets simultaneously and take advantage of powerful signal

processing capabilities for threat discrimination. Because the beam can be formed and steered electronically, no gimbal is required, permitting agile beam repositioning at extremely high rates.

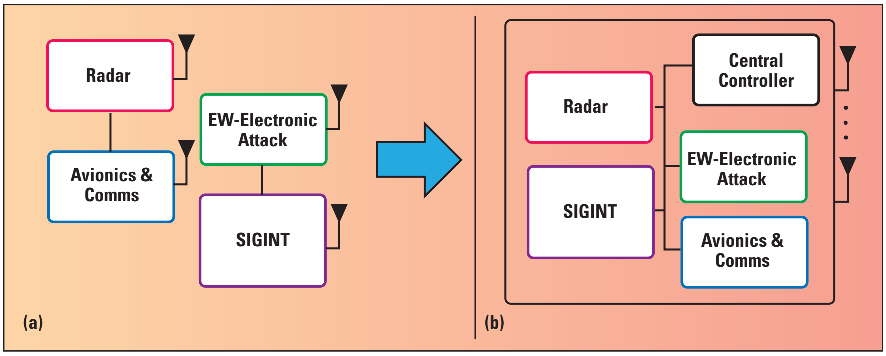


▲ *Fig. 2 T/R module concept for digital array radar.*

For satellite applications, rapid electronic repositioning of the antenna beam or the use of multiple beams permits a single AESA to communicate with multiple spatially distributed ground stations. Distributed TRMs provide an architecture tolerant to failure, providing high reliability in a harsh environment. Also, the antenna can be located on the surface of a spacecraft to avoid physical deployment.

A concept gaining favor for reducing AESA characterization time is using a wider bandwidth signal than is typically available with a traditional network analyzer. With a wideband signal, a group of frequency states is tested at one time, and the wide bandwidth stimulus more closely matches device or system operating conditions.

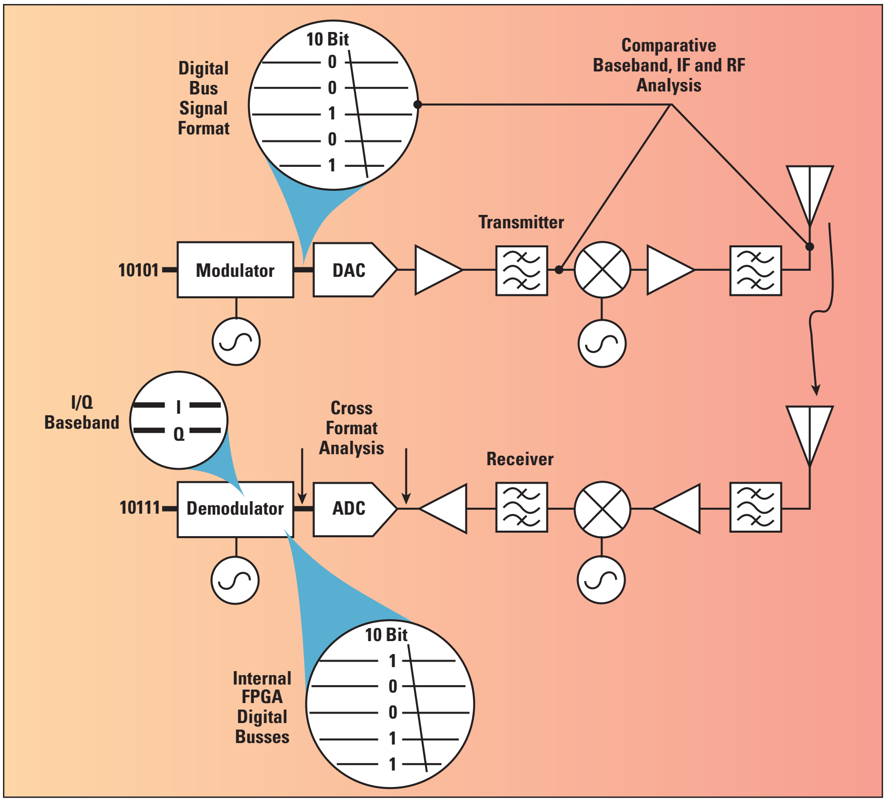
Digital broadband signal processing is moving closer to the antenna, creating a digital array radar (DAR), where the only connection to the TRM is a digital bus (see ***Figure 2***). It poses a new and unique problem when one side of a network is comprised of several lanes of digital data representing what began as an analog signal on the other side. A new methodology is needed to measure network response parameters. Parameters like true time delay might be extracted from the DSP rather than from analog measurements of phase and amplitude. Digital interconnects and serializer/deserializer links add their own distortion and latency that must be characterized.



▲ *Fig. 3 Systems that have historically operated independently (a) are more integrated (b).*

NEED FOR SOFTWARE DEFINED TEST SYSTEMS

A&D system architectures are becoming more integrated (see ***Figure 3***), sharing physical resources such as antennas and processors to reduce size, weight and power (SWaP) as well as sharing information to make better and more timely decisions, such as how to configure in a given environment or react to a specific threat. This, in turn, drives changes in the way these systems are evaluated. Like the systems they assess, test solutions must use common hardware elements, be software and firmware definable and rapidly reconfigured when required.



▲ *Fig. 4 Test challenges with mixed signal implementation.*

MIXED SIGNAL TESTING REQUIRES COMPARATIVE MEASUREMENT

In modern satellite, radar and EW architectures, formats change as the signal passes through the transmitter and receiver. The signal is often represented on time sampled dual I/Q signal busses, which further complicates testing. Diagnosing digital issues requires different test interfaces to different hardware and the probing of I/Q busses with many test connections. Probing is often complicat-

ed when using FPGAs, as many of the desired test points may not be accessible outside of the chip.

As illustrated in ***Figure 4***, cross format analysis is often needed for troubleshooting. For A&D systems, it is frequently necessary to compare an analog signal with the originating digital signal, requiring a cross-domain analysis capability. Comparative analysis can extend well beyond baseband I/Q measurements, continuing through IF and RF frequencies to Ka-Band and higher into the mmWave region.

Vector signal analysis (VSA) software using the same measurement algorithms that can be used with logic analyzers, digital oscilloscopes, and RF signal analyzers is needed to ensure proper comparison of results. This enables the performance of a mixed-signal digital/RF transmitter chain to be probed at various stages, providing the system engineer with insight into which sections of the design are causing issues or contributing the most to transmitter output error vector magnitude (EVM). This can be valuable both to debug and budget system-level transmitter performance.

If FPGAs are used, an FPGA dynamic probe can probe at various stages of the FPGA design using the VSA software with a logic analyzer. The same VSA software can then be used with a digital oscilloscope or RF signal analyzer at points further along the transmit and receive chain.

NEW APPLICATIONS IN mmWAVE

The smaller wavelengths at mmWave frequencies (30 to 300 GHz) enable antenna dimensions to be small compared with microwave antennas, so transmitter and receiver systems can be very compact. Smaller wavelengths also enable higher resolution, particularly for synthetic aperture radar (SAR). With a smaller user base, mmWave bands tend to be much less cluttered than the VHF, UHF and microwave frequency bands. Additionally, large modulation bandwidths can be realized with the current abundance of available spectrum.

In contrast to the advantages offered by mmWave systems, there are also a number of challenges and difficulties. Millimeter wave signals have a poor ability to penetrate materials and are easily blocked. Losses through most propagation mediums, such as the atmosphere, or through transmission lines like coaxial cable or waveguide are very high. Because the physical dimensions decrease, the associated hardware becomes smaller and more fragile. That also means that it is harder to manufacture and machine to the tolerances needed for adequate performance. The combination of these factors, along with the lower volume of mmWave products manufactured, keeps costs high. These challenges are faced by the test equipment industry, as well.

CONCLUSION

Test equipment must adapt and improve to support the applications enabled by advancing A&D system technologies. Flexible, reconfigurable software-defined mixed-signal instrumentation provides a method for controlling test costs through hardware reuse and reduced time to first measurement. ■

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	RUDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	-	✓	$625
	RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	$725
	RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	$695
	RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	$795
NEW	RUDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	-	✓	$895
NEW	RCDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	✓	-	$995
NEW	RUDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	-	✓	$895
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MWJ REVIEW BOARD APPROVED

Efficient Design and Analysis of Airborne Radomes

Gopinath Gampala, Martin Vogel and C. J. Reddy
Altair Engineering Inc., Hampton Va.

Keeping present-day challenges in mind, a complete solution is given for the design and analysis of radomes, from materials characterization through transmission loss analysis, to full 3D radome analysis for calculating radome induced effects. Also discussed is the design and analysis of frequency selective surface (FSS) radomes.

A radome (radar dome) is a structural, weatherproof enclosure that protects a radar system or antenna from its physical environment with minimal impact on the electrical performance of the antenna. Radomes must be radio frequency transparent and therefore constructed of materials that minimally attenuate the electromagnetic signal transmitted or received by the antenna. Selecting a proper radome for a given antenna can improve overall system performance by, for example, maintaining alignment, eliminating wind loading, allowing for all-weather operation and providing shelter for installation and maintenance.[1] Radomes find use in a wide variety of applications like satellite, broadcast, weather, communications, telemetry, tracking, surveillance and radio astronomy. Simulation results are obtained using the commercial 3D electromagnetic simulation software, FEKO.[2]

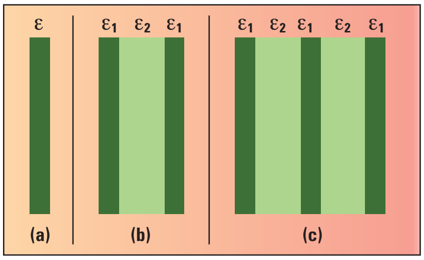
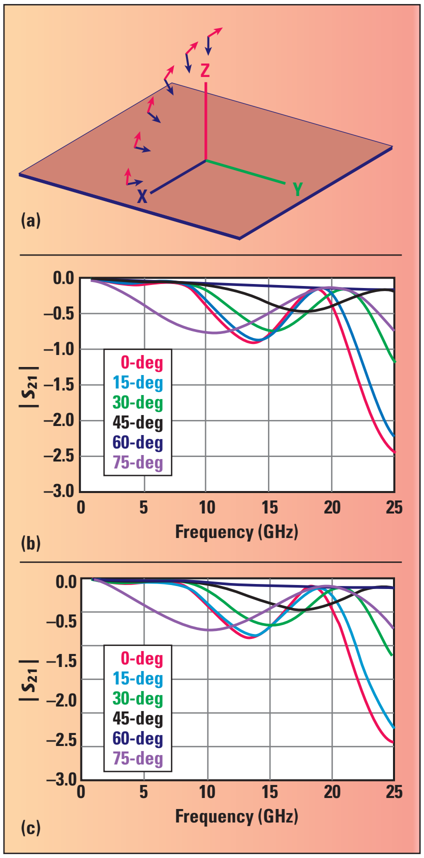


Fig. 1 Monolithic radome wall (a), A-sandwich ($\varepsilon_1 > \varepsilon_2$) or B-sandwich ($\varepsilon_1 < \varepsilon_2$) design (b), multi-layered dielectric wall design (c).

CHARACTERIZING THE RADOME WALL CONFIGURATION

Radomes, on a broad scale, are classified as monolithic and sandwich designs, based on wall construction as shown in ***Figure 1***.[3] There are two types of monolithic designs, half-wave radomes (style-a) and electrically thin-walled radomes (style-b). The sandwich designs can be categorized into A-sandwich (style-c), B-sandwich (style-e) and multi-layered dielectric wall (style-d) radomes. One can also introduce an FSS layer into any of the styles to reduce its out-of-band radar cross section (RCS). The choice of a particular configuration or style depends on the application.

Transmission loss serves as a key design criterion in selecting wall construction materials irrespective of the radome style. The wall construction material can be used to design a radome of any shape, depending on the application, after characterizing transmission loss. There are several different computational electromagnetic (CEM) methods to determine transmission loss of single- and multi-layered dielectric wall configurations, but the most accurate and efficient is the use of planar Green's functions with the Method of Moments (MoM).[4] The perfect alignment of transmission loss data computed using planar Green's functions with published results, as shown in ***Figure 2***, validates the accuracy of this method. Transmission loss data is computed for various incident angles over a broad frequency range for an A-sandwich radome, constructed using 0.0762 cm quartz polycyanate skins (ε_r = 3.23, tan d = 0.016) and a

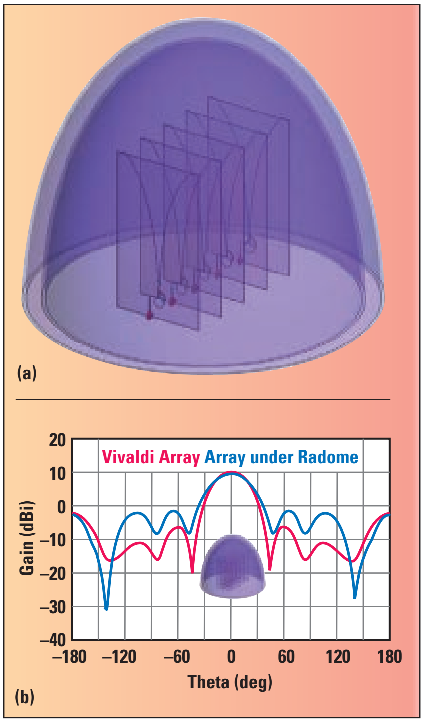


▲ *Fig. 2 Plane wave incident on the planar Green's function layers at various incident angles (a), transmission loss data computed using Planar Green's Functions (b), published transmission loss results[3] (c) for A-sandwich radome.*

1.016 cm phenolic honeycomb core (ε_r = 1.10, tan d = 0.001). The computation time required for these simulations is a nominal 3 seconds, consuming a total of 171 kBytes of memory.

FULL RADOME ANALYSIS

Although transmission loss can be calculated for any incident angle of a planar wall configuration, the shape of the radome introduces other dynamic constraints that change electrical performance. Dissipative losses within the dielectric material, electrical phase shifts introduced by the radome's presence and internal reflections cause insertion loss, increased antenna sidelobe levels and boresight error.[3] It is important, therefore, to analyze radome performance with respect to these additional parameters. The following are various examples of radomes ranging from electrically small to large along with a discussion of CEM methods used for analysis.



▲ *Fig. 3 Vivaldi antenna array under a nose cone shaped A-sandwich radome (a), array patterns with and without the radome at 9.4 GHz (b).*

Modest-Size Radomes

One can use the full-wave CEM solvers like MoM,[5] Finite Element Method (FEM)[6] and Finite Difference Time Domain (FDTD)[7] for the complete analysis of an arbitrary shaped radome. These full-wave solvers are equally accurate but differ in the computational resources consumed. MoM outshines FEM and FDTD for monolithic and A-sandwich radomes because of the small number of dielectric interfaces in these designs and the fact that an air or free-space volume doesn't need to be included. As the number of dielectric interfaces increase with multilayered radomes, FEM being the sparse matrix approximation method, consumes less resources compared to MoM. FDTD has the potential to be the optimal solver for broadband applications, which require solutions over a wide frequency range.

