Vol. 65 • No. 4

April 2022

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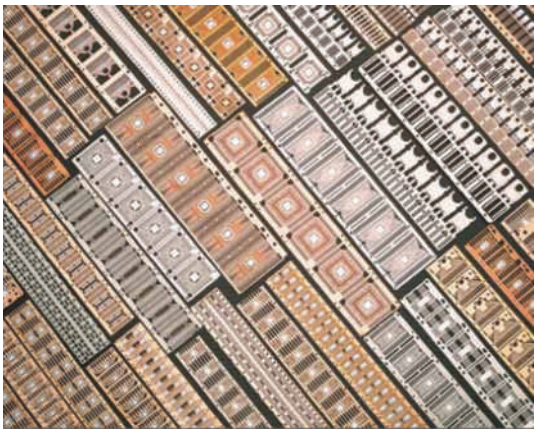

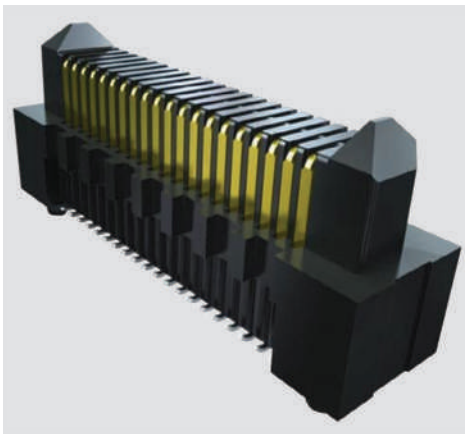

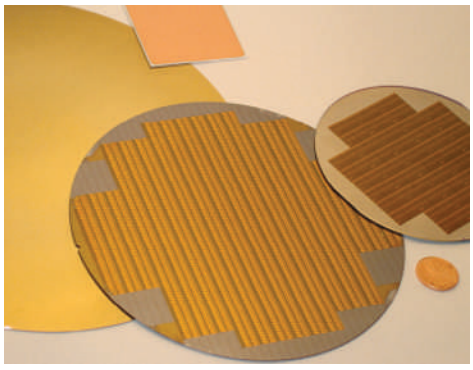

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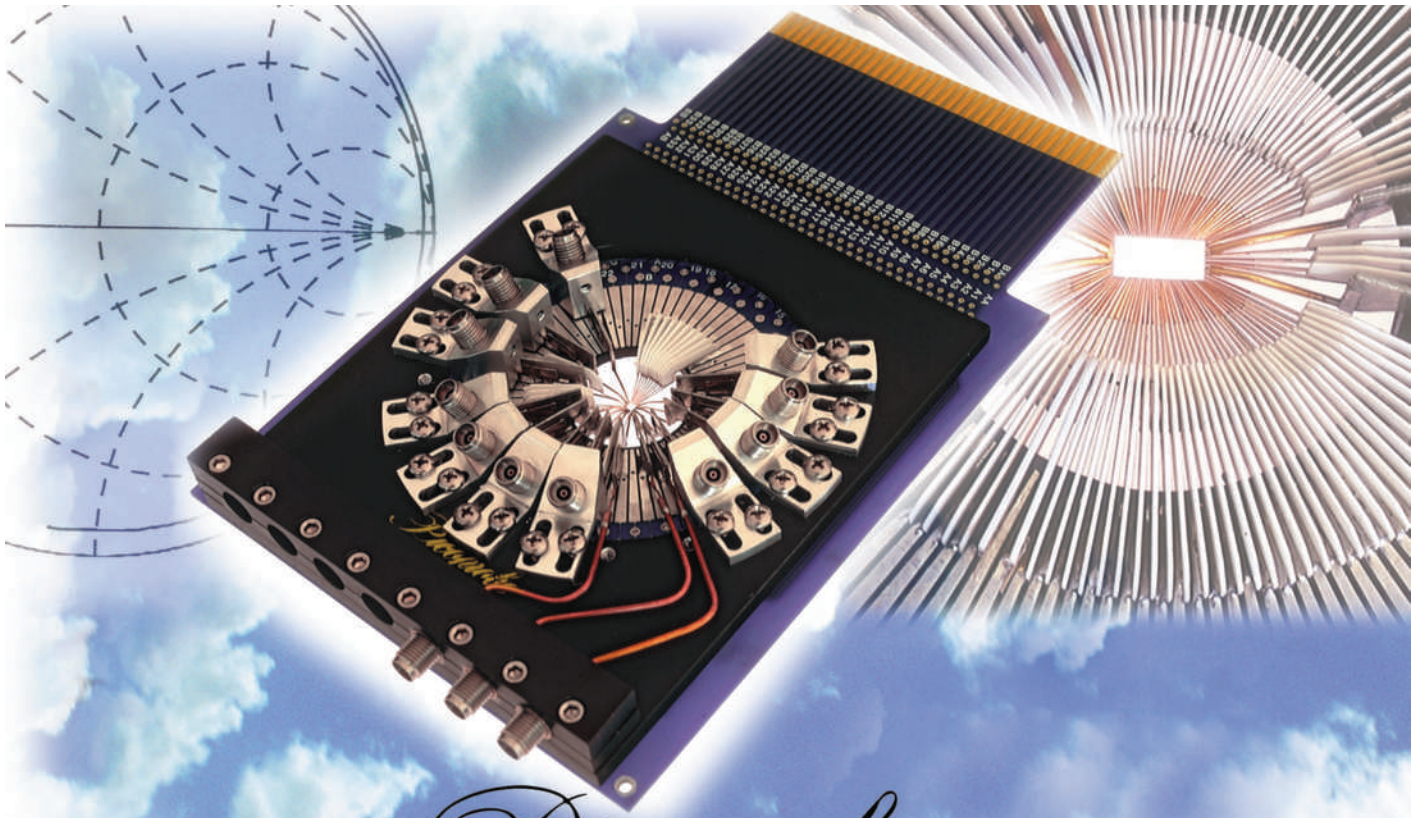

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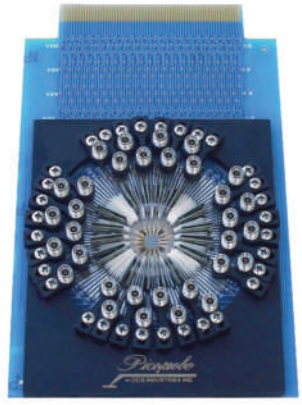

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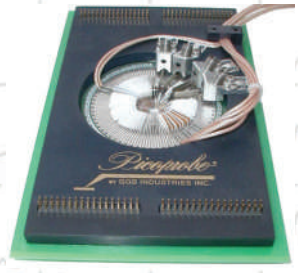

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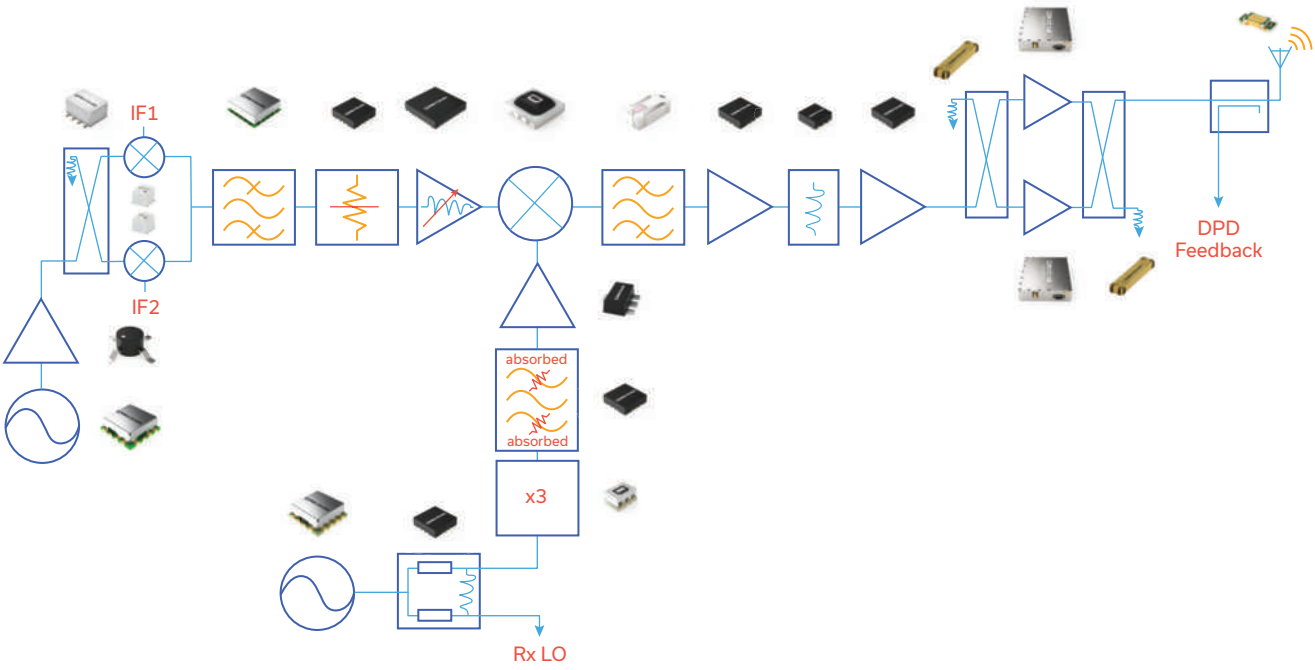

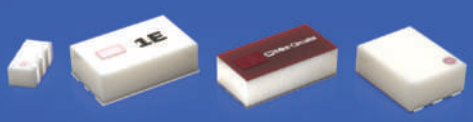

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- **Couplers**: DC to 7.2 GHz
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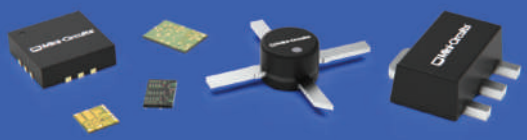