Figure 3 shows a nose cone shaped A-sandwich radome for X-Band applications treated with MoM. The radome profile is built with 0.79732 cm thick skins (ε_r = 4.8, tan d = 0.0002) and a 3.18972 cm thick core (ε_r = 1.3, tan d = 0.001). The radome is modest in size with a base inner radius of 1 wavelength and inner height of 1.75 wavelengths, at 9.4 GHz.

Radome induced effects can be calculated by comparing array patterns with and without the radome. One can readily deduce from Figure 3 that the radome introduces an insertion loss of 0.6 dB. There is no shift in the main beam direction which indicates zero boresight error. The sidelobe levels are increased by 5.4 dB, because the signal blockage from the radome reflects RF energy back and reduces the gain. This reflection and retraction of the RF wave front increases sidelobe levels.

Thin-Walled Radomes

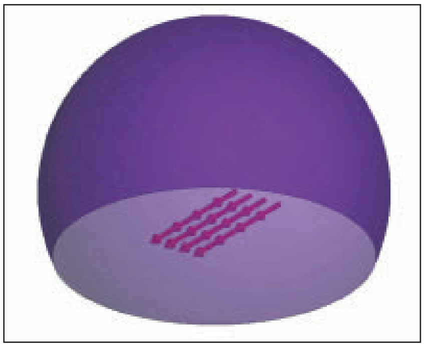
A comprehensive radome analysis that explicitly models the dielectric layers is expected to yield the most accurate results. Unfortunately, modeling the physical layers is nearly impossible in scenarios where the overall thickness is much smaller than a wavelength, because the discretization required for the CEM solvers should be comparable to the thickness. However, one can utilize the special formulations that facilitate the analysis of multiple layers of thin dielectric and anisotropic sheets/layers, referred to as the thin dielectric sheet (TDS) approximation.[4] TDS replaces all the dielectric layers with one equivalent layer treated with a special impedance boundary condition. The TDS formulation can be used in combination with MoM, where the integral equation (MoM solves the electric/magnetic field integral equations to determine the unknown surface currents) is modified to include the surface impedance of the equivalent dielectric layers.

The transmission loss data illustrated in Figure 2 indicates that the A-sandwich configuration should be completely transparent to the RF signal at the lower end of the frequency band. A spherical shell radome is built with the same A-sandwich configuration and analyzed for radome induced effects. ***Figure 4*** shows the radome protecting a dipole array. This radome is treated with the TDS approximation as the overall thickness of the 3-layer radome wall is much smaller than a wavelength at the lower end of the frequency band (more specifically at 2.35 GHz).

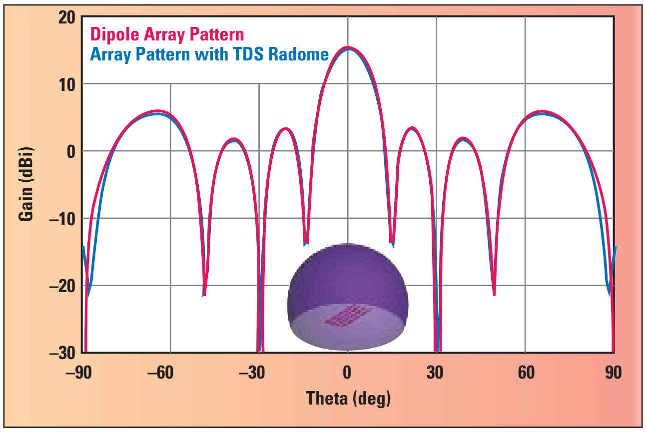
The gain patterns with and without the radome (see ***Figure 5***) demonstrate that the A-sandwich configuration introduces minimal insertion loss, analogous to the data in Figure 2. The gain pattern also indicates negligible boresight error as there is no shift in the main beam direction.

Moderate Size Radomes

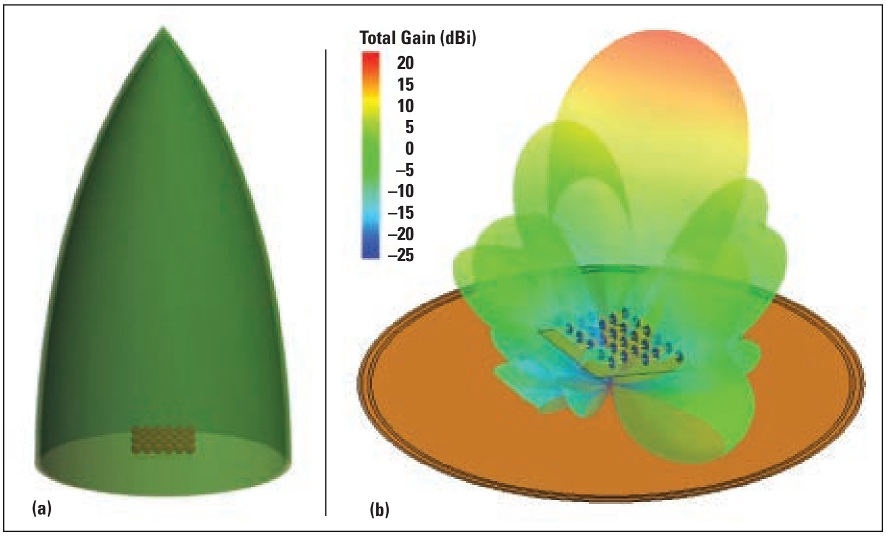
As the electrical size of radomes increase, standard full-wave solvers (e.g., MoM and FEM) require significant computational resources. The multi-level fast multipole method (MLFMM)[8] overcomes this challenge by the accelerating MoM solver with fewer computational resources. MLFMM tremendously reduces the computational resource requirements when applied to geometries measuring multiple wavelengths in size. The most appealing aspect of MLFMM is the preserved accuracy, which is governed by a user-controlled residual. In addition, MLFMM can be hybridized with FEM.



▲ *Fig. 4 Dipole array under the spherical shell A-sandwich radome, treated with TDS approximation.*

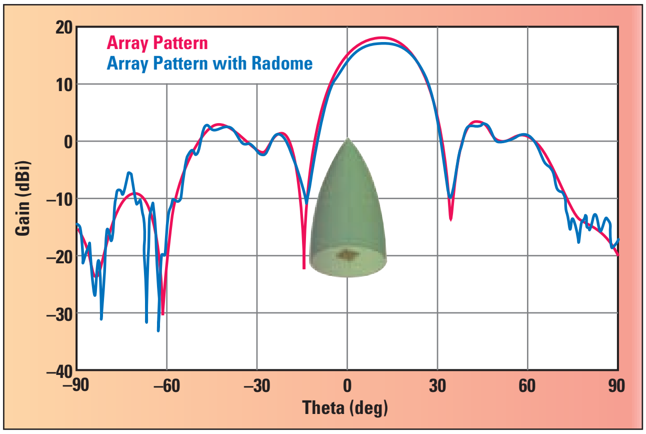


▲ *Fig. 5 Dipole array patterns, with and without the radome, at 2.35 GHz.*



▲ *Fig. 6 Dipole array under an ogive shaped A-sandwich radome (a), radiation pattern of the dipole array (b).*

Figure 6 shows an ogive shaped A-sandwich radome protecting a dipole array. The electrical size of the radome at its operating frequency of 8.5 GHz is 4.5 and 16.5 wavelengths for base inner radius and inner height, respectively. MLFMM is the optimal solver for the analysis of this electrically large radome. The A-sandwich configuration is constructed with 0.24 cm thick skins (ε_r = 4.8, tan d = 0.0002) and a 0.4 cm thick core (ε_r = 1.3, tan d = 0.001). The layers are explicitly present in the simulation (the TDS approximation was not used). The antenna array under the radome is mechanically tilted to point at a 10° elevation angle.



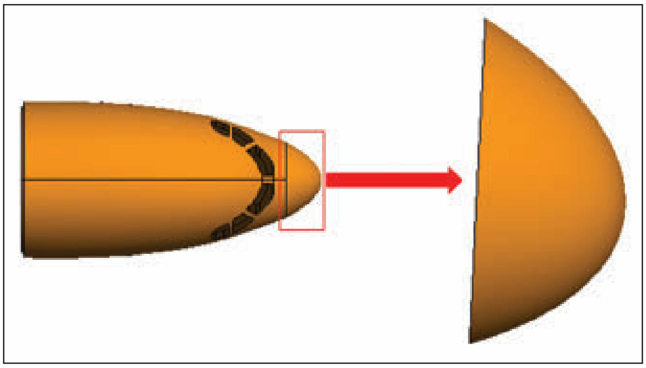
▲ *Fig. 7 Array pattern with and without the radome.*

The radome induced effects are illustrated in ***Figure 7***. The A-sandwich ogive introduces a 2.3 degree boresight error and a 1.1 dB insertion loss. Note that the radome design leaves the antenna sidelobe levels intact.

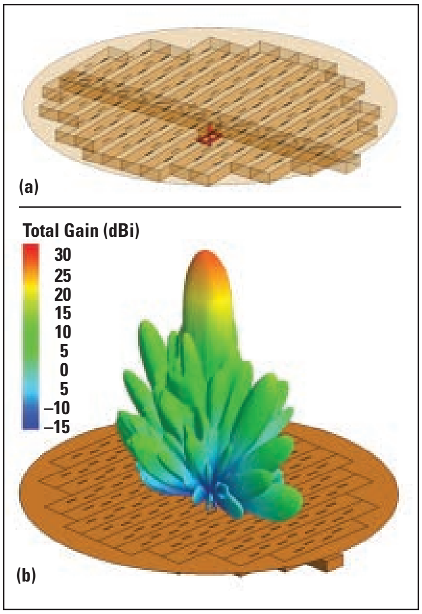
Electrically Large Radomes

Applications such as satellite communications and airborne weather radar require huge radomes to protect the electrically large antennas. The computational resources required to analyze these large structures could become prohibitively large with the aforementioned solvers. One must therefore use asymptotic solvers, particularly Ray Launching Geometrical Optics (RL-GO),[9,10] which are efficient when modeling the transmission of rays through objects, like radomes or lenses.

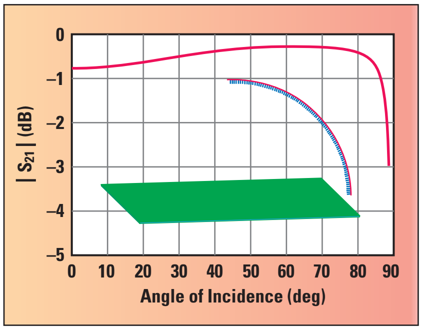
Figure 8 shows the nose cone of an Airbus A380-800 passenger aircraft, which usually covers the weather radar that operates in X-Band, typically at 9.4 GHz. A slotted waveguide (SWG) array, illustrated in ***Figure 9***, is the most popular antenna for the weather radar. The SWG array is designed in such a way that it is fed from the bottom with a single waveguide that is orthogonal to the array waveguides. The length, width and spacing of the slots is optimized for the de-



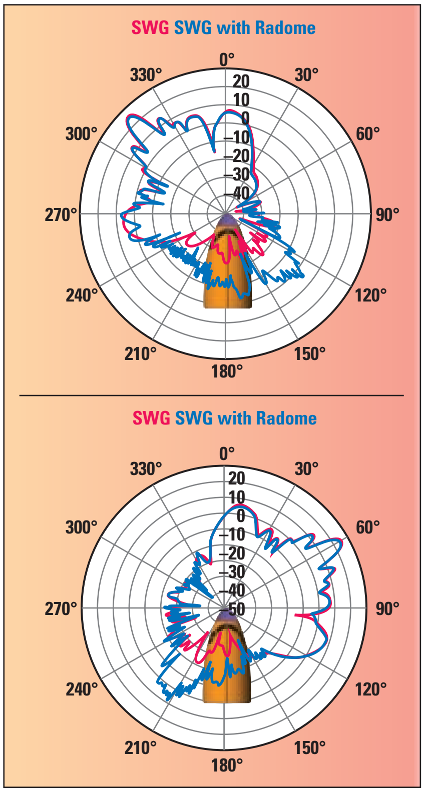
▲ *Fig. 8 Nose cone of Airbus A380-800 passenger aircraft.*



▲ *Fig. 9 Slotted waveguide array design (a) and array pattern (b).*



▲ *Fig. 10 Transmission loss data of a monolithic radome made of glass composite.*



▲ *Fig. 11 SWG array scanning at different angles on both sides of the aircraft, with and without the radome.*

sired pointed beam pattern.

Aircraft require nose cone radomes that can withstand extreme aerodynamic stresses. For such applications, monolithic half-wave wall configurations are preferred over other styles. ***Figure 10*** shows the transmission loss data of a monolithic wall configuration made of a glass composite (ε_r = 4.0, tan d = 0.015) with a thickness of 9 mm. The outer surface of the radome wall is coated with a 0.2 mm typical paint layer (ε_r = 3.46, tan d = 0.068). The material properties chosen for the nose cone radar are obtained from Nair and Jha.[11] According to its transmission loss data, the radome performs well over a wide range of incident angles.

The weather radar typically scans 60° to 90° on either side of the aircraft heading, while the tilt feature permits the crew to adjust the vertical projection of the beam, typically 10° up or down from the aircraft longitudinal axis. ***Figure 11*** shows the SWG array scanning on both sides of the aircraft. Comparison of its array pattern with and without the radome indicates that a transmission loss of 0.7 dB is introduced because of the glass composite. It can also be observed that the monolithic radome does not introduce any boresight error. The complete analysis of this huge radome is performed using the asymptotic RL-GO method in combination with TDS.

FSS Radomes

FSS structures are two-dimensional arrays of periodic resonant elements (printed or slot) designed to either transmit or reflect certain frequency bands. Radomes constructed with slot-FSS layers sandwiched between the dielectric walls act as bandpass filters and reduce out-of-band RCS.[12] Transmission loss analysis is also used to characterize the electrical performance of layered FSS wall configurations; however, the planar Green's function approach becomes computationally expensive as it requires modeling a large finite FSS layer sandwiched between infinite dielectric layers. One can overcome this problem by using periodic boundary conditions (PBC)[13] for transmission loss analysis.

PBC analysis requires only a single unit cell large enough to include the FSS element sandwiched between the dielectric layers. The boundary conditions effectively duplicate the unit cell indefinitely, representing the layered configuration as an infinite structure in both dimensions of a 2D plane. This allows for transmission loss analysis of the layered FSS configurations over a range of incident angles. The accuracy of this approach is substantiated by comparison with the planar Green's function method, which was previously validated with published data. ***Figure 12*** shows a comparison between the planar Green's functions and PBC approach at various incidence angles for two different wall thicknesses of a monolithic radome (ε_r = 4.0, tan d = 0.015). The perfect alignment between PBC and planar Green's function results validates the accuracy of the approach.

The first step in designing an FSS radome is the selection of a periodic element to meet electromagnetic specifications. A Jerusalem cross-slot FSS geometry is chosen to design an X-Band radome. The FSS layer is placed in the middle of the core layer in an A-Sandwich configuration,[1] with

0.319 mm thick skins (ε_r = 4.8, tan d = 0.0002) and a 1.595 mm thick core (ε_r = 1.3, tan d = 0.001).