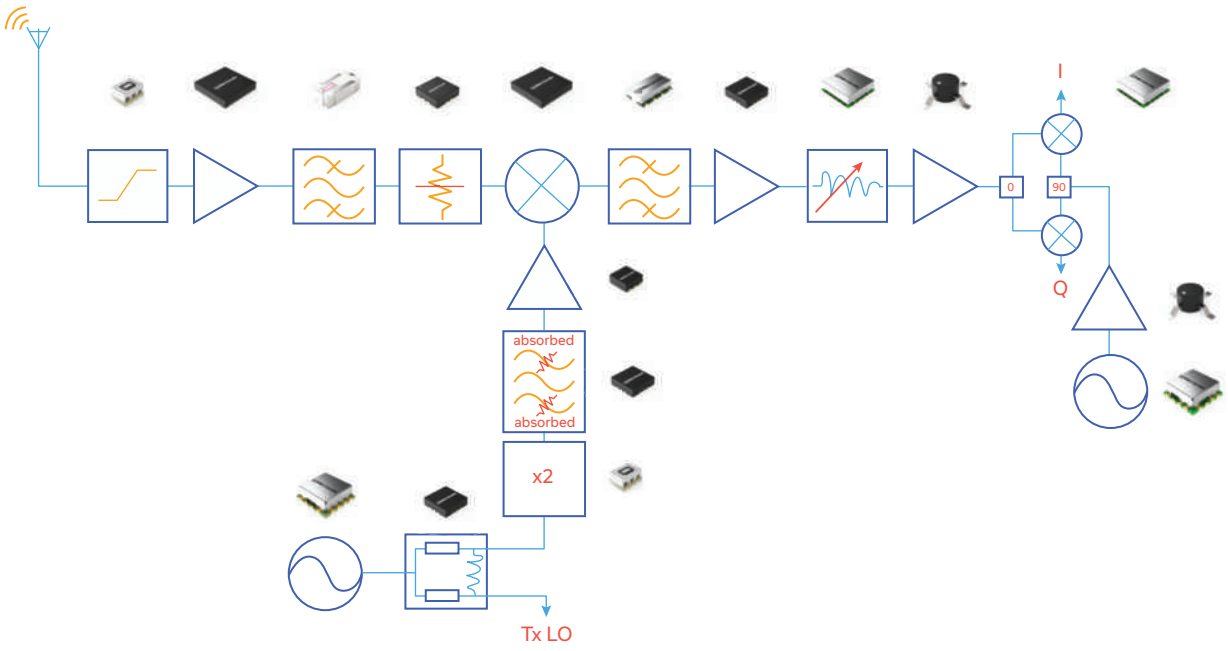
MMICs

700+ Models in Die or SMT

- **Amplifiers**: DC to 50 GHz
- **Control Products**: DC to 45 GHz
- **Frequency Conversion**: RF & LO to 65 GHz
- **Passives**: DC to 50 GHz
- **Reflectionless Filters**: Passbands to 40 GHz

AND MORE

DC TO mmWAVE



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PS-2G6G-8B-SFF

PS-2G18G-360-12D-TS

PS-255-2G18G-8B-SFF

PS-5G18G-400-A-SFF

PS-360-DC-3
OPTION 618-15D

Phase Shifters

PMI Model No.	Frequency Range (GHz)	Insertion Loss (dB)	Switching Speed	Phase Shift Range	Control	Size (Inches) / Connectors
PS-85M4G-9B-SFF	0.085 - 4	13 Max	500 ns Max	0 - 360°	Digital (9-Bit)	4.95" x 3.38" x 1.00" SMA Female
PS-200M10G-8B-SFF PS-2G6G-8B-SFF	0.2 - 10 2 - 6	10.5 Typ	500 ns Max	0 - 360°	Digital (8-Bit)	3.25" X 3.25" X 0.84" SMA Female
PS-2G18G-360-12D-TS	2 - 18	18 Max	410 ns	0 - 360°	Digital (12-Bit)	4.25 X 3.50 X 1.00 SMA Female
	2 - 18	18 Max	500 ns Max	0 - 255°	Digital (8-Bit)	2.00" x 2.10" x 0.50" SMA Female
PS-5G18G-400-A-SFF	5 - 18	12 Max	20 ns	0 - 400°	Analog	1.08" x 0.71" x 0.29" Removable SMA Female
PS-360-DC-3 OPTION 618-15D	6 - 18	12 Max	50 ns Max	0 - 360°	Digital (8-Bit)	1.6" x 1.75" x 0.5" SMA Female
PS-360-3237-8-292FF	32 - 37	13.0 Typ	500 ns Max	0 - 360°	Digital (8-Bit)	1.15" X 1.8" X 0.4" 2.92mm Female

Bi-Phase Modulators

PMI Model No.	Frequency Range (GHz)	Phase States	Switching Speed	Insertion Loss (dB)	Control	Size (Inches) Connectors
PS-90-0510 PS-90-2040	0.5 - 1 2 - 4	0° / 180°	75 ns Max	2.5 Typ 3 Max	TTL (ECL available)	1.0" X 1.0" X 0.50" Removable SMA Female
BPM-1G2G-1-SFF	1 - 2	0° / 180°	5 ns Max	8.8 Max	TTL	2.0" x 1.0" x 0.5" Removable SMA Female
BPM-2G6G-1	2 - 6	0° / 180°	50 ns Max	2.5 Max	TTL	1.5" x 1.5" x 0.5" Removable SMA Female
BPM-2G18G-180-SFF-MB	2 - 18	0° / 180°	100 ns Max	5.5 Max	TTL	2.25" x 1.60" x 0.60" SMA Female
PS-90-4080 PS-90-6012-HS15NS	4 -8 6 - 12	0° / 180°	75 ns Max 15 ns Typ	2.5 Typ 3 Max	TTL	1.0" X 1.0" X 0.50" Removable SMA Female
PS-90-8018	8 - 18	0° / 180°	75 ns Max	3 Typ 3.5 Max	TTL	1.0" X 1.0" X 0.50" Removable SMA Female
BPM-1840-180-292FF	18 - 40	0° / 180°	100 ns Max	8 Typ	TTL	1.0" x 1.0" x 0.5" 2.92mm Female

PS-360-3237-8-292FF

PS-90-0510
PS-90-2040

BPM-2G6G-1

BPM-2G18G-180-SFF-MB

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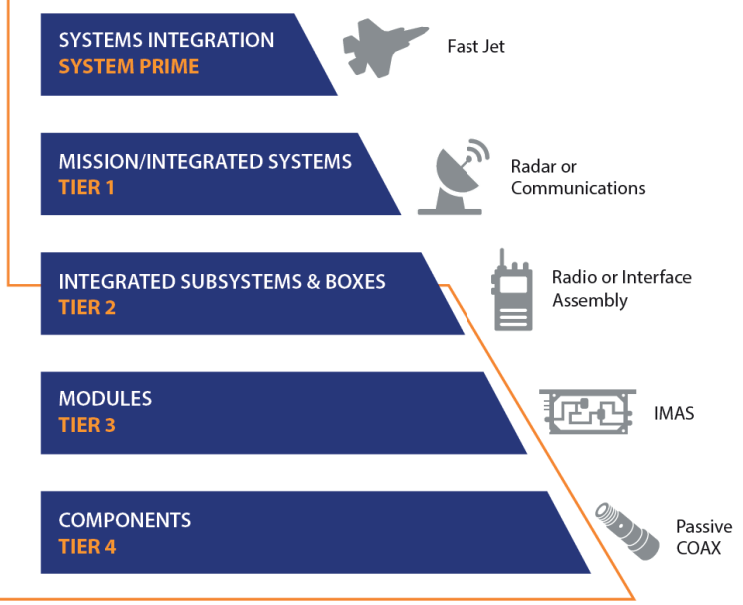

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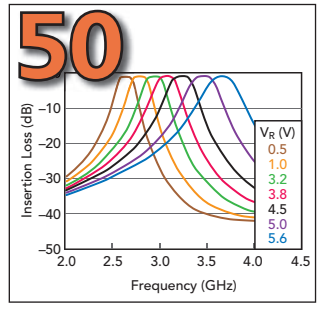

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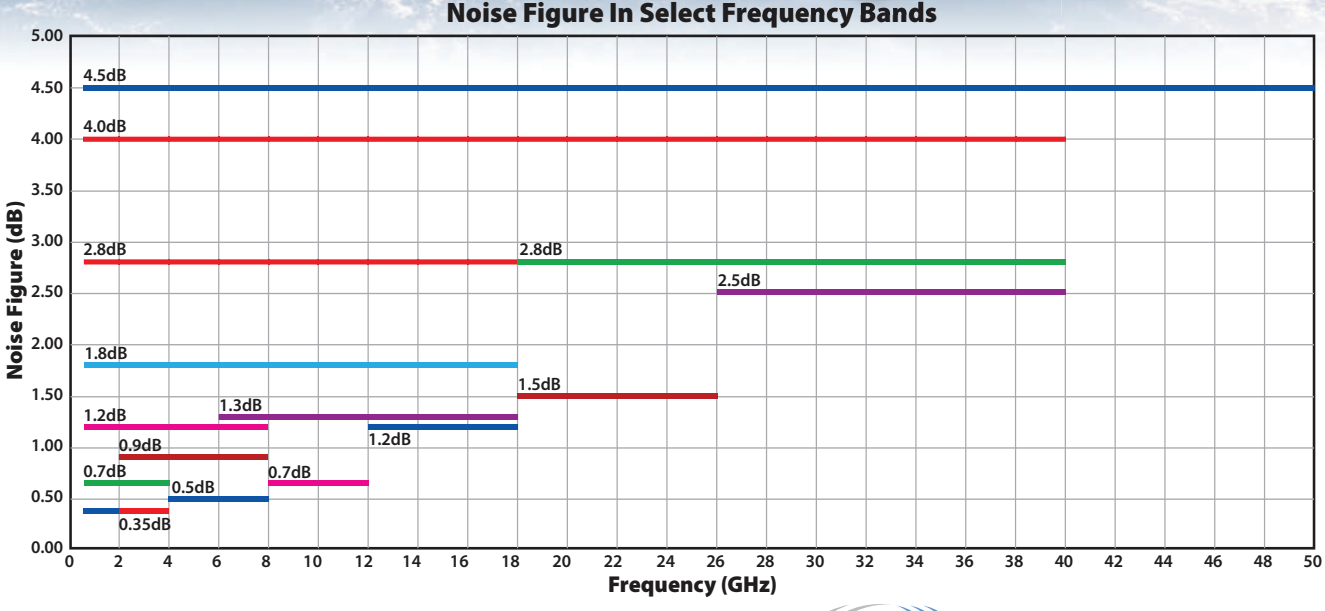

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Andy Lowery, the chief product officer at **Epirus**, shares the startup's vision for directed energy and power management systems, the technologies enabling the vision and why investors are excited about the opportunity.

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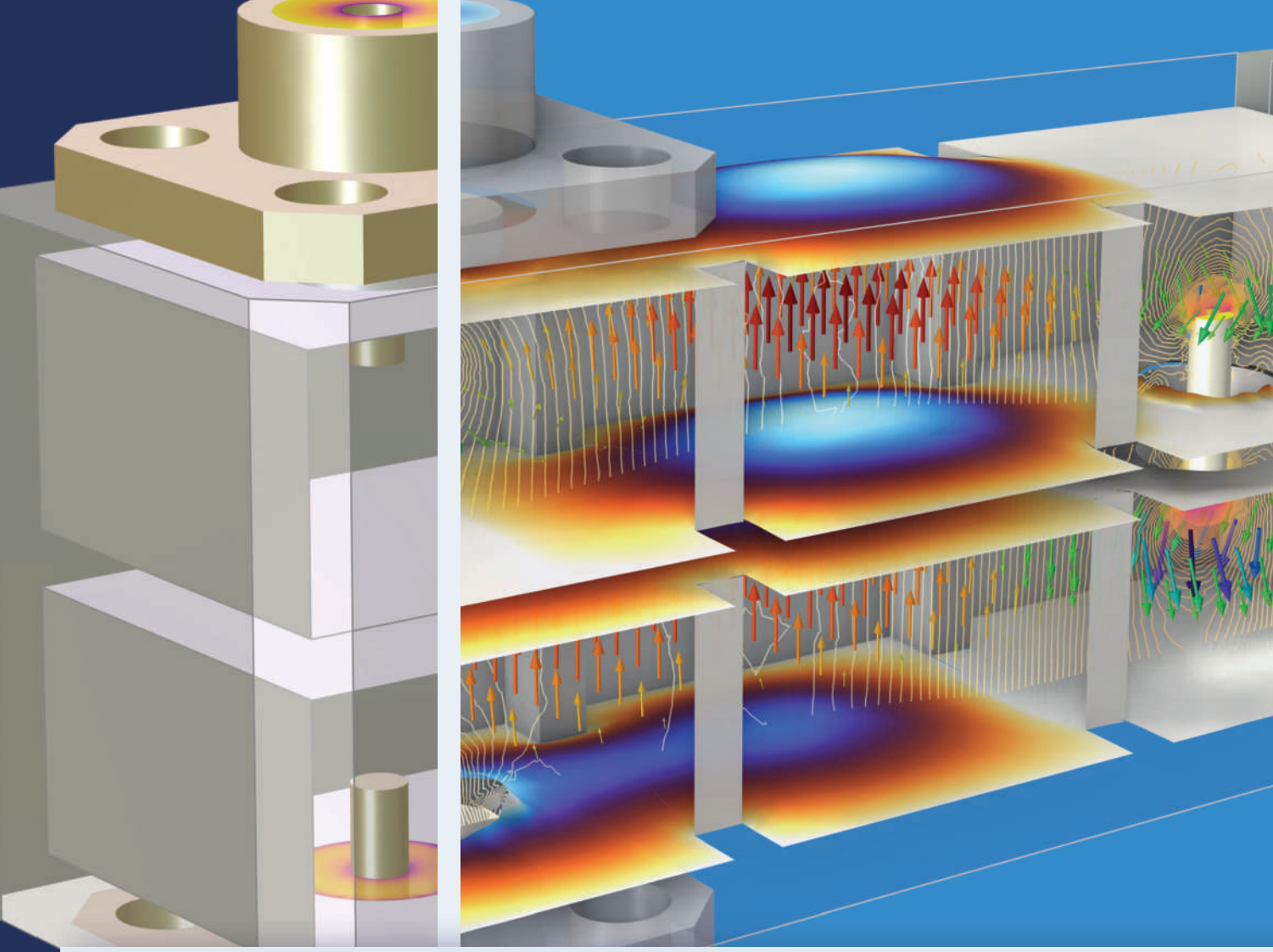

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Improving Oscillator Dynamic Phase Noise with Passive Vibration Isolation and Accelerometer-Based Vibration Compensation

Narayan Propato, Mehran Mossammaparast and Patrick Mullin
Wenzel Associates, A Quantic Company, Austin, Texas

Oven-controlled crystal oscillators (OCXOs) provide highly stable, low aging and low noise frequency sources for applications in instrumentation, test equipment and telecommunications (including 5G) in the commercial, defense, military and space markets. When OCXOs are employed in high vibration environments, such as ships and aircraft, the resulting performance degradation must be considered. Improving an OCXO's dynamic phase noise by lowering its acceleration sensitivity can help improve overall system performance in these applications.

In this article we present an accelerometer-based vibration compensation system that mitigates the effects of vibration on OCXO dynamic phase noise. We examine the use of this active compensation system as well as passive vibration isolation and discuss challenges and design considerations related to these techniques.

THEORETICAL BACKGROUND

Vibration and Dynamic Phase Noise

An OCXO's performance is largely dependent on the exciter's quartz crystal, a piezoelectric resonator whose high Q factor enables the low phase noise characteristic of this type of oscillator.[1] However, the dynamic phase noise exhibited by an OCXO in a high vibration environment often exceeds its static (resting) phase noise, limiting its performance. This is due to the fact that when mechanical force is applied to the crystal, such as when it experiences what is referred to as "proper acceleration" (as opposed to free fall, for example), the stress induced in the quartz lattice causes the oscillator's frequency to change.[2] The crystal's acceleration sensitivity (or g-sensitivity) is a measure of how much its frequency changes in relation to the acceleration experienced by it. Since the quartz lattice structure is anisotropic, the crystal's g-sensitivity is characterized by the vector $\vec{\Gamma}$ (1/g). Applying an acceleration vector $\vec{a}$ (g) to a crystal of frequency f_0 (Hz) results in a frequency change Δf (Hz) determined by the relationship

$$\Delta f = \left(\vec{\Gamma} \cdot \vec{a}\right) f_0 \quad (1)$$

When the applied acceleration $\vec{a}$ is a sinusoid characterized by a vibration frequency f_v (Hz) and peak acceleration vector $\vec{A}$ (g)

$$\vec{a} = \vec{A} \cos\left(2\pi f_v t\right) \quad (2)$$

the resulting vibration-induced frequency shift described in Equation 1 will vary over time. This type of frequency modulation creates spectral line pairs that are offset from the carrier frequency f_0 at integer multiples of the vibration frequency f_v. In practice, for many applications the corresponding modulation index is sufficiently low that only the first spectral line pair contains a measurable amount of power, as shown in ***Figure 1***. In these cases, I_1 (f_v) (dBc), the ratio

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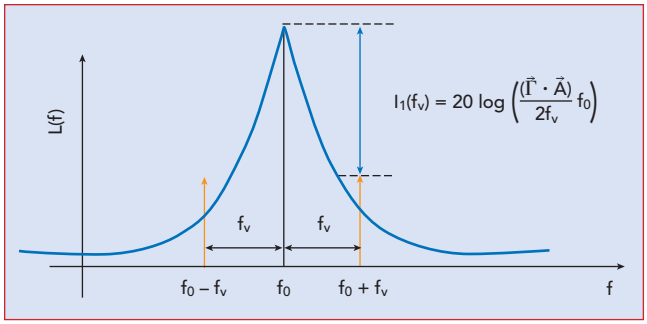

Fig. 1 **Spectral line pair induced by sinusoidal vibration.**

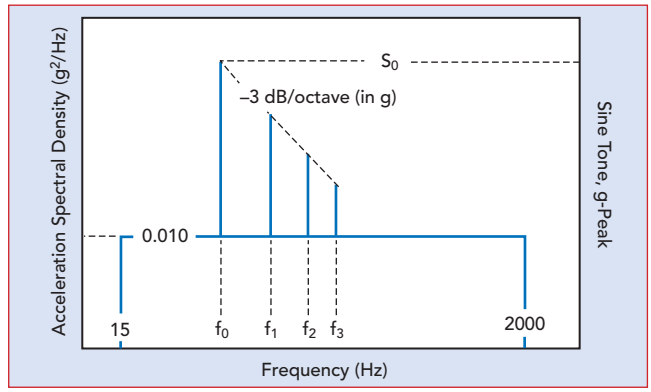

Fig. 2 **MIL-STD-810H Method 514.8, Annex D, Section 2.2, Category 13 – Propeller aircraft, Fig. 514.8D-2. Vibration environment characterized as sine-on-random vibration profile.[3]**

of the power of this first spectral line pair to the power of the carrier, is

$$I_1(f_v) = 20\log\left(\frac{(\vec{\Gamma}\cdot\vec{A})}{2f_v} f_0\right) \quad (3)$$

For example, a 100 MHz SC-cut crystal with a $|\vec{\Gamma}|$ of 3×10^{-10}/g is vibrated with a 100 Hz, 2g single-amplitude sinusoid in the direction of its $\vec{\Gamma}$ will have its frequency shift within ±60 mHz of its nominal frequency (Equation 1). The corresponding spurious power ratio would be approximately -70 dBc (Equation 3). If the vibration frequency had instead been 1000 Hz the spurious power ratio would decrease by 20 dB to approximately -90 dBc. Finally, if instead the vibration were applied perpendicularly to the crystal's $\vec{\Gamma}$ the oscillator's frequency would be unaffected, and no spectral lines would be created.

Real-world environments are usually not limited to exhibiting deterministic vibration in the form of discrete sinusoids. Instead, they exhibit random (non-deterministic) vibration which is characterized by using the statistical approach of power spectral density, specifically acceleration spectral density (ASD) specified in g^2/Hz. ***Figure 2*** shows an example "sine-on-random" vibration profile comprised of discrete sine tones overlaid on top of an ASD profile. The single sideband phase noise L(f) (dBc/Hz) caused by a vibration ASD profile $\vec{G}(f)$ (g^2/Hz) at a particular frequency offset from the carrier is

$$L(f) = 20\log\left(\frac{(\vec{\Gamma}\cdot\hat{G}(f))\sqrt{2|\vec{G}(f)|}}{2f} f_0\right) \quad (4)$$

For a flat ASD profile, induced phase noise will decrease by 20 dB per decade just as in the example provided for Equation 3. This can be observed in the hard mounted configuration performance shown in ***Figure 3***.