Analysis of 3D arbitrary shape radomes with all the explicit layers including the FSS layers is a near impossible task because of the difficulty involved in wrapping the FSS layer onto the curved radome surface. This analysis is simplified by converting the transmission/reflection coefficients of the layered FSS configuration into frequency dependent impedance parameters. One can then replace the explicit layers with a single impedance sheet. This approach dramatically reduces the computational resources when compared with a full analysis of the complete explicit geometry. ***Figure 13*** shows both the layered FSS configuration and its equivalent impedance sheet. The transmission/reflection coefficients of the impedance sheet are compared with the complete A-sandwich layered FSS configuration in ***Figure 14***, validating the accuracy of the impedance sheet approximation. The results also illustrate that the radome is designed to be completely transparent at 9.4 GHz, while exhibiting high insertion loss at both upper and lower frequencies.

The radome induced effects are computed through the analysis of a nose cone radome of the above A-sandwich FSS configuration covering a Vivaldi antenna. The Vivaldi antenna patterns with and without the radome (see ***Figure 15***) demonstrate that the radome introduces negligible insertion loss and boresight error at the center of the passband (9.4 GHz).

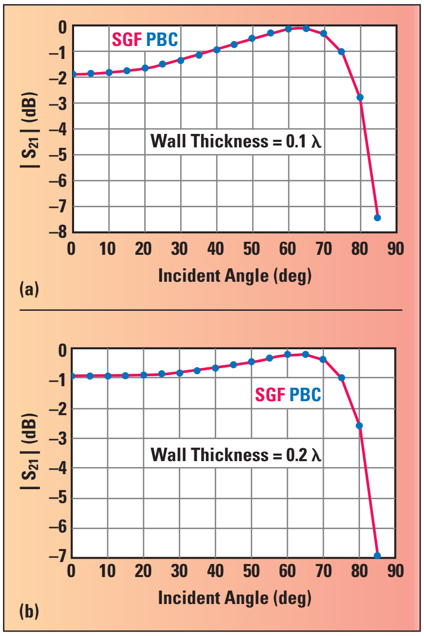


Fig. 12 Transmission performance of a thin-walled radome for various incidence angles, comparing planar Green's functions and PBC with wall thickness of 0.1 λ (a) and 0.2 λ (b).

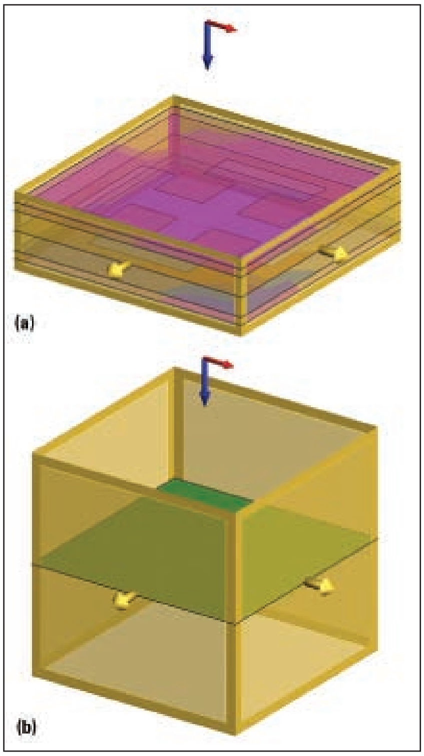


Fig. 13 Jerusalem cross-slot FSS layers inside an A-sandwich layered configuration (a), impedance sheet replacing the layered FSS configuration (b).

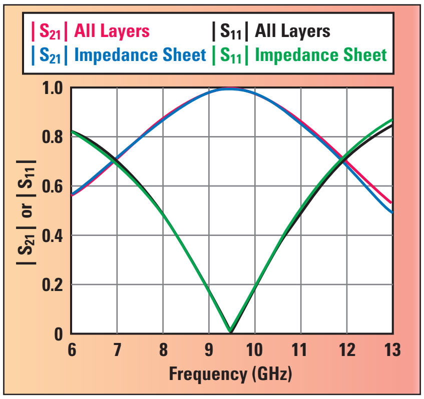
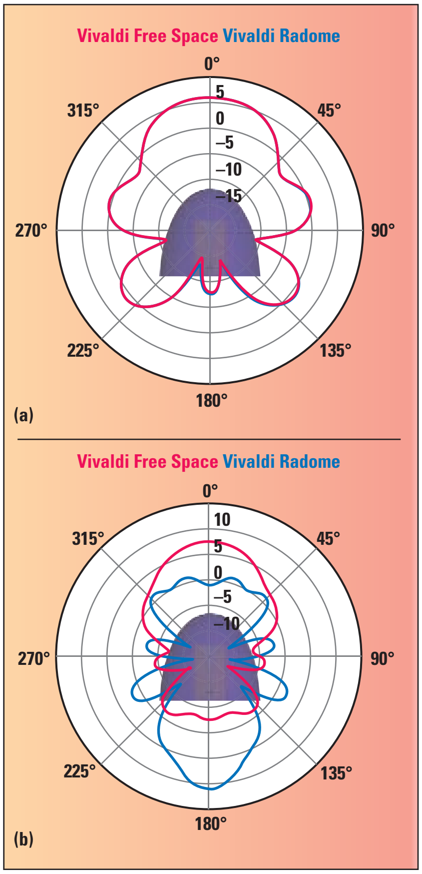


Fig. 14 Comparison of transmission and reflection coefficients between the layered configuration with FSS and its equivalent impedance sheet.



▲ *Fig. 15 Vivaldi antenna pattern with and without the radome at 9.4 GHz (a) and 12.5 GHz (b).*

The sidelobe level is also unaffected when operating within the intended frequency band. In contrast, the FSS radome has the greatest rejection at 12.5 GHz, which is consistent with the data in Figure 14.

CONCLUSION

The computational electromagnetic methods for the complete analysis of radomes ranging from electrically modest to electrically large are discussed with examples. Radome wall construction materials can be quickly characterized for different configurations through a transmission loss analysis using planar Green's functions and/or periodic boundary conditions. A complete radome analysis to investigate the radome induced effects can be performed using different solvers (e.g., MoM, FEM, FDTD, MLFMM or RL-GO). In addition, a hybridized combination of solvers can be used depending on the electrical size of the radome. The thin dielectric sheet approximation is available for the efficient analysis of thin-walled radomes. A radome with an embedded FSS can be approximated by an impedance sheet with frequency-dependent characteristics. In summary, efficient simulation methods are available for many practical antenna-with-radome applications. ■

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INVITED PAPER

Wideband Frequency Modulation Applications and Techniques

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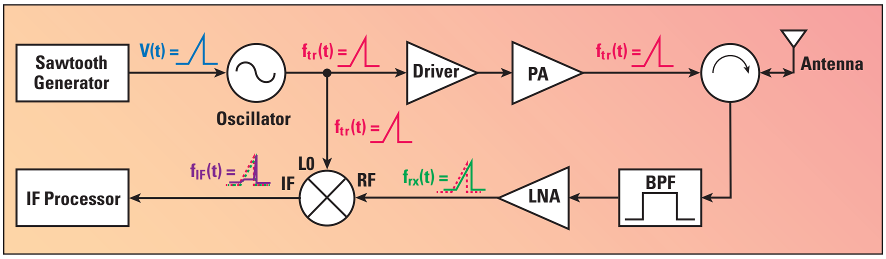
Frequency modulation (FM) is used extensively in audio communication and data transfer. When spectrum efficiency is important narrowband FM (NBFM) is used but when better signal quality is required wideband FM (WBFM) is used at the expense of greater spectrum usage. The term WBFM is used in applications where the modulation index is equal to or larger than 1. However, in this article, we are going to address applications and techniques for WBFM with modulation indexes much larger than that, going up to 100 and beyond. In such applications spectral efficiency is less important and sometimes large spectral spread is actually desired. The purpose of this article is to present some major applications in the commercial and defense markets as well as the common techniques of generating WBFM.

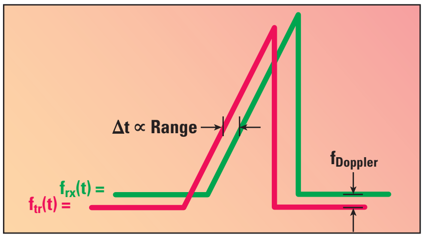
FM-CW radars generate a continuous-wave (CW) signal that is typically modulated by a saw-tooth waveform; such a signal is called a chirp. This signal is then amplified and transmitted. The received signal is amplified, filtered and converted to zero-IF by mixing with the transmitted signal. The basic block diagram of the FM-CW transmitter is shown in ***Figure 1***. The received signal is delayed by the time it takes the signal to reach the target and return. Also, the frequency of the received signal is shifted by the doppler effect due to the target's relative velocity. Overall, by the comparison (or mixing) of the transmitted and received signals both the range and the velocity of the target can be extracted. This principle is shown in ***Figure 2***.

The advantage of FM-CW radar is excellent signal to noise ratio (SNR) and, since it transmits all the time, the simplicity of the information extraction and the ability to detect very close-range targets. Pulsed radars, for instance, cannot receive the signal while transmitting. The result is a "shadow time" that prohibits the pulsed radar from detecting very close-range targets.

The FM-CW radar overcomes this problem and can support very close-range targets. In order to get an accurate reading of a target, the frequency change rate must be very high, so there will be a detectible frequency difference between



▲ *Fig. 1 FM-CW radar block diagram.*



▲ *Fig. 2 FM-CW transmit (red) and received (green) signals.*

the transmitted and received signals. Therefore, FM-CW radars use a very wideband FM modulation technique.

TECHNIQUES

There are many techniques to generate a WBFM signal: analog based, digitally based and hybrid techniques.

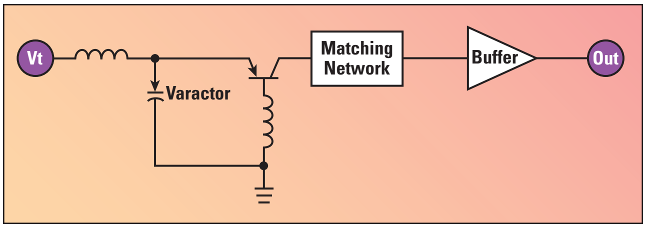


Fig. 3 VCO simplified schematic.

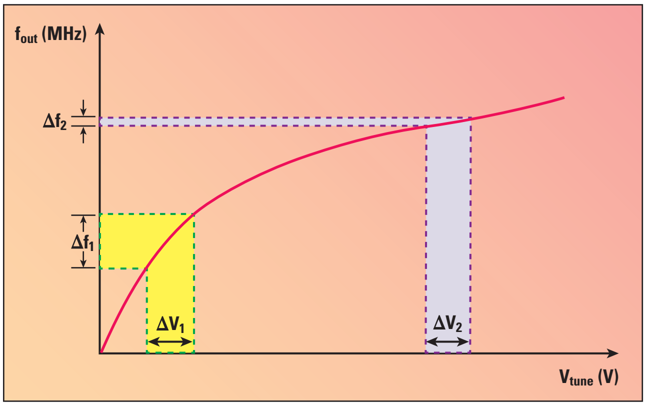


Fig. 4 MSR effect on frequency span.

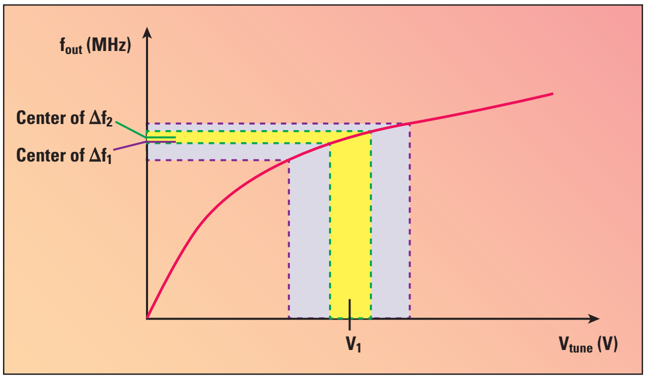


Fig. 5 MSR effect on center frequency.

In this article the commonly used solutions and hardware are reviewed.

Free Running Voltage Controlled Oscillator

A free running VCO is a device based on an unstable transistor circuit. The frequency of oscillation depends on the resonance frequency set by its equivalent capacitance and inductance. By applying variable bias voltage to a varactor diode, the capacitance is changed and the oscillating frequency is changed accordingly. A simplified schematic is shown in ***Figure 3***.

The VCO is a very low cost method of generating WBFM signals, such as chirp signals. The VCO has some important properties that are common to all frequency sources. The definitions of these properties are detailed below and will be used for the rest of the article:

Frequency range is defined as the lowest and highest frequencies generated by the VCO. A VCO may cover a full octave band.

Settling time is defined as the time it takes the VCO to reach the final frequency within an allowable window. Typical values are 50 ns to ±10 MHz and 1 µs to a ±4 MHz for a 12 to 18 GHz jump.

Post-tuning drift: After a VCO reaches what seems to be its final frequency it may slowly drift until it reaches the real final value. This post-tuning drift may cause an additional few MHz of deviation after a few micro-seconds.

Sensitivity and maximum sensitivity ratio (MSR) is defined as the "voltage to frequency" transfer function of the VCO and is measured in MHz/Volt. A perfect VCO will have a constant sensitivity throughout its range of operation. Unfortunately there are no ideal VCOs and therefore the sensitivity varies across the VCO frequency range. The maximum sensitivity divided by the minimum sensitivity is defined as MSR. Using a VCO with poor MSR (>>1) will yield a wide range of problems. Some examples:

Applying a perfect saw-tooth waveform as the tuning voltage will not generate a perfect chirp. Range measurements in altimeters, for example, will become inaccurate as a result.

The same modulating waveform, for different center frequencies, will result in different frequency spans. This is demonstrated in ***Figure 4***.

Different modulating waveform amplitudes, for a constant offset voltage, will result in different center frequencies. This is demonstrated in ***Figure 5***.

Frequency total accuracy is defined as the maximal frequency error that will be measured after a "voltage to frequency" calibration table has been established. The frequency error is mainly effected by temperature and aging. This is the major drawback of the VCO as a frequency source. A system using a simple VCO as a WBFM generator may end up with a signal that has some deviation in its center frequency and also in its span. For example, an EW system may jam the wrong frequency band reducing its effectiveness and its coexistence capabilities.

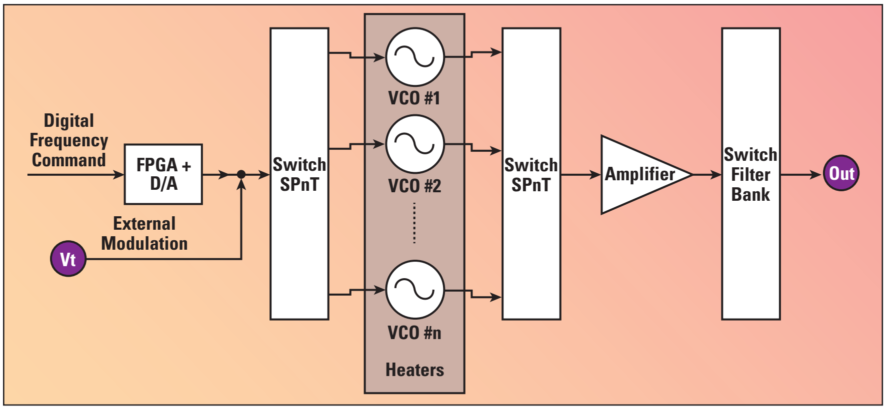


Fig. 6 Multi-octave DTO conceptual block diagram.

Frequency modulation span is defined as the maximal frequency span that a VCO may cover when driven by a modulating signal. With VCOs there is no actual limit to the span and a VCO can support WBFM starting at its lowest frequency and ending at its highest frequency. For example, a 4 to 8 GHz VCO will support modulation with a span up to 4 GHz. As will be shown later, this is not the case for other devices.

Modulation frequency bandwidth is defined as the maximal modulation frequency or modulation rate that may be applied to the modulation control pin before the span droops by more than 3 dB. For example, a VCO is being modulated by a very slow changing control voltage to generate a 1 GHz span. The control voltage is then changed to be a fast sine-wave. The frequency of this control voltage is increased until the span starts to become less than 1 GHz. The frequency that causes the span to be 707 MHz is the 3 dB modulation bandwidth. A typical value for a VCO would be 250 MHz.

Digitally Tuned Oscillator

Since the VCO requires the user to prepare a look-up-table in order to know what voltage to apply to get the desired output frequency, a more convenient approach is to have this look-up-table stored within the module. This allows the user to input a digital command and the pre-calibrated information is used to generate the correct frequency. Since the transfer function of a VCO is greatly dependent on the temperature, a heater connected to the VCO is used to produce a constant VCO temperature. For supporting frequency ranges of more than an octave, several VCOs may be housed within the same DTO. The basic block diagram of a multi-octave DTO is shown in ***Figure 6***. The main advantages of the DTO are its multi-octave frequency range and its relatively low price. The main DTO disadvantage is the need for an elaborate calibration process.

When modulating the DTO by the external modulation signal, only one of its internal VCOs is being modulated and therefore the modulation span is limited. The same problems of changing modulation spans and shifting center frequencies with different modulation voltages exist when using a DTO as well.

Frequency Locked Oscillator

To improve the frequency accuracy of a DTO, a correction circuit is used. The output signal is sampled and its frequency is measured with an accurate frequency discriminator. The output of the discriminator is used as feedback to the tuning voltage of the VCO. The VCO is said to be frequency locked and its accuracy is as good as the discriminator's ability to measure frequency. When commanded to jump to a new frequency, the FLO's control circuit applies a tuning voltage to the VCO according to its internal look-up-table. This is

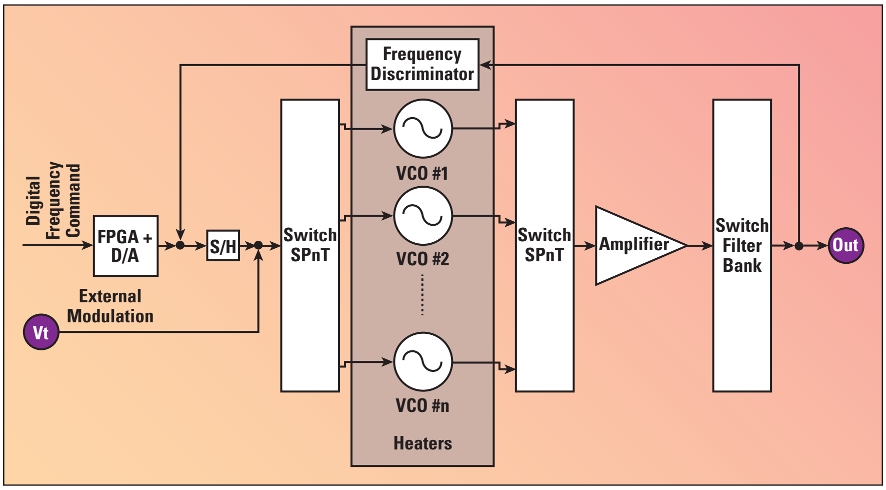


Fig. 7 Multi-octave FLO conceptual block diagram.

called a “DTO Mode” since this is exactly what is being done in a DTO. Once the VCO converges to the vicinity of the final frequency, the discriminator reading is connected with a closed loop to the tuning voltage in order to achieve enhanced accuracy. This is called “FLO Mode”. As with the DTO, the FLO output signal may be modulated. For NBFM the module can still be in “FLO Mode” during the modulation and the center frequency accuracy is guaranteed. However, for WBFM the frequency locked loop must be opened (due to the limited BW of the discriminator) and the module works in a “DTO Mode” with reduced accuracy. Usually, for the same frequency range of operation, the FLO is larger and more expensive than a DTO. The basic block diagram of a FLO is shown in ***Figure 7***.

Fast Indirect Synthesizer

A cost effective solution for generating wideband signals is the indirect synthesizer. With the indirect synthesizer the VCO is phase-locked to a reference oscillator. That is why the indirect synthesizer is also known as a PLL based signal generator. The frequency accuracy of the output signal is the same as the reference signal used to lock the synthesizer, and is several orders of magnitude better than all the previously described solutions. The basic block diagram of an indirect synthesizer is shown in ***Figure 8***.

The indirect synthesizer has been widely used in the market for many years and is successfully supporting many non-modulated frequency applications. To add modulation ability to the indirect synthesizer, there are several approaches.

NBFM techniques: Two major techniques are commonly being used. The first is to inject the modulating

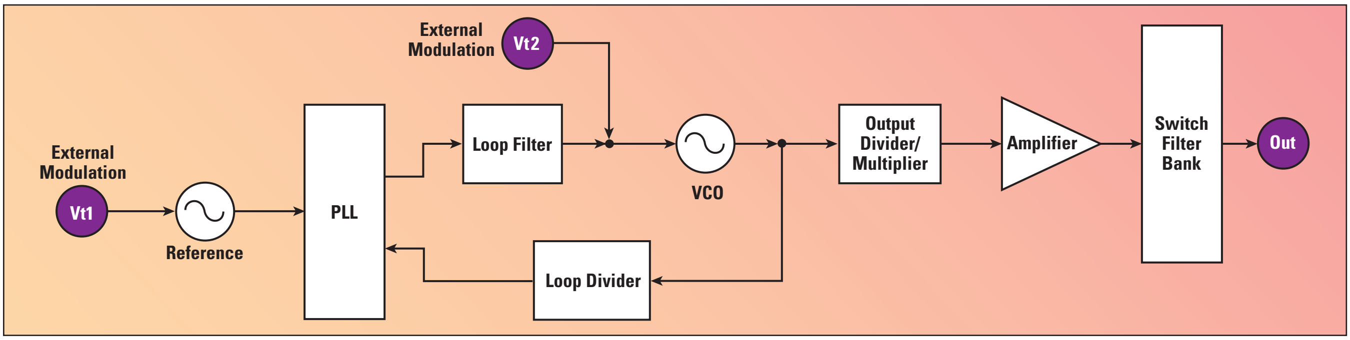


Fig. 8 Indirect synthesizer conceptual block diagram.

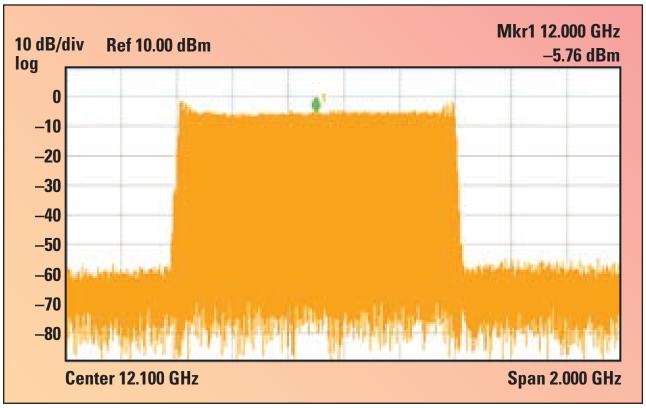


Fig. 9 Model SM6220 spectrum plot.

voltage directly to the tuning voltage of the VCO. This solution is effective as long as the modulating signal is a relatively higher frequency than the loop BW (also known as AC coupling). Otherwise the loop will be able to detect and remove this modulation. The second technique is to modulate the reference signal to the PLL. This technique is effective as long as the modulating signal is within the loop BW so that the loop will cause the VCO to follow the changing frequency of the modulated reference. Other methods are also being used, such as hybrid methods (two and three point modulation) but they are behind the scope of this article.

WBFM techniques: Two major techniques are commonly used. The first is to use the PLL in order to jump to the new center frequency, then to keep the tuning voltage to the VCO at a constant value (e.g., by a S/H) and inject the modulating voltage directly to the tuning voltage. This technique is called "DTO Mode" since the loop is open during the modulation and the VCO is actually in free running mode. This technique suffers from all the drawbacks explained previously for the "DTO Mode" in DTOs and in FLOs.

The second technique is to use a "pure locked mode" (PLM). Using PLM the reference signal to the PLL is modulated and the synthesizer is always locked, similar to the NBFM case. This technique is very challenging due to the fact that the loop elements of the PLL need to support extremely high rates of voltage changes (both voltage and frequency). But the advantages of the PLM are quite clear, perfect center frequency and well known modulation spans, without the need for factory or customer calibration. The PLM supports modulation waveforms from DC to high rates (DC coupled).

PRODUCT EXAMPLE

There are many benefits of using the indirect synthesizer technology to generate WBFM especially when using it in PLM. The Model SM6220, offered by General Microwave Israel (GMI), is a 2 to 20 GHz synthesizer that has a very fast settling time; less than 1 micro-second. This settling time is guaranteed for any jump between any two frequencies, including end-to-end. The SM6220 is also capable of WBFM in PLM with up to a 1 GHz span. The 1 GHz span can be located anywhere within the 2 to 20 GHz range (no "sub-bands"), thus enabling continuous coverage. The 3 dB modulation bandwidth is 10 MHz. A spectrum plot of a 1 GHz WBFM span is shown in **Figure 9**. This state-of-the-art product is compared to other solutions in **Table 1**. ■

TABLE 1

COMPARISON OF MODELS THAT SUPPORT WBFM

Model	V6120A	D6218	FL6218	SM6220
Technology	VCO	DTO	FLO	Synthesizer
Frequency Range (GHz)	12 to 18	2 to 18	2 to 18	2 to 20
Settling Time (µs)	1	1	1	1
Modulation Span (GHz)	6	0.5	1	1
Modulation BW (MHz)	250	10	10	10
WBFM Mode	Free Running	DTO Mode	DTO Mode	PLM
Steady State Accuracy	±4 MHz	±2 MHz	±1 MHz	±200 kHz

ACKNOWLEDGMENTS

All the photos and measurements in this article are courtesy of General Microwave Israel (GMI), a KRATOS Company.

Dr. Ronen Holtzman *is VP of engineering at General Microwave Israel Ltd. He has more than 25 years of experience and is a specialist in RF and microwave components and subsystems.*

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INVITED PAPER

Silos of Inefficiency: Overcoming Closed RF Design and Development Practices

Lorne Graves
Mercury Systems Inc., Chelmsford, Mass.

Within the defense industrial base, adherence to standards such as IEEE and ISO are nothing new. However, there has been little standards-based activity born out of defense; nearly all standards activity emanates from the commercial sector. This is not surprising, since much of the work within defense electronics is centered on platforms designed to meet very specific applications, where standards-based solutions are difficult to design, engineer and develop. This is especially true within RF and microwave-based defense applications where, to date, little to no progress has been made in developing electronic warfare (EW) applications based on open systems architectures (OSA).

How did it get this way? Historically, each branch of the armed services would typically develop their own systems for specific platforms. Even worse, systems on similar platforms in each branch were often incompatible. One explanation for this "siloed approach" was that different platforms targeted different threats, an argument still used today in many circles. However, regardless of the platform, the mission is really the same: controlling the electromagnetic spectrum, which requires RF and microwave technology.

This article outlines a new vision for an OSA approach within the RF and microwave industry, explores the need for such an architecture, discusses what it will take and ways it can be implemented.

BREAKING DOWN THE SILOS

The stovepipe approach completely contradicts the U.S. Department of Defense's (DoD) mandate that all systems move toward open architectures in order to lower costs and facilitate ongoing upgrades to essential electronic systems, so they remain on the cutting edge of technology. In 2013, then Deputy Secretary of Defense Ashton Carter opined in the DoD Electromagnetic Spectrum Strategy, "DoD systems must become more spectrally efficient, flexible and adaptable, and DoD spectrum operations must become more agile in their ability to access spectrum in order to increase the opportunities available to mission planners." In essence, that means systems must be designed so they can be reused or repurposed for various missions and platforms. That means scaling systems from surface vessels, long-range bombers, armored vehicles and strike aircraft to remotely piloted vehicles (RPV). As RPV use increases, the systems must be scaled down in size, weight, power and cost (SWaP-C), as well as adapt to mission parameters and the ever-evolving threats from adversaries. In order to realize the DoD's vision, the next steps in eliminating silos must mimic the commercial industry's recent rapid advances in cellular network, smartphone and other technologies.

To simplify the discussion, the focus here will be on a single domain: cellular networks. The use of mobile devices has exploded over the past decade, and today they are used in virtually every aspect of life. Their rapid adoption was accelerated by an infrastructure designed to support the vast amounts of data being communicated. At the heart of this infrastructure are RF and microwave transmitters and receivers. While the RF equipment may have different frequencies, the same essential building blocks are used across the network, in a sense providing multi-function RF equipment in a system. Providers use common equipment with tailored software to add user features and

ensure quality of service (QoS). Software-defined radios (SDR) are used to adapt to various protocols. The use of SDR equipment allows software to be easily uploaded to address features needed in order to scale or adapt a system.

Another important aspect that leads to the rapid deployment of the infrastructure that supports all of these disparate devices is the use of common control and data transport protocols, such as Ethernet. In summary, common, modular "building blocks" are used throughout the system. Multifunction RF building blocks provide the heart of the communication between mobile devices and the base stations. The flexibility and adaptability around the commercial equipment controlled by common software protocols led to the deployment of a scalable, cohesive and affordable solution for the telecommunications industry (see ***Figure 1***). This type of system is essentially an open systems architecture approach.