Due to practical difficulties associated with effecting vibration in all three axes simultaneously, testing methodologies such as ones defined in MIL-STD-810H allow for dynamic performance to be assessed on a per axis basis.[3] In applications that specify a vibration profile be applied to the OCXO, the resulting dynamic phase noise is used to evaluate performance. When the vibration profile is not yet known, the OCXO's g-sensitivity can be presented instead, which can be calculated from phase noise data using Equations 3 or 4 for sinusoidal and random vibration, respectively.

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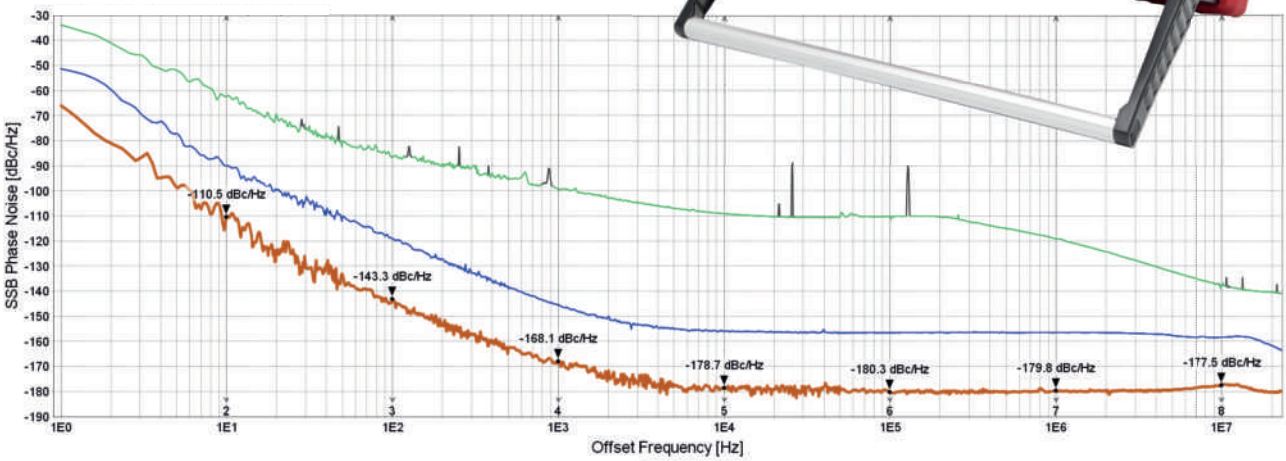

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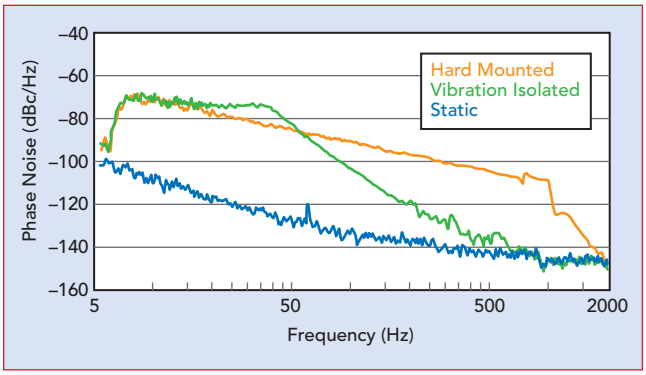

Fig. 3 **Effect of passive vibration isolation on Wenzel OCXO dynamic phase noise measured with Microchip Technology 53100A phase noise analyzer. (Note: measured static phase noise limited by measurement setup.)**

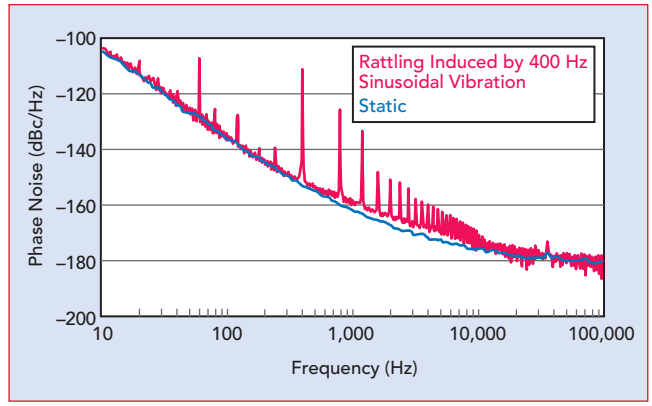

Fig. 4 **Rattling induced by 400 Hz sinusoidal vibration on Wenzel OCXO measured with Rohde & Schwarz FSWP signal analyzer.**

Resonances and Rattling

Each part of a physical system has a natural frequency that is determined by its relevant mass and stiffness. If the relevant damping factor is low enough the system becomes resonant: amplifying the vibration experienced around the resonant frequency but attenuating it above the resonant frequency. The specific transfer function associated with each of these resonances is determined by the mechanical properties of the system and the affected area can range from a single component to the entire product.

Unintentional resonances caused by components, PCBs and chassis can create spectral lines, degrade dynamic phase noise and reduce reliability. It is often possible to move these resonances beyond the bandwidth of the vibration profile by staking components, adjusting chassis geometry and increasing the number of PCB mounting points. In environments with high acoustic levels, damping material may be necessary to reduce resonances in the kilohertz range.

Since resonances amplify vibration, they also cause displacement relative to non-affected parts of the system. Collisions occur when this relative displacement becomes too large for a given geometry and rattling can occur due to the repetitive nature of vibration. This can occur even between coupled objects if the force created by vibration exceeds the coupling force holding the objects together. Unlike resonances, rattling is a non-linear phenomenon that may only occur at higher vibration levels and causes abrupt force impulses. This phenomenon can manifest itself as spurious content harmonically related to the rattling frequency and/or as broader phase noise degradation, as seen in ***Figure 4***. Consequently, one tell-tale sign of rattling is the presence of dynamic phase noise degradation outside the frequency range of the vibration profile.

G-sensitive Components

It is important to identify an OCXO's highest g-sensitivity components early in the design process to ensure they do not cause unacceptable phase noise degradation. The quartz crystal is generally the single largest source of g-sensitivity in a well-designed OCXO. However, other components such as transformers, inductors and capacitors can also exhibit significant g-sensitivity. Many RF cables, including ones rated to survive in high

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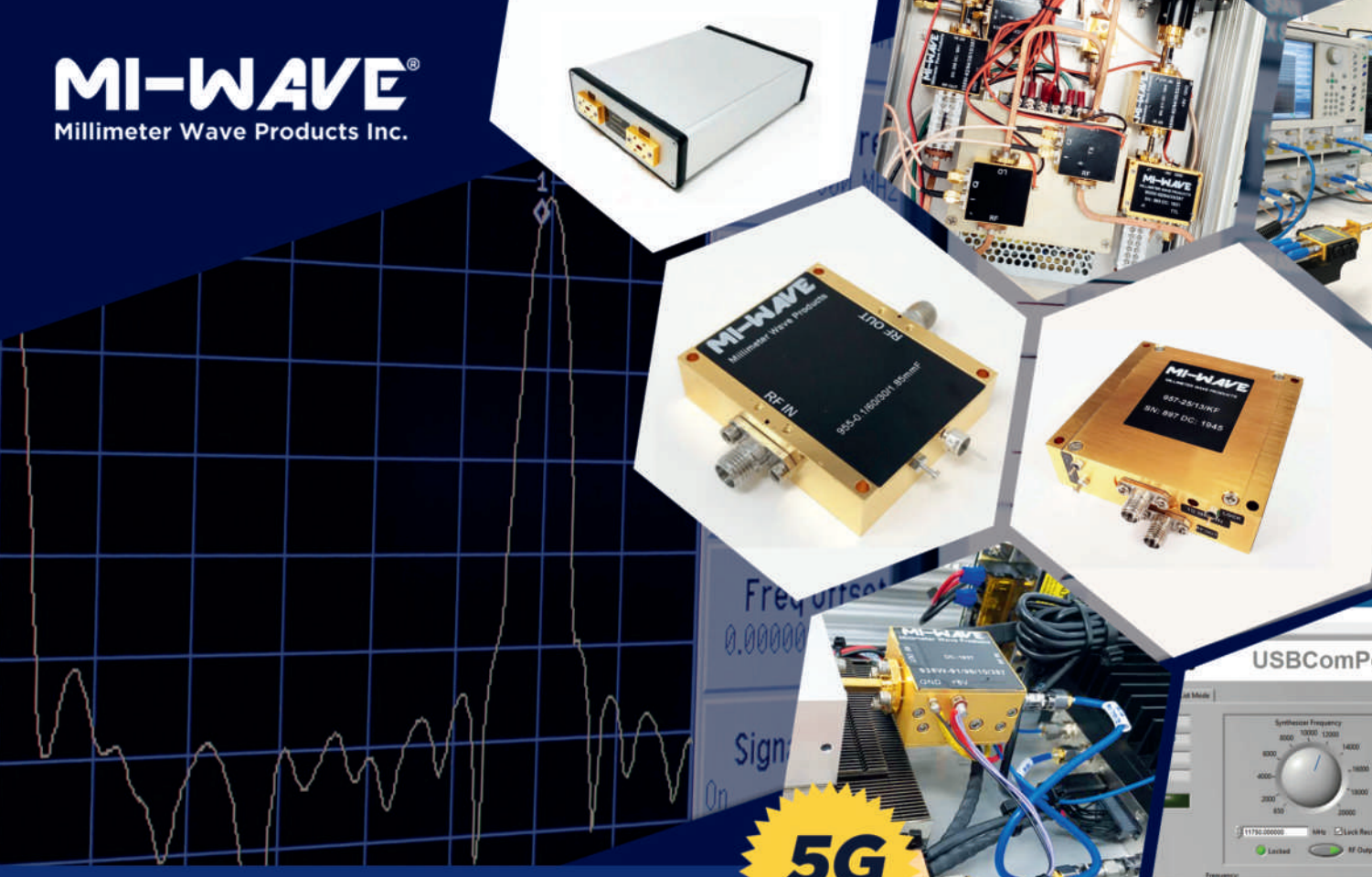

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vibration environments, have significant g-sensitivities and should be vibrated separately to confirm their performance is adequate.

Since most components do not list g-sensitivity on their datasheets, sinusoidal vibration can be applied on a component-by-component basis to help identify g-sensitive components and resonances. This data can be used to choose alternative parts or to position sensitive components to leverage the techniques discussed below.

Magnetic Interference

Due to the frequency content of many vibration profiles specified in modern applications, electrodynamic shakers, which can shake up to at least 2 kHz, are often used to simulate real-world vibration environments. Unfortunately, unlike a typical real-world vibration environment, electrodynamic shakers also create strong magnetic fields (both AC and DC) capable of degrading the phase noise of high performance OCXOs. It is important to separate this phenomenon from vibration-induced phase noise, since the magnetic degradation will not correlate to actual field performance. One simple way to distinguish between the two effects is to suspend the unit under test (UUT) near its normal mounting point on the test fixture while running the vibration profile, so that the UUT experiences roughly the same magnetic field without being vibrated.

Any degradation seen in this configuration is likely caused by the AC magnetic interference (typically observed under 30 Hz). Magnetic interference can be mitigated by several approaches, including the use of magnetic shielding materials (such as mu-metal), active magnetic compensation or the use of a hydraulic shaker (which is typically limited to a bandwidth of up to 500 Hz).

TECHNIQUES FOR IMPROVING DYNAMIC PHASE NOISE

Passive Vibration Isolation

Passive vibration isolators are a common way of mitigating the vibration experienced by a system. They attenuate external vibration experienced by the OCXO above the resonant frequency of the isolation system, thus lowering the resulting dynamic phase noise. As mentioned above, this resonant frequency is determined by the payload mass and the stiffness of the shock mounts used. Passive isolation can be very effective in vibration environments with high frequency vibration, but care must be taken, as the environmental vibration will be significantly amplified around the resonant frequency. This can be seen in Figure 3.

This is often a worthwhile tradeoff as attenuation increases every decade past the resonant frequency and many vibration profiles contain a significant portion of their power at higher frequencies. Passive isolation does significantly increase an OCXO's dimensions as the system must accommodate vibration isolators, a payload and outer case, and sway space for the two to move independently of one another.

Vibration isolation can also cause thermal isolation since the payload cannot be easily heat sunk effectively to the chassis. Careful thermal management is required for military temperature environments (-40°C to +85°C) to prevent overheating of the payload. Finally, snubbers should be placed to prevent exceeding the shock mounts' rated maximum displacement and should be sized to avoid damaging deceleration of the payload, particularly during shock acceleration events. When used properly, passive isolators can provide significant attenuation of high frequency vibration and prevent shock-induced damage to the OCXO.

Accelerometer-Based Vibration Compensation

Another way to improve an OCXO's dynamic phase noise is by using accelerometer-based vibration compensation. This method employs an accelerometer to measure the vibration signal vector $\vec{G}(f)$ (f) experienced by the crystal and uses this information to generate a compensation signal C(f) to counteract the vibration-induced phase noise. C(f) is applied to the OCXO's tuning line, modulating

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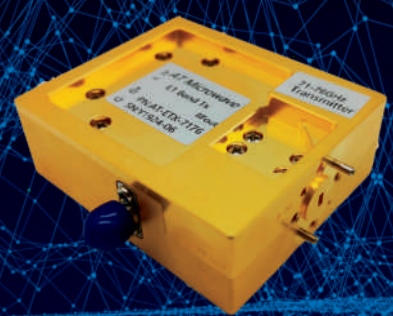

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its frequency according to its tuning sensitivity (Hz/V) much like the vibration signal $\vec{G}(f)$ modulates the OCXO's frequency according to the crystal's g-sensitivity vector $\vec{\Gamma}$. The vibration data for each axis is scaled according to its calibration factor (determined through testing) and combined to create a C(f) whose frequency modulation is the additive inverse of $\vec{G}(f)$'s. In practice, the compensation system's bandwidth is finite and can be limited by many factors including the accelerometer, the digital processing speed and the coupling between the accelerometer and the crystal. As the system's bandwidth is approached the phase shift between $\vec{G}(f)$ and C(f) increases, resulting in the compensation system's effectiveness diminishing over frequency.

The dynamic phase noise improvement obtained from applying accelerometer-based vibration compensation to a hard mounted 100 MHz OCXO subjected to an ASD of 0.02 g^2/Hz from 8 Hz to 1 kHz is shown in ***Figure 5***. The vibration compensation system achieves a Y-axis improvement of 30 dB or more from 40 to 160 Hz. The worst-axis phase noise is improved by 20 dB from 20 to 500 Hz. The compensation system's effectiveness is reduced at higher frequencies but still achieves a phase noise improvement of over 13 dB at 1000 Hz. The OCXO's compensated effective g-sensitivity $\vec{\Gamma}$ calculated at 100 Hz is (1.8×10^{-11}/g, 8.84×10^{-12}/g, 1.9×10^{-11}/g). The OCXO's worst-axis RMS jitter in the frequency range of interest (10 Hz to 1 kHz) is reduced from 2×10^{-12} to 1.7×10^{-13} s.

Achieving the results described above requires careful selection of key components, chief among them the accelerometer itself. Important performance characteristics of the accelerometer include frequency bandwidth (discussed above), cross-axis sensitivity and g range. Excessive cross-axis sensitivity may limit performance across the entire frequency range if not accounted for by the compensation system. The accelerometer's g range must be large enough to avoid saturation in the specified vibration environment.

Piezoelectric accelerometers provide a good combination of these characteristics, however as the bandwidths of MEMS capacitive accelerometers continue to improve, their inherent excellent temperature stability, small form factor and DC-coupled frequency response may prove more suitable for many applications. Low noise accelerometers of both technologies are available with signal-to-noise ratios that will neither limit compensation performance nor degrade the OCXO's static phase noise. Some are offered in triaxial configurations, which are easier to incorporate into a design than three individual uniaxial accelerometers but may not be available with the required combination of performance characteristics.

Implementing the compensation system digitally allows for calibration to be done via software and even be automated to facilitate batch production. The digital architecture can be leveraged to provide additional functionality such as phase-locking to an external reference, frequency holdover and frequency aging correction. Additionally, many modern accelerometers only offer a digital interface such as SPI or I^2C for communication, requiring the use of digital circuitry to decode their output. Furthermore, since a typical OCXO's tuning sensitivity (Hz/V) is not constant over voltage, vibration compensation performance can be compromised if the phase-locked loop shifts the tuning

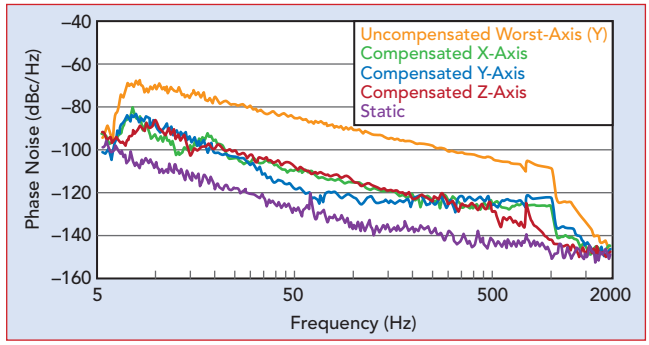

Fig. 5 **Effect of vibration compensation on Wenzel OCXO dynamic phase noise measured with Microchip Technology 53100A phase noise analyzer (Note: measured static phase noise limited by measurement setup).**

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voltage away from the point at which the unit was calibrated. While this effect can be minimized through careful tuning of the OCXO circuit, a digital system can eliminate it altogether by applying a correction factor derived through polynomial curve-fitting.

A potential drawback of using mixed-signal ICs such as ADCs and DACs is the introduction of additional sources of noise and bandwidth limitations. Noise mechanisms include noise voltage density, quantization noise and DAC glitch impulses. Attempting to filter this noise would result in degradation of the compensation signal C(f) and therefore lower compensation effectiveness. Consequently, it is necessary to prevent these sources of noise from being introduced into the circuit altogether.

Combining Passive Vibration Isolation and Accelerometer-Based Vibration Compensation

The two methods discussed above can be combined to provide synergistic benefits. An OCXO utilizing both techniques is shown in ***Figure 6***. Accelerometer-based vibration compensation attenuates the effects of vibration on the OCXO's dynamic phase noise at frequencies below its bandwidth. Conversely, passive vibration isolation is effective at reducing higher frequency vibration content, including frequencies above the compensation system's bandwidth, but amplifies vibration near the resonant frequency (typically below 100 Hz) where active compensation is most effective. The combined effect of both dynamic phase noise mitigation approaches can significantly improve an OCXO's performance, as shown in ***Figure 7***.