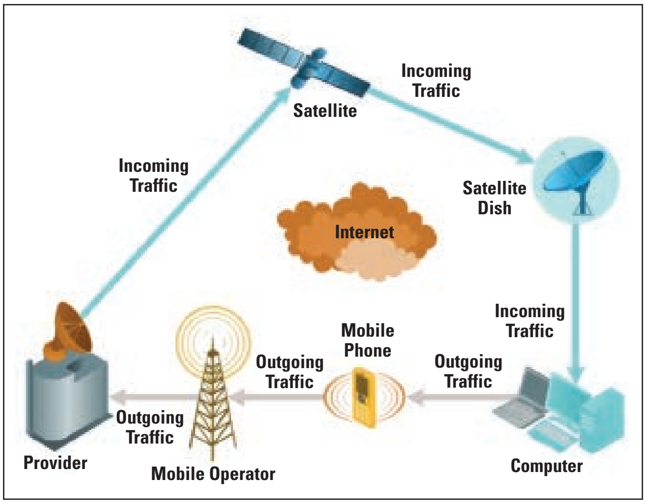
OPEN SYSTEMS ARCHITECTURE FOR RF/MICROWAVE

Why would an open systems architecture be valuable to the RF and microwave industry supporting the Department of Defense? There are several major reasons:

- Provides scalability for common hardware blocks
- Reduces integration schedules
- Reduces program risk
- Provides maximum flexibility and rapid adaptability
- Eliminates duplicate efforts
- Restores productivity and creates an ecosystem of affordability

Scalable hardware building blocks provide the framework for any open architecture. The real key is to have a common framework that also provides adequate freedom for creative developments within the framework. Reducing the time developers need for integration is essential in any open architecture. This reduction in the integration schedule mitigates program risk caused by using known intellectual property. The flexibility of using a common infrastructure allows new technologies from new or previously unused companies to be inserted rapidly into various systems. This flexibility provides a new level of adaptability for enhancing and maintaining a system. The aforementioned benefits all lead to a reduction in duplicate, custom efforts. The reduction of duplicate efforts leads to a new level of productivity and yields maximum affordability for developers within the ecosystem. All of these points are evident in the wireless infrastructure example from the previous section. Given this, how can an open systems architecture approach to RF and microwave be implemented to provide these benefits to the DoD?

Developing an open systems architecture requires working with existing standards. Open architectures such as OpenVPX (VITA 65) have brought rapid integration of digital subsystems under common hardware and software protocols into the realm of the possible. Of course the ecosystem did not develop overnight. OpenVPX started as an architecture and turned into a high-level system specification defined by common modular hardware. The system specification enables scalability and flexibility at the system level. The next step is to bring RF/microwave (RFM) into this ecosystem. This seamless integration of RFM into consolidated systems provides the first step to a new era of multi-function systems.



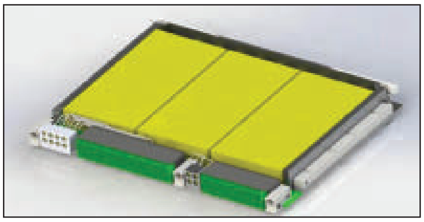
▲ *Fig. 1 Wireless network infrastructure.*

This is the intent of Mercury Systems' proposed OpenRFM™ initiative – an affordable, modular open systems architecture that standardizes the electromechanical interfaces and control planes to drive affordability, ease of integration and interoperability within the RF/microwave domain. It is ideally suited to EW applications. Its modular approach and leverage of commercial technology enables scalability, adaptability, high channel density and export features.

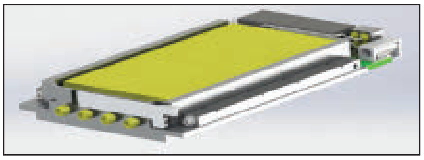
OpenRFM MODULE PARAMETERS

To begin the OpenRFM architectural design, a mechanical structure and connectivity must first be developed. To enable a scalable architecture from 6U OpenVPX to 3U OpenVPX, a mechanical volume that permits use in both ecosystems must be adapted. The concept of supporting both ecosystems is shown in ***Figures 2*** and ***3***.

Starting with the smallest common denominator, the module must have an outline that fits within 2.7 × 5.6 inches. The height may vary depending on the module design but must not violate the pitch set forth by the existing VITA standards. The next step is to define the electrical connectivity for power and control. The architecture uses a very high-speed connector with an abundance of connections for power and grounding. The connector must be capable of high data rate signaling, such as set forth in the JESD204B standards, be rugged and easily placed by automated manufacturing equipment.



▲ *Fig. 2 6U OpenRFM payload.*

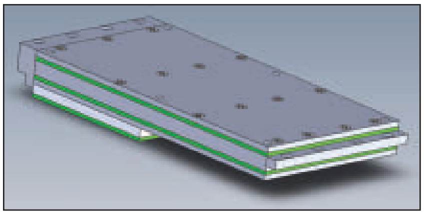


▲ *Fig. 3 3U OpenRFM payload.*

The control signals to the OpenRFM modules have to serve a myriad of purposes. There must be a low-speed diagnostic type path for module identification and basic operational parameters as well as a high-speed path to provide a standard control and data path. The high-speed control and data path used for OpenRFM is a multiplexed address and data path, used to preserve signals and to provide general purpose input-output (GPIO) signaling to the RFM module. A small complex programmable logic device (CPLD) within the OpenRFM module is sufficient for more complicated modules requiring many control signals. The power rails provided to an OpenRFM module are standard voltages such as 5 V and 3.3 V. The OpenRFM connector also provides some modules with power directed at RFM circuitry. The voltages are ± 8.5 V and an adjustable low voltage supply for special biasing and control circuitry.

To allow direct control of the OpenRFM module's RF circuitry, a hardware abstraction layer has to be developed to enable control from various protocols, such as Ethernet, PCI Express or Serial RapidIO. These are all control or data protocols within the VITA standards outlined for OpenVPX. The hardware abstraction layers can be implemented by various circuits. In a fashion similar to the use of SDR for easy upgrades in a wireless network infrastructure, a system on a chip (SoC) device is used in the OpenRFM architecture to enable protocol agnostic communication. Developing a hardware abstraction layer also relies on a level of software sophistication to prevent bottlenecks in control and status of an OpenRFM module. The application program interface (API) is used to simplify the application level software access to the OpenRFM modules. This RFM "middleware" provides a common software interface to OpenRFM modules, enabling easy system integration of RFM modules into a system.

The OpenRFM architecture does not restrict any RF or microwave circuitry within the modules. This allows RFM designers to be as creative as needed to solve the system problems for communication through the electromagnetic spectrum (EMS). The OpenRFM module (see ***Figure 4***) can consist of any RFM assembly – from a high frequency receiver, transmitter, local oscillator generator or power amplifier to a complete SDR with data conversion by an analog-to-digital converter (ADC) or digital-to-analog converter (DAC). The only restrictions are the power consumed within the module. An exact number has not been set for the OpenRFM module; as the architecture matures, the power within a module will be confined by the VITA standard in which it resides. The modules are designed to be compliant to the VITA 48 – VPX ruggedized enhanced design implementation (REDI) specifications.



▲ *Fig. 4 Typical OpenRFM module.*

CONCLUSION

The proposed OpenRFM approach is the first step toward enabling a new, affordable open systems architecture in the DoD RF/microwave industry. Breaking down the siloed approach to design and following the open approach used in the commercial industry should enable the rapid deployment of a multi-function RFM ecosystem that can tackle even the toughest problems. The mechanical envelope and electrical connectivity enables a flexible and scalable architecture. The hardware abstraction layer and RFM middleware provide a highly adaptable architecture that will address the next level of sophistication in DoD RFM systems. This flexibility, scalability and adaptability should provide the means to reduce duplicate custom design efforts and enable maximum productivity and a new level of affordability. Equally important, this approach aligns with the DoD directives to lower costs and increase the ability to rapidly and continuously upgrade critical defense electronics systems, thereby keeping pace with emerging EW threats. ■

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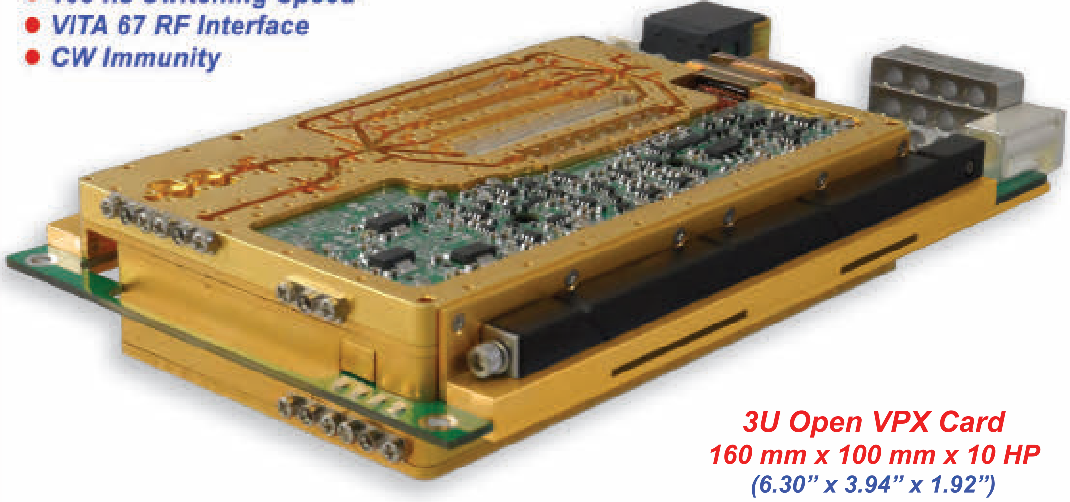

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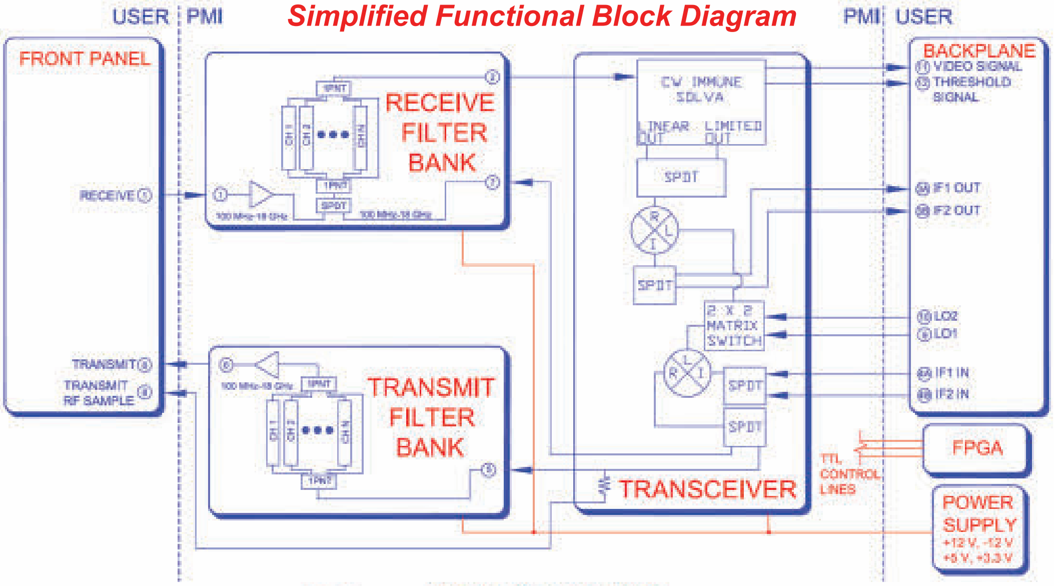
Simplified Functional Block Diagram



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Signal and Spectrum Analyzer for Long Radar Pulse Sequences

Rohde & Schwarz
Munich, Germany

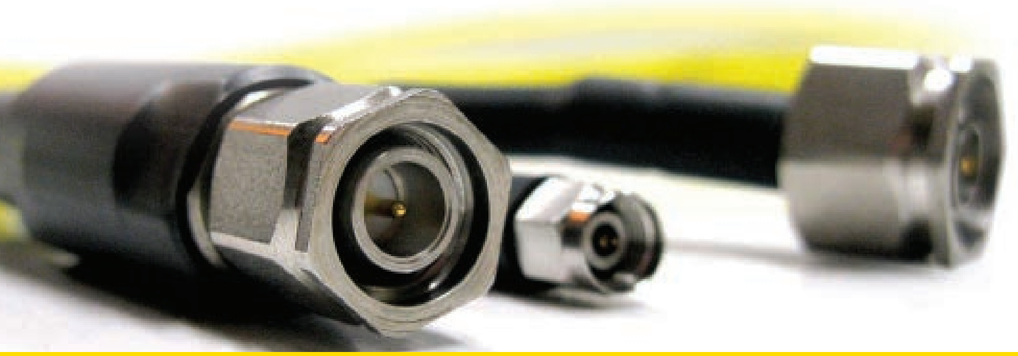
Pulsed radar systems transmit high power signal pulses followed by a pause during which echo signals are received. In many pulsed radar systems, the radio frequency of the emitted pulses remains constant, while the pulse repetition interval (PRI) and the pulse width (PW) vary.

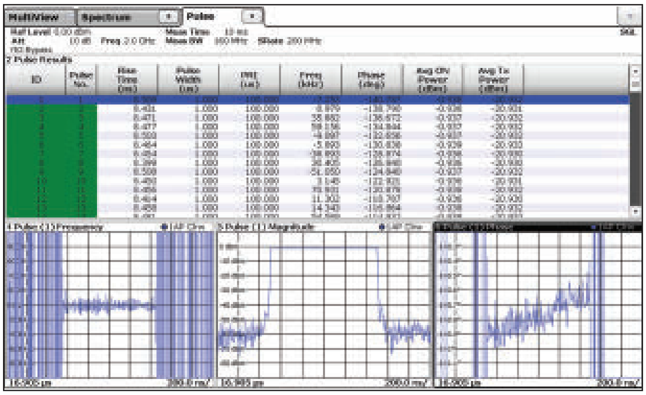
The PRI determines the unambiguous range; the longer the PRI, the higher the unambiguous range. The width of an unmodulated pulse determines the minimum distance to the target and the range resolution. Shorter pulses allow detection at shorter distances and improve the range resolution, i.e., to resolve objects as separate items, but they require more spectral bandwidth. Longer pulses emit more energy per pulse and therefore reach higher ranges.

PULSE ANALYSIS

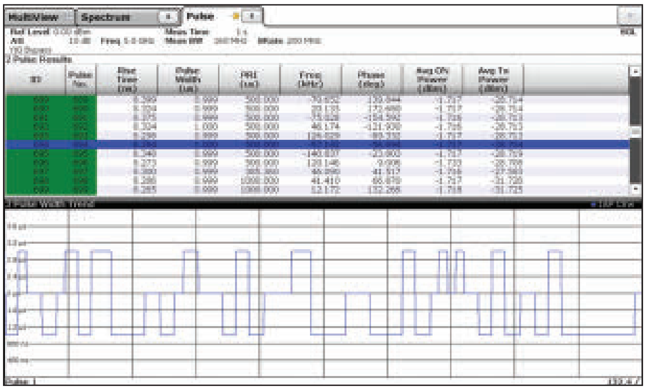
Spectrum analyzers have become the tool of choice for analyzing radar signals. They provide a wider frequency range than oscilloscopes and allow detailed in-pulse measurements of phase and frequency, which cannot be achieved by simple, power-based pulse analyzers. Spectrum analyzers have made huge leaps in bandwidth analysis over recent years. The R&S FSW signal and spectrum analyzer from Rohde & Schwarz now features up to 2 GHz bandwidth analysis and a frequency range of up to 67 GHz. This makes it possible to analyze even very short pulses.