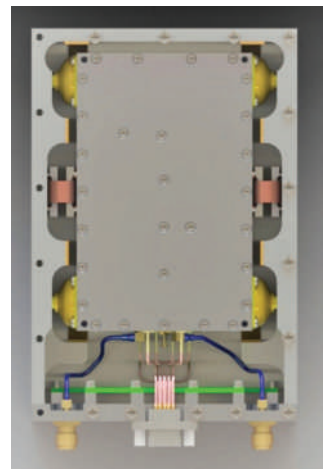

Fig. 6 **Vibration isolated and actively compensated OCXO.**

CONCLUSION

An accelerometer-based vibration compensation system achieved considerable dynamic phase noise improvement. The technology was successfully combined with passive vibration isolation. This active compensation technique complements the company's existing Bootstrap active compensation technology. ■

ACKNOWLEDGMENTS

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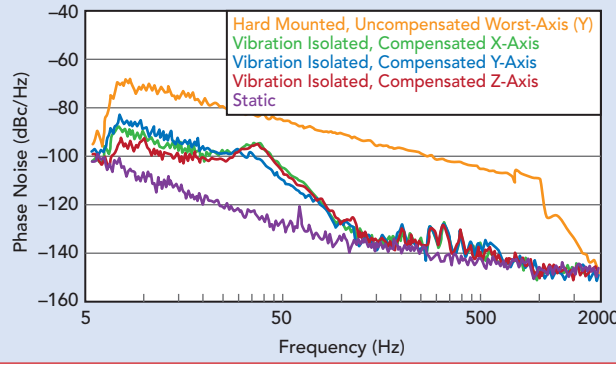

Fig. 7 **Combined effect of passive vibration isolation and active compensation on Wenzel OCXO dynamic phase noise measured with Microchip Technology 53100A phase noise analyzer (Note: measured static phase noise limited by measurement setup).**

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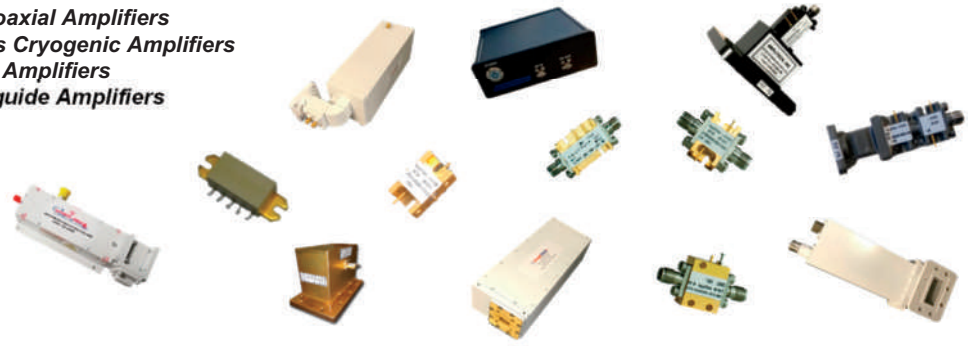

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APTW5-10951275-40K15-WR75D6	10.95-12.75	50	±0.5	35	1.5:1	15	+15	200
APTW4-17802130-100K10-WR42D4	17.3-22.0	38	±2.0	100	1.8:1	10	+15	175
APTW5-19251940-82K20-WR42D22	19.25-19.40	45	±0.5	82	1.3:1	+20	+15	250
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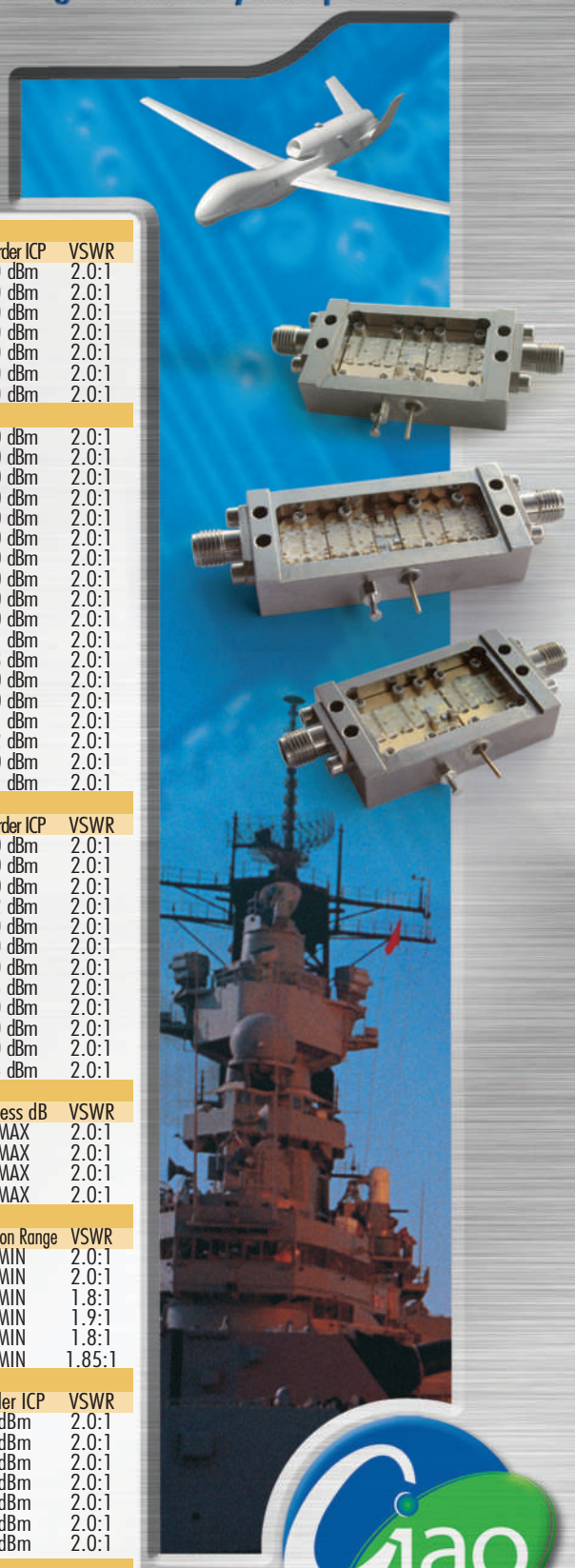

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Boeing is Building WGS-11+ Satellite Using Advanced Techniques to Deliver at "Record-Breaking Speed"

Boeing has begun building the latest version of the Wideband Global Satcom satellite system, WGS-11+, using advanced techniques to effectively integrate the latest commercial technology while enabling a high-paced five-year schedule that will deliver years faster than similar clean-sheet designs.

"We're moving at record-breaking speed to deliver the unmatched resilience, efficiency and throughput WGS-11+ offers our warfighters," said Col. Matt Spencer, Space Systems Command Geosynchronous Earth Orbit and Polar Division Senior Materiel Leader. "Boeing's ability to rapidly integrate the latest commercial technology into our infrastructure gives us a competitive edge on the battlefield."

Boeing and the U.S. Space Force completed the system's critical design review in late 2021, officially launching the program's production phase. Leveraging additive manufacturing, rapid prototyping, agile development and other advanced techniques, Boeing has created cost and schedule benefits, while boosting system performance.

"We're printing more than a thousand parts for WGS-11+, giving us the capability to introduce customization in a way that improves system performance, without requiring extensive integration times or customized tooling," said Troy Dawson, Boeing Government Satellite Systems vice president. "We understand how important speed is to the mission. That production speed translates to effectiveness against threats. As we continue to invest our technology and processes, we know that a similarly capable satellite could be delivered even faster."

WGS-11+ showcases an evolution in phased array technology. Based on Boeing's advances on its commercial 702X software-defined satellite payload, it is capable of generating hundreds of electronically-steered beams simultaneously, providing users with more than twice the mission capability compared to satellites within the existing WGS fleet.

Like 702X, each individual beam is shapeable and can be uniquely tailored to any operation, enabling increased mission flexibility and responsiveness. Narrower beamwidths with dual polarization unique to WGS-11+ help protect against jamming and interference while allowing greater frequency reuse.

When it joins the constellation of ten WGS satellites, WGS-11+ will substantially increase throughput capacity of essential communication services for the U.S. government and its allies. It is scheduled for delivery in 2024.

LM Selected to Prototype Next-Generation USMC 5G Communications

The U.S. DOD has awarded Lockheed Martin a $19.3 million Prototype Project Agreement to create a 5G communications network infrastructure testbed for expeditionary operations experimentation for the Office of the Under Secretary of Defense for Research and Engineering (OUSD R&E) and the U.S. Marine Corps. The testbed, known as Open Systems Interoperable and Reconfigurable Infrastructure Solution (OSIRIS), is a key initiative of Lockheed Martin's 5G.MIL® programs which are positioned to help its customers field, scale and integrate 5G technology rapidly and affordably across all operations on land, water, in air, space and cyber.

"OSIRIS will serve as a critical proof point of Lockheed Martin's 5G.MIL® capabilities," said Deon Viergutz, vice president, Lockheed Martin Spectrum Convergence. "We are integrating the technical capabilities of 5G waveforms, software and hardware with higher bandwidth and low latency data rates into our defense products to enhance their performance for our warfighters. We want to ensure that warfighters operating in communications contested and denied environments have resilient access to data to perform their missions anywhere in the world."

OSIRIS (Source: Lockheed Martin)

The OSIRIS program will help address the need for test facilities that enable rapid experimentation and dual-use application prototyping. The testbed will identify areas for further compatibility between 5G network and DOD platforms that will enhance customer capabilities. The infrastructure will also allow for the connection of various 5G-ready user devices, sensors, vehicles and endpoints to explore the military utility of commercial 5G technologies and pave the way for onboarding of new technologies from other OUSD investments while addressing cybersecurity requirements. This capability will further enable and advance the DOD's Joint-All Domain Operations concept.

Teams from Lockheed Martin, along with subcontractors DISH Wireless, Intel Corporation, Radisys Corporation and Rampart Communications, Inc., will create the 5G network testbed infrastructure at U.S. Marine Corps Base Camp Pendleton. The period of performance will begin immediately and conclude in September 2024.

For More Information Visit mwjournal.com for more defense news.

Israel Completes First 'C-Dome' Interceptions from Aboard the Navy's Sa'ar Six Corvettes

The Israel Missile Defense Organization (IMDO), in the Directorate for Defense R&D of the Israel Ministry of Defense, the IDF and Rafael Advanced Defense Systems have completed a successful series of live-fire tests of the 'C-Dome' system—an advanced naval configuration of the Iron Dome defense system. The 'C-Dome' was operated for the first time aboard the Israeli Naval Ship (INS) Sa'ar 6 'Magen' corvette against multiple advanced threats. Crew members of the INS 'Magen' led the 'C-Dome' tests.

The test campaign consisted of several scenarios simulating advanced threats, including rockets, cruise missiles and UAVs. The 'C-Dome' is capable of successfully intercepting such threats. This successful live-fire test is an important milestone and demonstrates the operational capability of the Israeli Navy to defend the strategic assets and vital interests of the State of Israel against current and evolving threats.

The 'C-Dome' onboard missile defense system is based on the Iron Dome defense system developed by Rafael, with the command-and-control system developed by mPrest. 'C-Dome' interfaces with the Saar 6's 'Adir' radar, developed by IAI's ELTA division. It joins other advanced systems that make up Israel's multi-tier missile defense array, including the Arrow and David's Sling systems. Development of the 'C-Dome' was led by the IMDO in Israel's Ministry of Defense.

C-Dome (Source: Rafael)

Director of the IMDO, Moshe Patel said, "Today we mark another historic milestone for the Iron Dome defense system—the completion of a series of successful offshore tests of the missile defense system onboard a naval vessel. The advanced detection system accurately identified various threats including rocket fire, cruise missiles and UAVs. The system successfully intercepted the threats with surgical precision. The success of today's tests further strengthens our confidence in our missile defense systems as well as the ability of the Israeli Navy to defend the maritime assets of the State of Israel."

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Smartphone OEMs to Drive RFFE Industry Practices Through a Defined Consumer-Oriented Roadmap

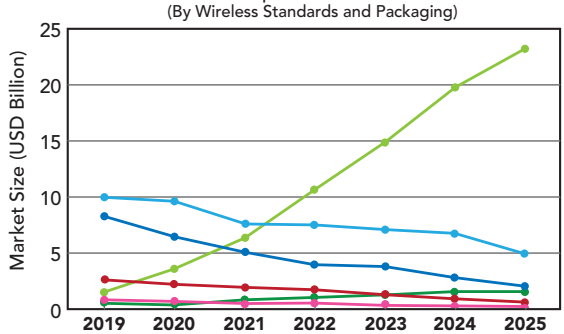
Netscribes, Inc. has published its market and industry findings on radio frequency front-end (RFFE) for smartphones in the 5G era. In this white paper, the research firm examines the RFFE industry at a strategic framework level, followed by an overview of relevant market size and various consumer factors which drive the smartphone industry in different geographic regions.

The RFFE is a critical component of a smartphone device that impacts the overall radio communication and user experience. Considering recent growth in 5G commercialization and the need to meet its challenging requirements, RFFE for smartphones will also undergo changes right from design to manufacturing, assembly, testing and packaging.

For example, with the advent of the complex 5G frequency spectrum, RFFE packaging trends have shifted from placing discrete RF components inside the mobile devices to packaging, assembling and integrating them on a single substrate as much as possible. To undergo technological advancements on the material, architectural and design levels, the industry will require a high-level investment appetite, expertise, innovation and close collaboration with the suppliers and foundry players.

Moreover, smartphone OEMs, in their efforts to capture the market share of an already matured industry, tend to differentiate themselves from others by offering better specifications, sleeker form factor devices, superior quality and enhanced performance levels at various price points. However, with a clear consumer-oriented market strategy roadmap, the smartphone OEMs associate and collaborate with either RFFE integrated module or discrete components suppliers.

Smartphone RFFE TAM
(By Wireless Standards and Packaging)



	2019	2020	2021	2022	2023	2024	2025
2G/3G Integrated	0.8	0.7	0.6	0.6	0.4	0.3	0.2
2G/3G Discrete	2.7	2.3	2.0	1.8	1.3	1.0	0.6
4G Integrated	10.1	9.7	7.7	7.5	7.1	6.8	5.0
4G Discrete	8.3	6.5	5.2	4.0	3.8	2.9	2.1
5G Integrated	1.6	3.7	6.4	10.7	14.9	19.9	23.3
5G Discrete	0.5	0.4	0.8	1.1	1.2	1.5	1.5

Smartphones RFFE Packaging Industry Market Growth (2019-2025)

RFFE TAM (Source: Netscribes, Inc.)

"RFFE was always a secondary priority, after modems and transceivers, until a couple of years ago. This is evident from the fact that almost 80 percent of expert coverage emphasized modems while discussing the smartphones' transmission and reception design architecture," said Saurabh Gupta, Innovation Research and Business Strategy expert at Netscribes. "However, the situation and dynamics have changed with the 5G commercialization and frequency bands supported (including the mmWave spectrum). It is not possible to effectively use the spectrum solely with innovations in modem architectures. Hence, RFFE has gained prominence and will witness a huge spike in the innovation space within the ecosystem."

38 Technology Stats You Need to Know for 2022 and Beyond

The COVID-19 pandemic quickened the pace of digital transformation, placing technologies at the very center of how people live and work—and that pace shows no signs of slowing down. In its new white paper, "38 Technology Stats You Need to Know for 2022," ABI Research has identified and highlighted the most impactful forecasts that illuminate the direction in which digital transformation is heading.

"The rise of always-on 5G portable devices, an explosion of edge AI adoption, a proliferation of smart manufacturing platforms, the formation of the metaverse and a growing concentration on cybersecurity are just some of the many changes on the horizon that are indicative of a more connected, more vulnerable and ultimately, more technology-driven world," according to Stuart Carlaw, chief research officer at ABI Research.

5G and mobile network infrastructure stats highlighted include:

Open RAN installs will increase from 1.37 million in 2021 to 22.52 million in 2026.

"Open RAN revenue will not match traditional RAN revenue but will slowly increase throughout the forecast period. Due to integration and technology developments issues, considerable vendor resistance may entirely delay or even kill the Open RAN movement before it reaches a large scale. The industry has now become aware of the fact that Open RAN will still need years of development before it can match large vendor performance and cost efficiency," said Dimitris Mavrakis, senior research director at ABI Research. This has translated to reduced interest in Open RAN in early 2022.

ABI Research expects Open RAN to morph into the next generation RAN concept, driven mainly by large infrastructure vendors that will be more open in terms of interfacing with other vendors and will include open elements in their proprietary platforms. Ericsson, Huawei and Nokia, among others, will adapt to Open RAN.

For More Information Visit mwjournal.com for more commercial market news.

The satellite communications serviceable addressable market (SAM) potential for Asia-Pacific will increase from 161.5 million premises in 2021 to 169.0 million premises in 2026.

According to Jun Wei Ee, research analyst at ABI Research, "The Asia-Pacific market has contrasting high broadband penetrated markets, such as Japan, South Korea, China and countries such as India, Indonesia and the Philippines, where high speed broadband has yet to gain significant penetration. Many rural communities in the region continue to see significant population growth over the forecast period. Fiber-optic and Fixed Wireless Access continue to be rolled out, but face challenges in addressing the rural markets." The SAM potential consists of possible community satellite broadband access deployment opportunities, as well as a smaller number of direct-to-home deployments to households that have the disposable income to afford satellite broadband solutions. In the lower-income areas, service providers may need to amortize the cost of the customer premises equipment (CPE) across the duration of the service contract, or government agencies may need to proactively subsidize the cost of the CPE to make the service more affordable.

Global massive MIMO deployment is expected to grow at a six-year compound annual growth rate of 61 percent, reaching 32.1 million in 2026, up from 4.4 million in 2021.

According to Fei Liu, industry analyst, with massive MIMO being the key enabler for 5G, operators will continue to deploy massive MIMO (mMIMO) globally.

mMIMO typically refers to 32T32R and 64T64R; 64T64R is better suited for dense urban areas and 32T32R is usually deployed in urban and suburban areas. Worldwide mMIMO deployment was driven by the Asia-Pacific region, which is expected to lead the future growth due to significant adoption, followed by the U.S. and Europe.

China, Japan and South Korea were all early adopters of 5G, and 2020 was the year of 5G acceleration for China. Japan and South Korea favor mMIMO with 32T32R configurations due to space/weight limitations. China initially deployed 64T64R, but switched to 32T32R when it advanced beyond urban areas for 5G deployments. Semiconductor shortages and high-power consumption may also contribute to the decision to switch.

Europe is picking up speed in mMIMO deployments with 32T32R configurations, and an acceleration is expected from 2023. The U.S. was initially focusing on mmWave and only gained access to the C-Band in 2021. As U.S. operators are still deploying 5G networks in dense urban areas, 64T64R mMIMO is still mainly deployed there. An acceleration of mMIMO deployments can be expected as of 2023.

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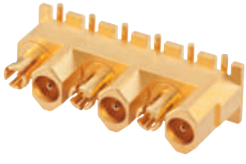

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

RF Industries has completed its previously announced acquisition of **Microlab**, the RF components business of Wireless Telecom Group. Microlab designs and manufactures high performance RF and microwave products enabling signal distribution and deployment of in-building distributed antenna systems, wireless base stations and small cell networks and generated unaudited revenue of approximately $16 million and adjusted EBITDA of approximately $3.7 million for the 12-month period ended September 30, 2021. RF Industries expects the acquisition to be immediately accretive to its stand-alone financials and anticipates realizing meaningful operating synergies upon the integration of the Microlab business.

AMD announced that it has received approval from all necessary authorities to proceed with the acquisition of **Xilinx Inc**. With the exception of the remaining customary closing conditions, all conditions to the transaction closing have been satisfied. AMD announced its intention to acquire Xilinx in an all-stock transaction on October 27, 2020. The transaction brings together two industry leaders with complementary product portfolios and customers, combining CPUs, GPUs, FPGAs, adaptive SoCs and deep software expertise to enable leadership computing platforms for cloud, edge and intelligent end devices.

KYOCERA AVX is set to acquire **ROHM Semiconductor**'s tantalum and polymer capacitor business assets. The two companies recently reached a final agreement, which states that ROHM Semiconductor (ROHM Co., Ltd.) will transfer its tantalum and polymer capacitor business assets—including all of its tantalum and polymer capacitor manufacturing lines and relevant intellectual property—to KYOCERA AVX. The transfer is scheduled to be executed on August 5, 2022, and ROHM will continue to produce tantalum and polymer capacitor products and supply them to KYOCERA AVX until all relevant production lines have been successfully transferred to the KYOCERA AVX manufacturing site.

COLLABORATIONS

Curtiss-Wright's Defense Solutions, a supplier of modular open systems approach-based rugged avionics solutions, announced that it is collaborating with **Northrop Grumman** to bring real-time virtualization and modernized protection (ReVAMP) technology to the embedded avionics market. Northrop Grumman's ReVAMP software brings the advantages of enterprise virtualization and layers of cyber hardening to embedded systems to decouple software from specific hardware configurations and combat obsolescence. The use of ReVAMP effectively "future-proofs" software systems by virtualizing obsolete hardware currently being used to run existing software. Northrop Grumman has enabled multiple programs to migrate their valuable application software from obsolete hardware to modern hardware using ReVAMP.