To analyze radar signals in the modern world the R&S FSW signal and spectrum analyzer needs to offer flexibility. For instance, marine and air surveillance radars regularly change their operation modes. They use different PRI and PW in search mode, acquisition mode or tracking mode where different trade-offs between measurement accuracy, minimum and maximum range and range resolution are required. Further techniques include modulation of





▲ *Fig. 1 Result table of the R&S FSW-K6 pulse analysis software, displaying key parameters for each pulse, such as rise time, pulse width, PRI and frequency.*



▲ *Fig. 2 Display of 20s capture time, revealing that the analyzed radar system operates in three different modes.*

phase or frequency during a pulse, which encompasses pulse compression.

For development, optimization and troubleshooting of radar transmitters, pulse trains have to be characterized over long periods. To detect sporadic events or small but continuous effects like temperature drifts, it is desirable to contiguously capture and observe all emitted pulses over a period of up to several minutes.

Furthermore, a common means of influencing radars is range gate pull-off. The radar pulses are recorded and played back delayed, at higher power and probably with a changed pulse shape or frequency than for the naturally scattered pulses from the subject aircraft. The other radar receiver may lock onto the stronger echo return and the resolution cell eventually moves completely away from the subject aircraft. If the play-back is then suddenly stopped, the other radar receiver needs to readjust the leveling and go back through search, acquisition and tracking mode again. Development and optimization of such intelligent influencing techniques and countermeasures also requires the recording and analysis of long radar pulse sequences.

To address such issues, features such as rapid identification of spurious emissions, low phase noise and extensive pulse analysis functions running as software tools on the analyzer provide in-depth signal analysis possibilities, making the R&S FSW an essential tool in the development and production of radar systems.

Figure 1 shows the result of an analysis of radar pulses with the R&S FSW equipped with the R&S FSW-K6 pulse analysis software. Pulses of 1 µs width with a PRI of 100 µs were captured at a 200 MHz sample rate. The table highlights the pulse of interest and displays key parameters for each pulse such as rise time, pulse width, PRI and frequency. The graphs show frequency, magnitude and phase versus time of a single pulse. The analysis software allows further in-depth analysis of pulse parameters such as rise and fall times, dwell time, settling time, overshoot and undershoot.

SEGMENTED CAPTURE

The required high sample rate in combination with a limited capture buffer, however, reduces the total seamless capture and analysis period. As a solution, the R&S FSW-K6 pulse analysis software has been equipped with efficient memory management for analyzing pulse trends over long periods. It is in the nature of pulsed signals that during pauses only noise can be received. This makes it possible to extend the total capture time by omitting the noise during pauses.

A simple but effective algorithm to increase the total observation period is to store and time-stamp I/Q samples over a user-defined period once a certain power level triggers the capture. In addition, a certain number of pre-trigger samples are also stored. All other samples are omitted until the next trigger event. With typical duty cycles of 1 percent, the maximum observation period can principally be extended by up to a factor of 100.

Practically, with 50 percent pre-trigger capture and a capture time per pulse of twice the pulse period, the maximum recording time is extended by a factor of 50. Lower duty cycles extend the maximum recording time even further. The segmented I/Q capture can be triggered by an external trigger as well as by an IF power trigger.

EVALUATION OF PARAMETER TRENDS

Capturing many consecutive pulses makes it possible to analyze parameter trends and track changes that occur from pulse to pulse. ***Figure 2*** displays the pulse width versus the pulse number over 20s capture time. This reveals that the radar system operates in three different modes (1, 2 and 3 µs pulse width), which appear in a random order. Without segmented capture, the maximum capture time for this signal at 200 MHz sample rate was only 2.3 seconds, not enough to see the pattern of different modes.

Segmented capture increases the total analysis period by omitting the pauses between pulses. Effects that occur over many pulses, like changing modes, become visible, making it easier to analyze complex radar systems with changing parameters.

VENDORVIEW

Rohde & Schwarz
Munich, Germany
+49 89 4129 12345
www.rohde-schwarz.com

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Handheld VNA Delivers Benchtop Performance to 40 GHz

Anritsu
Morgan Hill, Calif.

The Anritsu Microwave Site Master™, model S820E, is a handheld two-port cable and antenna analyzer designed for field use yet delivering benchtop performance. Five models covering 1 MHz to 8, 14, 20, 30 or 40 GHz are available. An optional VNA mode provides fully reversing S-parameter measurements. An optional vector voltmeter (VVM) mode, with standard A/B and B/A ratio capability, may be used as a drop-in vector voltmeter replacement.

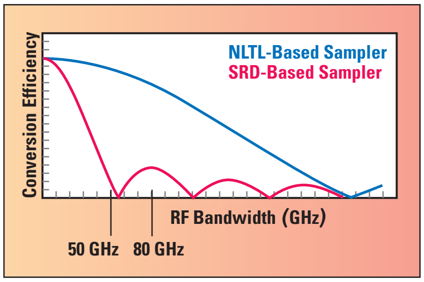
Key specifications of the Site Master are:

- Dynamic range: 110 dB typical from 20 MHz to 40 GHz, 100 dB specified
- Sweep speed: ≤ 650 µs/point
- Frequency resolution: 1 Hz from 1 MHz to 40 GHz
- Simultaneous extended USB sensor transmission and error-corrected reflection measurements
- Field-proven design: explosive atmosphere MIL-PRF-28800F Section 4.5.6.3 compliant
- Coaxial and waveguide measurements
- USB/Ethernet connectivity, full remote control capability
- Intuitive, menu-driven 8.4 inch touchscreen with daylight/nighttime viewable modes
- Standard three-year warranty

Two decades ago, in 1995, the world's very first handheld one-port vector network analyzer was introduced by Anritsu. Considered unbelievable by many, the measurements were initially challenged until proven to be highly accurate and repeatable. That product still exists in many forms and is universally recognized as the de facto industry standard, known as Site Master.

The standard Site Master is ideal for applications up to 6 GHz. However, there are needs for higher frequency coverage. Until recently, no product on the market offered VNA capability beyond 26.5 GHz. The Anritsu S820E Microwave Site Master breaks through that barrier and delivers benchtop performance up to 40 GHz.

To understand how the S820E is capable of delivering up to 110 dB of dynamic range, even at 40 GHz, consider the advanced technology that is deployed inside the S820E. The traditional VNA is comprised of a source, transfer switch, couplers or bridges, and reference/measurement receivers. Measurements are typically down-converted to an intermediate frequency (IF), where the signal is processed. The most common method for conversion uses mixers. However, mixers typically do not have sufficient bandwidth to directly down-convert signals higher than just a few GHz. Higher frequency signals, which exceed the funda-

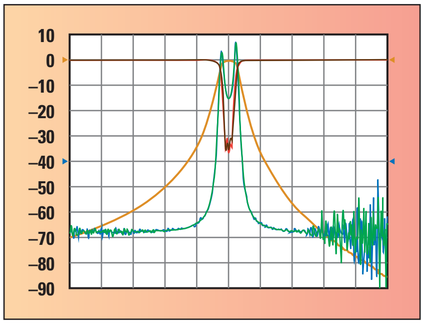


▲ *Fig. 1 The NLTL sampler exhibits much wider bandwidth than one using SRDs.*

mental mixer band, must be downconverted using harmonics of the mixer. The disadvantage is that the conversion efficiency rapidly declines as the harmonic order increases. The consequences are reduced dynamic range, elevated noise floor and often degraded sweep frequency resolution. Very large amounts of IF gain are required to compensate for the reduced conversion efficiency, often adding undesirable side effects, such as increased noise, higher nonlinearity, additional heat and thermal drift and increased power consumption. Mixers with good high frequency performance typically perform poorly at low frequencies, so the problem is simply shifted, not resolved.

An alternative method is a sampler using step recovery diodes (SRD). SRD samplers are widely deployed and offer many advantages over mixer-based methods. However, the SRD sampler method also suffers from declining down-conversion efficiency.

The most efficient down conversion method is the nonlinear transmission line (NLTL) sampler. Historically, it has been challenging to mass produce this technology with reasonable price and consistency. Anritsu engineers have successfully overcome these challenges with newly developed "VNA-on-a-chip" monolithic microwave integrated circuit (MMIC) devices. These devices are establishing new benchmarks in the high performance/price ratio for VNA instruments such as the S820E. These highly integrated MMIC devices have the performance advantages of NLTL technology and additional benefits, such as unmatched temperature stability and no degradation of frequency resolution. The extremely high conversion efficiency enables the S820E to deliver 110 dB of dynamic range up to 40 GHz. Since

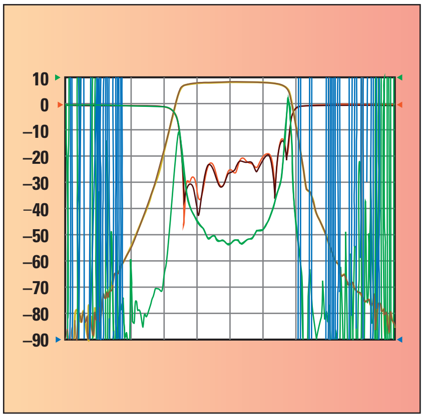


▲ *Fig. 2 S820E measurement overlaid with ShockLine measurement of a 1.95 GHz bandpass filter.*

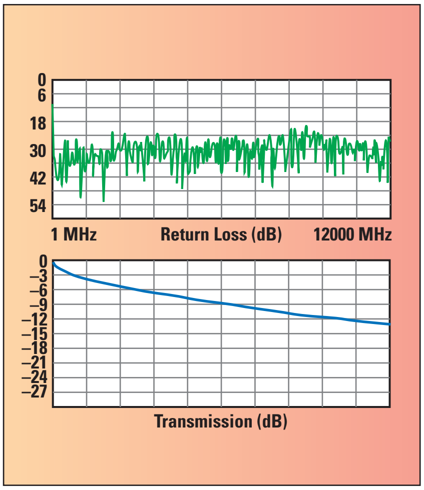
lower IF gain is required, longer battery life and better linearity are additional benefits. ***Figure 1*** compares the NLTL-based sampler technology to the SRD-based sampler.

Equipped with NLTL technology, the handheld S820E is able to correlate with Anritsu's premium VectorStar™ VNA and Anritsu's ShockLine™ series of benchtop VNAs with uncanny precision, bringing true benchtop performance from the lab to the field. ***Figures 2*** and ***3*** show examples of measurement correlation.

Although capable of providing benchtop quality measurements, the S820E is designed to handle the unique challenges of the field. Measurements on long transmission lines are a fine example, where the ends of the line are far apart and not reachable with conventional test port cables. Examples include communication or signaling cables that are embedded in aircraft wings or the fuselage, long waveguide runs in Navy vessels and satellite ground stations, and long microwave coaxial cable runs in the elevator shafts of high-rise office buildings. Historically, these measurements have been performed using scalar network analyzers (SNA). Detector modules could extend the transmission measurement capability using long extender cables, providing a scalar (magnitude only) response. S_{11} of the device being tested could also be measured using a calibrated auto-tester module. Today, VNAs have replaced SNAs for most measurements, and the SNA instrument is no longer readily available. Fortunately, the S820E can make these measurements with ease. Combining unique "USB Sensor Transmission" and vector error-corrected S_{11} measurement



▲ *Fig. 3 S820E measurement overlaid with VectorStar measurement of a WR28 waveguide 39.6 GHz bandpass filter. The slight variation is mainly due to the repeatability of the waveguide connection.*



▲ *Fig. 4 Simultaneous vector, error-corrected S_{11} (return loss) and USB sensor transmission measurements.*

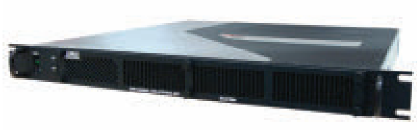
capabilities, the S820E measures both required parameters simultaneously with one user calibration. The USB sensor measurement is made using USB extenders. Anritsu provides a passive, plug-n-play USB extender kit. Users simply add a suitable length of CAT5e or CAT6 cable between the two USB extender modules. ***Figure 4*** shows a measurement example.

The Anritsu S820E is a rugged, handheld solution, allowing users to confidently make VNA measurements in the uniquely challenging field environment and achieve benchtop performance to 40 GHz.

VENDOR**VIEW**

Anritsu
Morgan Hill, Calif.
www.anritsu.com

Eight-Channel Narrowband High Frequency Tuner Subsystem



DRS Signal Solutions
Germantown, Md.

Thousands of individual signals are present in the high frequency (HF) spectrum. Often, the most difficult problem is to discern and capture a small signal in the presence of large interfering signals. DRS Signal Solutions' SI-8728A HF tuner is a best-in-class RF front-end for receiving small signals in dense signal environments. The SI-8728A is operationally proven, with several hundred units deployed on program platforms.

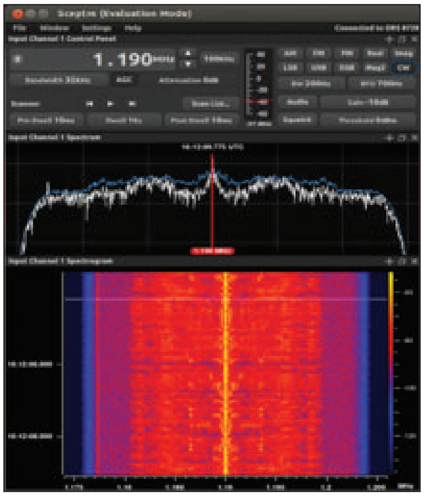
The SI-8728A is capable of continuous 1 Hz tuning resolution over the frequency range of 100 kHz to 30 MHz, while each of its tuner channels provides an instantaneous IF bandwidth of 25 kHz. The SI-8728A's very high density design, high dynamic range, VITA radio transport standard precision time-stamped I/Q data and non-blocking switch options, coupled with an easy-to-use graphic user interface (GUI), make the unit a best-in-class HF tuner.

The SI-8728A provides up to eight digital HF tuner channels in a compact 1U rack-mount chassis, half the size of the nearest competing unit. Its attractive low size, weight and power (SWAP) design includes a weight of less than 18 pounds and an internal power supply that accepts 100 to 250 VAC. This design and its extended temperature range of -20° to +60°C allow multiple units to stack for high-density systems.

With its eight channels, the SI-8728A can be remotely configured for independent or phase-coherent operation to support a variety of system applications. Possible applications for the SI-8728A include a high density HF monitor system, a phase-coherent tuner for super-resolution DF systems and a front-end for HF systems based on software-definable radio. The tuner provides flexibility to operate up to eight channels independently, up to eight channels phase-coherently or with a mix of some channels operating independently and the remaining phase-coherently. Simultaneous control of the SI-8728A's multiple tuner channels is controlled remotely using a Gigabit Ethernet interface and TCP/IP.

The SI-8728A features high dynamic range and low phase jitter. Amplitude and phase distortion within each channel are minimized as well as amplitude and phase mismatch among channels. The tuner is designed to expend very low emissions for operation in electromagnetic interference (EMI) sensitive environments. It may also be configured and used for precision direction finding and rapid signal analysis. A built-in self-test calibrator ensures that the unit functions properly.

Each channel's IF output is processed digitally and made available as baseband in-phase and quadrature-phase (I/Q) data. The



▲ *Fig. 1 Graphical user interface for the SI-8728A.*

tuner features an analog-to-digital converter (ADC) that digitizes data that is passed to the digital signal processor (DSP), where it is filtered and decimated, resulting in a complex data output. The processed data outputs are packaged according to the packet structure of VITA 49.0 for output via the Ethernet interface. A real time clock is maintained for time-stamping the processed data. This clock may be synchronized to an external one-pulse-per-second (1 PPS) reference input.

The SI-8728A control GUI interface is simple to use and allows for easy signal detection, signal analysis, signal recording and digital playback. Its narrowband real time continuous fast Fourier transform (FFT) is shown with a spectral display and a waterfall display that depicts a spectrum's activity over time using color to indicate signal strength (see ***Figure 1***).

OPTIONS AND AUXILIARY EQUIPMENT

The 8728A/MULTI Switch Matrix option adds an 8×8 fully non-blocking matrix internal to the SI-8728A chassis. It allows any combination of eight antennas to be connected to any combination of tuner channels. The switch matrix is controlled through the same 1000Base-SX or 1000Base-T interface as the tuner, for ease in deployment. This switch matrix option limits its RF output power when a large RF input is applied, protecting sensitive RF input circuitry from high voltage transients and nearby lightning strikes.

Four SI-8728A units can be combined with one SI-9332, 32×32 HF fully non-blocking switch matrix. The SI-9332 receives up to 32 HF inputs in the 0.5 to 30 MHz range and provides up to 32 outputs. Any of the 32 SI-8728A channels can access any of the 32 SI-9332 inputs, allowing operational flexibility. The switch matrix provides near unity (0 dB) gain so that it is virtually transparent in system operation. The unit offers excellent intermodulation, noise figure and internal spurious performance.

DRS Signal Solutions
Germantown, Md.
www.drs.com

Compact 1 kW Power Amplifier for HF Applications

Delta-Sigma Inc.
Riverside, Calif.

While the focus today is primarily on devices, subsystems and systems for wireless frequencies, there are still many systems that operate within the HF band from 1 to 50 MHz. They include long-range radar, commercial and military communications, and scientific and industrial equipment, many of which require a combination of high RF output power and high linearity. As with their higher frequency counterparts, HF power amplifiers must be as small as possible to accommodate space constraints, while delivering rated performance with minimal cooling. The VEGA Series of RF power amplifier modules is designed to meet these requirements, delivering more than 1 kW CW in enclosures typically measuring only 4" × 2" × 1.2" and weighing about 1 lb.

The VEGA Series can be used either as standalone amplifiers or as building blocks in a higher power amplifier system controlled via RS-422, RS-232 or Ethernet. Delta-Sigma has used amplifiers in this series to create systems that deliver CW output power up to 4 kW over portions of the HF region and wider bandwidths.

The amplifiers achieve small size through a combination of very efficient, rugged LDMOS RF power transistors, low loss combining networks and precise impedance matching, using design techniques to achieve full rated RF output power with minimum heat sinking and external convection cooling. The amplifier's efficiency is between 65 and 68 percent depending on frequency, and it draws 27 A from a +50 V DC supply.

Over-temperature protection is integrated in the amplifier, and other protection circuits can be supplied depending on the requirements of the application. Key amplifier specifications include 26 dB gain, harmonic rejection up to -37 dBc, spurious rejection of -70 dBc and third-order intercept point of +69 dBm. More detailed specifications are shown in ***Table 1***. The gain, efficiency and return loss of a VEGA Series 1 kW RF power amplifier from 5 to 25 MHz are shown in ***Figure 1***.

Although they are specified for Class AB CW operation, the VEGA Series amplifiers are suitable for pulsed modulation, AM or FM and digital modulation schemes. Specifications can be modified to meet requirements from the standard broadband design to narrower or wider frequency ranges up to 230 MHz, RF output power, and mounting and connector types. The amplifiers can be specified to meet a variety of military specifications. One example is airborne operation, with an operating temperature range of -40° to +55°C, altitudes up to 10,000 ft., and shock and vibration per MIL STD-810F Method 516.5.

Other models in the series include:

- VEGA6 driver amplifier, delivering 6 W CW from 20 to 88 MHz or 20 W CW from 30 to 150 MHz or 1.7 to 30 MHz
- VEGA50, providing 50 W CW from 100 to 500 MHz
- VEGA100, with 100 W CW from 10 to 175 MHz
- VEGA150, delivering 150 W CW from 20 to 150 MHz
- VEGA200, providing 200 W CW from 30 to 88 MHz

The company has designed and manufactured solid-state RF power amplifiers that deliver extremely high power levels required for scientific and radar applications with RF

TABLE 1 TYPICAL VEGA SERIES AMPLIFIERS SPECIFICATIONS	
Frequency range (MHz)	1.5 to 30
RF Output Power, CW or P1dB (W)	≥ 1000
Gain (dB)	26
Efficiency (%)	65
Harmonic Rejection Second (dBc) Third (dBc)	 -37.3 -13.3
Spurious Rejection (dBc)	-70
Third-Order Intercept Point (dBm)	+69
Return Loss (dB)	Input: -14 Output: -20
Switching Rise and Fall Times (ns)	200
Environmental Operating temperature Range (°C) Humidity (%) Altitude (ft.) Shock and Vibration	 -40° to +55° 95 non-condensing 10,000 Meets MIL-STD-810F Method 516.5
Operating Voltage, Current (VDC, A)	+48 to +52, 27
Dimensions (in.)	4.1 × 2.6 × 1.2
Weight (oz.)	17
Connectors	SMA Female (input), Type-N (output)
Protection	Over-Temperature

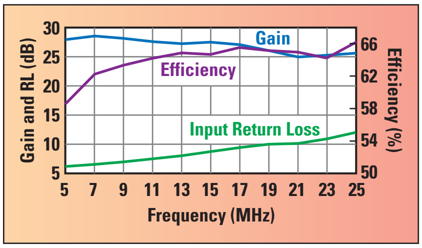
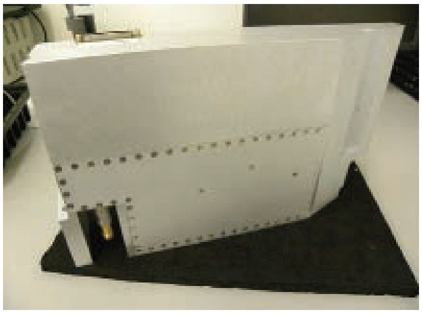


Fig. 1 Gain, efficiency and return loss of a VEGA Series 1 kW RF power amplifier.

outputs as high as 350 kW. A recent example is an amplifier system that powers the Doppler radar wind profiler (DRWP), recently deployed at the Kennedy Space Center. It consists of 20, 16 kW subsystems, each consisting of 10 hot-swappable LDMOS RF power amplifier modules for a total output per module of 2 kW. The subsystem can produce RF output power greater than 16 kW. The output of each subsystem is then combined to produce power up to 350 kW.

The DRWP power amplifier has a soft fail capability that allows it to continue to operate if one of the modules fails, after which a new module can be "hot swapped" for the failed one while the system is running. This quickly returns the system to full-power. Efficiency of the DRWP amplifier is about 75 percent, 45 percent from AC to RF output. The total combining losses for the entire amplifier system is only 0.3 dB, including the 40 final-stage transistors, absorptive lowpass filters, and a patented transmit/receive solid-state switch.

Delta-Sigma Inc.
Riverside, Calif.
www.111rfpower.com



1200 W, High Efficiency S-Band PA

Using GaN technology, Delta Microwave has developed a 1200 W high efficiency power amplifier (PA) for S-Band pulsed radar applications. The PA delivers a minimum of 1200 W across 2.9 to 3.1 GHz with 40 percent power-added efficiency and 45 dB minimum gain. The amplifier will handle pulse widths up to 100 µs and 10 percent duty cycle, with a maximum droop of 0.5 dB. Harmonics are -50 dBc maximum, and input VSWR is 2:1 or better. The signal interfaces to the PA are a female SMA at the input and female Type-N at the output.

The operating temperature range is -30° to +70°C, with integrated protection for over-temperature, high duty cycle and high pulse width conditions. The amplifier is biased with 32 V DC and includes over-current protection. SSPA includes internal microprocessor for TIA-485 data interface.

Delta Microwave
Oxnard, Calif.
www.deltamicrowave.com

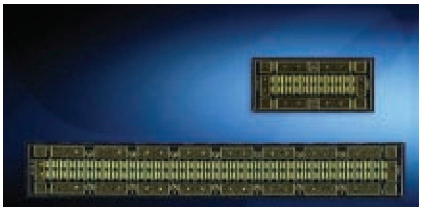
0.1 to 18 GHz, 80 x 5 Distribution Matrix

For airborne surveillance and similar applications, Custom Microwave Components offers a broadband distribution matrix that switches any of 80 octave-band inputs to any of five outputs (nonblocking). The output frequency range covers 100 MHz to 18 GHz. The signal path from input to output has a nominal gain of 0 dB with less than 14 dB noise figure. Leakage across any of the channels is less than 60 dB. Paths can be grouped into sets that amplitude and phase track. Channels can be selected within 2 μsec, and output blanking occurs in 100 nsec.

The 12U rack-mounted unit's environmental operating range is 0 to +55°C, up to 95 percent relative humidity, vibration meeting Mil-STD-810F Method 514.5 and 50,000 foot altitude.

First developed in 2003, the distribution matrix has a history of reliable service. The RF units are line replaceable, enabling field service and upgrades, if required. The design allows user-defined controls, which provides additional flexibility.

Custom Microwave Components Inc.
Fremont, Calif.
www.customwave.com



High Power 50 V GaN HEMT

Cree has extended its family of 50 V discrete GaN high electron mobility transistors (HEMT) with three new die products: a 320 W transistor, usable to 4 GHz; and 75 and 20 W devices, usable to 6 GHz. These three new products join two others – with 170 and 40 W output – to comprise the only 50 V GaN HEMT die product portfolio on the market.

The 320 W device is the industry's highest power 50 V GaN die product available. It typically provides 19 dB small-signal gain with 65 percent power-added efficiency at 4 GHz. The 20, 40, 75 and 170 W devices in the family operate to 6 GHz, with typical performance of 17 dB small-signal gain and 60 percent power-added efficiency. At 4 GHz, the devices deliver 18 dB small-signal gain with 65 percent power-added efficiency.

All devices in the family are fabricated with Cree's 0.4 µm, 50 V process and offer hybrid amplifier designers higher gain, efficiency and power density with wide instantaneous bandwidth. With its high breakdown voltage, thermal conductivity and saturated electron drift velocity, GaN is an effective alternative to silicon (Si) and gallium arsenide (GaAs). The 50 V product family is suitable for various market applications, including two-way private radio, broadband amplifiers, cellular infrastructure, test instrumentation, tactical and satellite communication and industrial, scientific and medical (ISM) amplifiers.

Cree's GaN HEMT die are supplied in Gel-Pak® Vacuum Release™ trays, a non-tacky membrane that immobilizes the components to ensure damage-free transportation and storage.

Cree Inc.
Durham, N.C.
www.cree.com/RF/Products/General-Purpose-Broadband-50-V

AEROSPACE & DEFENSE ELECTRONICS

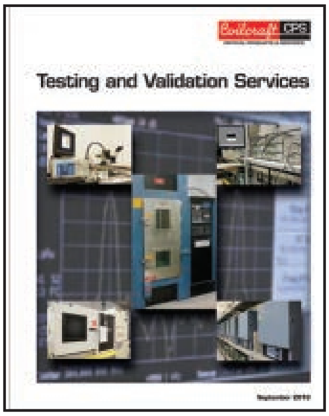
COMPANY SHOWCASE

RF and Microwave Technology

VENDORVIEW

Anaren Inc. is a Syracuse-based, global leader in RF and microwave technology used in wireless infrastructure, satellite, defense and consumer-electronics applications. The company has approximately 1,000 employees and five state-of-the-art facilities worldwide. Product lines include: standard passive components (e.g., couplers, power dividers, baluns, resistors, attenuators, terminations), RF multichip modules, high-reliability softboard and ceramic PCBs, and complex assemblies (e.g., switching, beamformers, antenna feed networks, DRFMs, IMAs).

Anaren Inc.
www.anaren.com



Testing & Validation Services

Coilcraft Critical Products & Services (CPS) offers a full range of product testing and validation services to help electronics manufacturers determine the reliability, repeatability and/or compliance of the electronic components and assemblies they manufacture or procure. Coilcraft CPS's testing capabilities include vibration and mechanical shock to MIL-STD-202, as well as complete electrical testing, elemental analysis, radiographic inspection, thermal shock and cycling, and other environmental and analytical lab services.

Coilcraft CPS Inc.
www.coilcraft-cps.com/pdf/testing.pdf

RF and Microwave Products

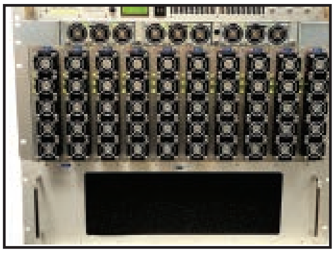
CPI's Beverly Microwave Division (BMD) designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. BMD has been located in Beverly, Mass. since 1947. CPI BMD is the world's largest manufacturer of receiver protectors and magnetrons. They also manufacture TWTs, CFAs, transmitter assemblies, scientific systems, high-power solid state switches and switch assemblies, pressure windows plus a wide variety of multi-function components and integrated microwave assemblies.

Communications & Power Industries
Beverly Microwave Division
www.cpii.com/bmd

Power Amplifiers Catalog

CTT announced a new four-page power amplifiers short form catalog. The catalog features more than 75 models developed for radar, EW and multi-function systems design. The amplifiers feature narrowband CW, narrowband pulsed, wideband (CW) and ultra-wideband (CW) coverage. Frequency coverage is 0.1 to 18 GHz. CTT's family of solid-state amplifiers are finding applications in many of the next generation of high-performance communications, instrumentation and medical systems where high power is required.

CTT Inc.
www.cttinc.com



High-Power Amplifier Showcase

Delta-Sigma Inc. has expanded its website with greater detail about its custom high-power RF amplifier modules, subsystems and complete systems (such as the 16 kW amplifier shown) for commercial, medical and scientific applications. The site describes the company's ability to design and manufacture unique RF power amplifier systems that combine high efficiency and linearity in compact footprints with CW or pulsed RF power output from 1 kW to more than 250 kW at frequencies up to 3 GHz.

Delta-Sigma Inc.
www.111rfpower.com

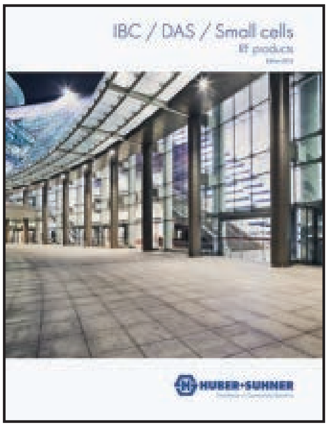
RF Relay Switches

Fairview Microwave recently debuted a new portfolio of electromechanical RF relay switches that cover ultra-broadband and millimeter wave frequencies up to 40 GHz. These high-reliability RF switches are guaranteed to perform up to 2 to 10 million life cycles, which make them an ideal solution for demanding industries and applications related to military/defense, aviation, radar, wireless communications, satellite communications, and test & measurement. Available in multiple varieties from SPDT (Single Pole Double Throw) to SP12T (Single Pole 12 Throw) and designed with either SMA, Type-N or 2.92 mm depending on frequency range.

Fairview Microwave
www.fairviewmicrowave.com

AEROSPACE & DEFENSE ELECTRONICS

COMPANY SHOWCASE

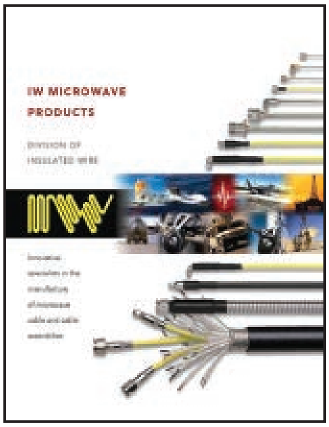


IBC/DAS/Small Cells Catalogue

VENDORVIEW

When it comes to availability and quality of wireless data communication services, the high coverage requirements apply equally both outside and inside buildings. With the implementation of dedicated solutions like distributed antenna systems (DAS), additional capacity for voice and data channels can be created as required. The HUBER+SUHNER IBC/DAS/Small Cells product catalogue contains a wide range of radio frequency solutions that support all applications in the deployment of the mobile communication network in urban environments. Visit HUBER+SUHNER's microsite at www.wireless-infrastructure.com/solutions for a closer look.

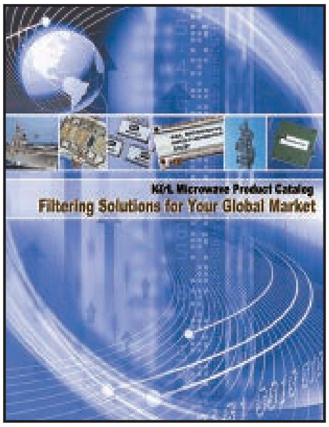
HUBER+SUHNER
www.hubersuhner.com



New 2015 Catalog

IW presents their new catalog for 2015. The latest edition features a new data sheet format with increased technical content including tabulated and graphical data for all cables including stranded center conductor, expanded Re-Flex™ options, attenuation values in dB/m, useful cable handling instructions and new product specifications – IW introduces 0471, 170 series and RF250 following customer demand for smaller diameter cable, improved attenuation and extended frequency range for SATCOM applications, and the most versatile RG401 replacement available, respectively. IW – We're Flexible!

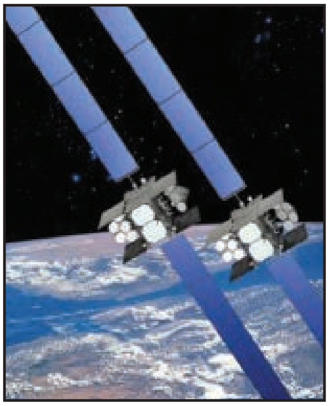
Insulated Wire Inc.
www.iw-microwave.com



2015 Product Catalog

K&L designs and manufactures a full line of RF and microwave filters, duplexers and subassemblies, including ceramic, lumped element, cavity, waveguide and tunable filters. The catalog shows filter responses, loss calculations and standard packages for all products. K&L supplies many of today's most significant military and homeland security electronics programs. Applications include space flight, radar, communications, guidance systems, mobile radio base stations as well as air traffic control and communications. Visit www.klmicrowave.com to download the complete catalog.

K&L Microwave
www.klmicrowave.com



Success in NewSpace

VENDORVIEW

The space industry is in the midst of dramatic change. NewSpace is driving disruption that hasn't been seen since the original space race in the 1960s. Developing new strategies, processes and requirements – especially those associated with electronic design, development and production – will be critical to working in NewSpace. Keysight's latest white paper, "Utilizing Commercial Best Practices for Success in NewSpace," describes the challenges that these business models put on electronic design and test strategies and processes.

Keysight Technologies Inc.
www.keysight.com/find/satellite-focus

Indirect Synthesizer with Frequency Modulation

Kratos General Microwave enhanced its family of indirect synthesizers with the addition of model SF6218 with frequency modulation capability. It can provide a frequency deviation of 1 GHz at up to a 10 MHz rate and can be controlled with either analog or digital inputs. Of special significance, the synthesizer output frequency remains fully locked even while in the FM mode. Its small size and high reliability make it ideal for use in demanding airborne environmental conditions as well as test systems.

Kratos General Microwave Corp.
www.kratosepd.com/solutions/kratos-general-microwave

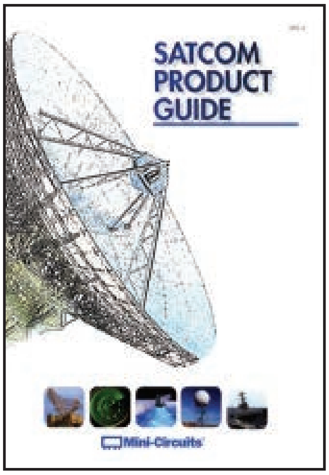
Advanced Microelectronics Centers

Mercury's Advanced Microelectronics Centers offer state-of-the-art design and manufacturing for RF and microwave components and subsystems. They offer capabilities designed to reduce costs and drive affordability. Highlights include: streamlined supply-chain with one-stop shopping from design through manufacturing, decreasing supply-chain complexity, significantly reducing risk; world-class automation – from production through testing – lowering costs; co-located design and manufacturing engineering assets to optimize on-board and build-to-print work; plus redundant, state-of-the-art manufacturing capabilities scale from design to full-rate production. ISO 9001 certified.

Mercury Systems Inc.
www.mrcy.com

AEROSPACE & DEFENSE ELECTRONICS

COMPANY SHOWCASE

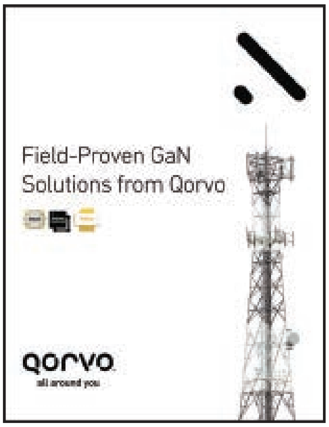


SATCOM Product Guide

VENDORVIEW

Mini-Circuits has released a new SATCOM product guide in print and for download from their website. This 32-page guide features a full survey of components and assemblies for satellite and earth station systems. With selected products from over 20 different product types to 40 GHz, the guide provides key performance parameters for each product and serves as a handy reference for engineers evaluating parts for their design needs.

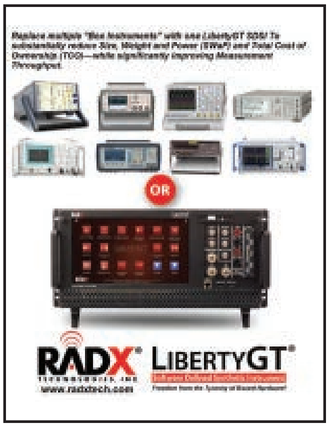
Mini-Circuits
www.minicircuits.com



Field Proven GaN Solutions

Qorvo's high-performance GaN technology supports products from DC through Ka-Band for military and commercial applications. Qorvo continues to build on its 15-year GaN legacy of innovation and reliability by offering new products and foundry services that strive to meet their partners' demanding system requirements. Their partners benefit from the 'trusted' supplier status and MRL-9 classification. Only Qorvo delivers performance, quality and reliability that sets the standard in the industry. For more information visit www.qorvo.com/defense.

Qorvo Inc.
www.qorvo.com/defense



RADX LibertyGT 1211B

Replace multiple "box instruments" with one LibertyGT SDSI to substantially reduce size, weight and power (SWaP) and total cost of ownership (TCO)—while significantly improving measurement throughput. The RADX® LibertyGT® 1211B is a modular, COTS, multifunction, programmable, upgradable software defined synthetic instrument (SDSI®) that supports a broad range of real time RF and microwave stimulus, test and measurement applications.

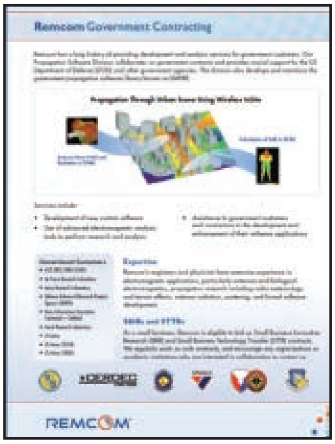
RADX Technologies Inc.
www.radxtech.com/lgt1211b

Filters, Multiplexers and Multi-function Assemblies

VENDORVIEW

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. This catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request your copy, please email reactel@reactel.com, or visit www.reactel.com.

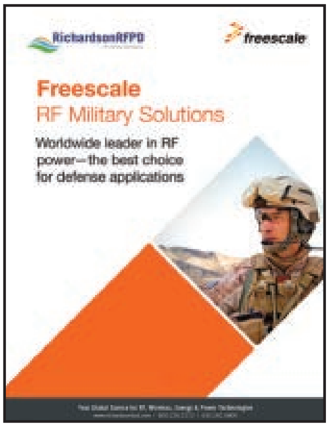
Reactel Inc.
www.reactel.com



Government Contracting

Remcom has a long history of providing development and analysis services for government customers. Their propagation software division collaborates on government contracts and provides crucial support for the U.S. Department of Defense (DoD) and other government agencies. The division also develops and maintains the government propagation software library known as EMPIRE. As a small business, Remcom is also eligible to bid on small business innovative research (SBIR) and small business technology transfer (STTR) contracts.

Remcom
www.remcom.com



Aerospace and Defense Portfolio

VENDORVIEW

Freescale's RF aerospace and defense portfolio encompasses a range of high-power solutions, including GaN, GaAs and LDMOS transistors and ICs, that support a wide variety of needs for military applications, such as avionics, HF through L- and S-Band radar, communications, electronic warfare, and identification, friend or foe (IFF). With leading-edge products and technology, a dedicated military products team, and its product longevity program, Freescale is your go-to source for aerospace and defense application needs. Brought to you by Richardson RFPD.

Richardson RFPD
www.richardsonrfpd.com

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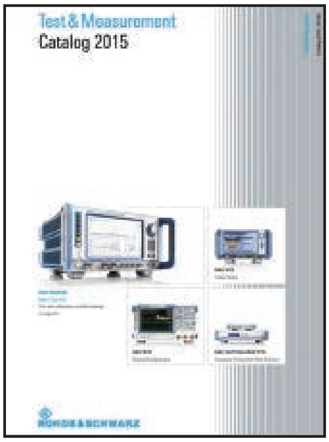
Coonrod's Corner Video Series

VENDORVIEW

John Coonrod hosts Coonrod's Corner, a series of videos approximately 5 minutes in length each, that will teach you about popular topics in the PCB industry. Become a member of the Rogers Corp. Technology Support Hub today to watch the video series, access Rogers' calculators, literature, technical papers and download the free ROG Mobile App for Apple and Android smartphones and tablets. Register for free at rogerscorp.com/techub.

Rogers Corp.
www.rogerscorp.com



Test & Measurement Catalog 2015

VENDORVIEW

Rohde & Schwarz' Test & Measurement Catalog 2015 features more than 200 pages of information about Rohde & Schwarz test & measurement instruments, systems and software. It includes a short description and photos of each product with important specifications and ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order a copy from customer support (order number: PD 5213.7590.42 V 05.00).

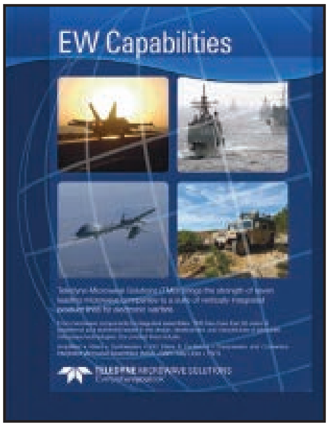
Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

Real-Time Spectrum Analyzer/RF Recorder

VENDORVIEW

The BB60C is a broadband real-time spectrum analyzer and RF recorder that captures and displays RF events as short as 1 µs. It has selectable IF streaming bandwidths from 250 kHz up to 27 MHz. With accurate operation from 9 kHz to 6 GHz over its entire temperature range (-40° to +65°C available), the BB60C is well-suited for lab or field use. It sells for $2879 USD, and includes an API for custom software development.

Signal Hound
www.signalhound.com



EW Capabilities

Teledyne Microwave Solutions (TMS) has deep experience providing a wide range of products and capabilities for the EW, ESM / ELINT and radar markets. They have worked with most of the large OEM system manufacturers to develop custom SSPAs for EW needs; produced a wide variety of high performance receivers based on their patented IFM and unique wideband super-heterodyne technology for specific RWR, EW, SIGINT and ELINT applications; and developed TWTs, TWTAs, YIGs, filters and other products for today's modern war-fighting systems.

Teledyne Microwave Solutions
www.teledynemicrowave.com

Harness Informational Briefing

Harnesses provide a multi-channel connectivity solution that requires minimal installation tools, delivers a compact connector footprint, removes the risk of crossed channels and misconnection, enables fast installation or replacement, and simplifies wire management and routing. This briefing discusses benefits, applications, design components, qualification testing and range of tailored harness solutions—both flexible and semi-rigid—that are available from Teledyne Storm.

Teledyne Storm Microwave
www.teledynestorm.com

GORE-FLIGHT™ Microwave Assemblies

GORE-FLIGHT™ Microwave Assemblies, 6 Series are lightweight cable solutions for airframe assemblies in military and civil aircraft applications. These new assemblies deliver the lowest insertion loss before and after installation, ensuring reliable performance for the life of the system. Their robust construction reduces total costs by withstanding the challenges of installation, reducing costly production delays, field service frequency and the need for purchasing replacement assemblies. The 6 Series are also lightweight, which improves fuel efficiency and increases payload.

W. L. Gore & Associates
www.gore.com/simulator

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The 2015 Defence, Security and Space Forum

At European Microwave Week

EuMA

Microwave Journal
Frequency Matters.

Wednesday 9 September – Palais Des Congrès, Paris

A focused Forum addressing the application of RF integrated systems for UAVs.

The 2015 EuMW Defence, Security and Space Forum will feature executives from industry, academia, the military and from space agencies. It will be held in combination with the opening of EuRAD and will conclude with a round-table discussion.

Programme:

10:50-18:45

EuRAD Opening Session

Strategy Analytics Lunch & Learn Session
This session will add a further dimension by offering a market analysis perspective, illustrating the status, development and potential of the market.

***Microwave Journal* Industry Panel Session**
The session offers an industrial perspective on the key issues facing the defence, security and space sector. In accordance with the theme for 2015, the Panel will address: RF and microwave development for UAVs.

EuMW Defence & Security Executive Forum
High-level speakers from leading European Defence companies present their view on RF microwave technology trends for the next generation UAV platforms and systems. The industrial speakers are complemented by speakers from government, agencies and research organizations who will offer their perspective of military/security needs, programmes, budgets and scientific research for next generation systems.

Cocktail Reception
The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates

Registration fees are €10 for those who have registered for a conference and €50 for those not registered for a conference.

As information is formalized, the Conference Special Events section of the EuMW website will give further details and will be updated on a regular basis.

Register online at www.eumweek.com

EuMW 2015
FREEDOM THROUGH MICROWAVES