MaxLinear Inc. and **Sivers Wireless**, a subsidiary of Sivers Semiconductor AB, announced the joint development of a V-Band RF/modem solution that enables disruptive unlicensed point-to-point microwave radios in the 57 to 71 GHz band. Because of the increased demand for 5G and broadband connectivity, the need for backhauling data traffic from and between base stations and fixed wireless access points has grown. Sivers and MaxLinear have joined forces with a leading microwave radio original equipment manufacturer (OEM) customer to develop an unlicensed point-to-point radio solution that enables long reach.

CAES and **Trident Systems**, a provider of multi-function RF and processing solutions and C4I technology, have announced a strategic partnership to offer an integrated portfolio of best-in-class advanced mission computing and communications solutions for space, air, sea and land defense applications. Under the partnership, CAES and Trident Systems will cooperate to address customer mission requirements in advanced RF and digital signal processing products. The partnership combines CAES' expertise in radiation hardened microelectronics and computing with Trident Systems' heritage of deploying high performance processing and communications subsystems in the most challenging mission environments.

Lantronix, a global provider of secure turnkey solutions for intelligent IT and IoT, **Taoglas**, a leading provider of advanced technology for a smarter world, and **Thales (Euronext Paris: HO)**, a leader in advanced technologies and designer and builder of IoT connectivity solutions, announced their collaboration at MWC 2022. Their combined expertise aims to deliver application-specific smart industrial IoT solutions to connect data-dependent vertical industries, including Industrial 4.0, security and transport markets. The Lantronix G520 series gives users the ability to connect all their controllers, even if they are using legacy equipment of different ages and brands. A single gateway device facilitates reliable connections with less hardware and delivers access to more meaningful data.

FRTek, a supplier of wireless, amplifier solutions, and advanced repeater technologies to the mobile communications industry, announced that it has entered an OEM partnership with **Movandi** providing semiconductors and antenna modules for FRTek PrimAer's smart repeaters in the 24/26 GHz (n258), 28 GHz (n257/n261) and 39 GHz (n260) spectrum bands. FRTek PrimAer smart repeaters with patented fiber cascading capabilities are being deployed with global tier-one 5G service providers including Verizon to deliver unprecedented 5G mmWave coverage.

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KBS-10-225	225 - 400	10.5 - 1	0.5	0.6 - 0.7	25 - 18	50
KDK-20-225	225 - 400	20 - 1	0.5	0.2 - 0.4	25 - 18	50
KDS-20-225	225 - 400	20 - 1.0	0.5	0.2 - 0.4	25 - 18	50
KEK-706H	500 - 2500	31.5 - 2	2.5	--	--	100
SCS-8012D	800 - 1200	20 - 1	0.6	--	22 - 18	100
KEK-704DH-2	850 - 1250	30 - 1.5	0.25	--	--	500
KEK-704H	850 - 960	30 - 0.75	0.25	--	--	500
SCS100800-10	1000 - 8000	10.5 - 1.5	2	1.2 - 1.8	8 - 5	25
SCS100800-16	1000 - 7800	16.8 - 1.5	2.8	0.7 - 1	14 - 5	25
SCS100800-20	1000 - 7800	20.5 - 2.0	2	0.4 - 0.75	12 - 5	25
SCS-1522B	1500 - 2200	10 - 1.0	--	--	23 - 18	100
SCS-1522D	1500 - 2200	20 - 1	--	--	23 - 20	100
SCS1701650-16	1500 - 15500	17 - 1.5	2.5	1 - 1.4	16 - 5	25
SCS1701650-20	1700 - 15000	21 - 1.5	2.5	--	10 - 7	25
SDC360440-10	3600 - 4400	8.6 - 0.5	0.25	--	18 - 10	10
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Around the **Circuit**

ACHIEVEMENTS

Keysight Technologies Inc. has been granted the first **Federal Communications Commission (FCC)** Spectrum Horizons Experimental license for developing 6G technology in sub-Terahertz (THz) frequency bands, between 95 GHz and 3 THz. The FCC license enables Keysight to develop cutting-edge technology used by researchers in academia and the industry to accelerate innovations that support data-intensive high bandwidth applications, imaging and sensing. Keysight is also the first company to be granted FCC licenses above 246 and 275.5 GHz. Access to large swaths of contiguous spectrum in sub-THz frequencies allows 6G innovators to realize high data throughput speeds of 100 Gbps up to 1 Tbps, as well as ultra-low latencies across short distances.

Cobham SATCOM, a provider of satellite communications solutions to the land and maritime sectors, announced that it has joined the **Digital IF Interoperability Consortium (DIFI)**, the independent space industry group formed to advance interoperability in satellite and ground system networks. Cobham is a long-standing proponent of standard interfaces, reflected in modular designs and compatibility across a broad range of RF vendors, and has developed a range of digitizers and innovative digital interfaces. DIFI members are coming together to support innovation and the digital transformation of space, satellite and related network technologies through the development of industry interoperability standards.

CONTRACTS

Natilus, a U.S. company producing the industry's first purposefully designed and manufactured autonomous aircraft for air freight transport, has announced advanced purchase commitments of more than $6 billion for the delivery of 440+ aircraft in pre-orders, from companies including major airlines and integrators: **Volatus Aerospace, Astral Aviation, Aurora International, Dymond, Flexport** and others to be announced. Flexport completed a $900 million investment round and has signed a Letter of Intent for two 100T Natilus aircraft, with an option for a third. Natilus was co-founded by Aleksey Matyushev and Anatoly Starikov in 2016.

VSE Corp., a provider of aftermarket distribution and maintenance, repair and overhaul services for land, sea and air transportation assets for government and commercial markets, announced that its **Federal and Defense** segment has been awarded a 12-month, ~$100 million contract by **Naval Sea Systems Command (NAVSEA)**. VSE is the current contractor providing foreign military sales follow-on technical support to NAVSEA and has the technical capability, customer knowledge and expertise to execute repair and maintenance of critical foreign assets. Under the terms of the contract award and in conjunction with NAVSEA's International

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Fleet Support Program Office (PMS 326), VSE will continue to support eligible foreign navies with a broad range of aftermarket services.

Kratos Defense & Security Solutions Inc. announced that it has recently received an approximately $50 million contract value increase for an existing **Command, Control, Communications, Computing, Combat System and Intelligence, Surveillance and Reconnaissance (C5ISR) Program**. Under this program, Kratos is providing specialized products, hardware, engineering and other services and deliverables. Kratos C5ISR business manufactures and provides specialty hardware, products and systems in support of certain U.S. and Allies most important and mission critical national security programs, including unmanned aerial drone systems, missile and radar systems, high power, directed energy and hypersonic systems, naval combatant and space and satellite communication systems.

Smiths Interconnect announced a manufacturing contract from **Lockheed Martin** to manufacture high gain high sensitivity (HGHS) antenna systems to protect U.S. Navy ships from threats during mission critical operations. The HGHS antenna is enabled by Smiths Interconnect's 30-year heritage of antenna and software capabilities to provide enhanced frontline situational awareness and ship protection from inbound threats. The contract includes manufacture and test of the HGHS antenna systems along with embedded control and interface software. The award is a five-year contract and will deliver up to 74 antenna subsystems. Smiths Interconnect's HGHS antenna is integrated into Lockheed Martin's SEWIP system to provide anti-ship missile defence, counter-targeting and counter-surveillance capabilities.

NASA has awarded three contracts under the on-ramp feature of the Rapid Spacecraft Acquisition IV (Rapid IV) contract. These multi-agency contracts are available to support all NASA centers and other federal agencies. The awardees are **Lockheed Martin Corp.**, Lockheed Martin Space of Littleton, Colo.; **QinetiQ Space** of Nevada, **Kruibeke** of Belgium and **Space Flight Laboratory** at the University of Toronto Institute for Aerospace Studies in Toronto, Canada. The work will be performed at the contractors' facilities at the locations listed above. The Rapid IV multiple-award, indefinite delivery/indefinite quantity (IDIQ) contracts allow the U.S. government to place firm-fixed price delivery orders for spacecraft and related services.

TurbineOne, the frontline perception company, was awarded a Small Business Innovation Research (SBIR) contract to advance its machine learning capabilities and deploy its software with the **U.S. Air Force**. The specific offices within the Air Force that made the SBIR award to TurbineOne are the Air Force Research Laboratory and AFWERX. SBIR programs are highly competitive programs that encourage domestic small business-

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Around the **Circuit**

es to engage in Federal Research and Development. Through a competitive awards-based program, SBIRs enable small businesses to explore their technological potential and provide the incentive to profit from its commercialization.

Echodyne, the radar platform company, announced that **Advanced Technology Systems Company**, the prime contractor for the $191 million IDIQ contract for the U.S. Army's Security Surveillance System (SSS) program of record and a leader in Force Protection Systems and Border/Maritime Surveillance Systems, has received its first order for Echodyne radars to be used under the SSS program. The IDIQ contract has a five-year base period, with a three-year option to extend the period of performance.

Excella, a pioneer in Agile technology solutions, has been awarded the Digital Innovation and Development (DID(it)) II contract to support the U.S. Citizenship and Immigration Services (USCIS). Excella has supported the USCIS mission for over six years. Through the DID(it) contract, valued at $116.6 million over five years, Excella will provide Agile and modern software delivery capabilities to develop and deploy secure critical services that impact citizens and internal government users.

The **U.S. Army** and its Army Application Laboratory award a Phase 2 SBIR contract to **Taqtile** to fulfill their Augmented Reality Maintainer-Operator Relay System (ARMORS) vision. Taqtile, a leader in augmented reality-based work instruction solutions will expand deployment of the company's innovative Manifest® platform to address the Army's Maintenance, Repair and Operations (MRO) needs across multiple vehicle platforms. The recently completed Phase 1 program enabled the Army to validate Manifest's unique capabilities to support digital transformation of motor pool MRO.

PEOPLE

▲ *Gregory Bryant*

Analog Devices Inc. (ADI) announced that **Gregory Bryant** will be appointed to the newly created position of executive vice president (EVP) and president of business units. In this role, Bryant will have oversight of the company's business units—Industrial, Automotive, Communications, Digital Healthcare and Consumer—and will be responsible for continuing to scale ADI's rapidly growing businesses. Bryant is a proven global business leader with three decades of experience and a track record of driving growth. Most recently, he was EVP and general manager of Intel's Client Computing Group, the company's largest and most profitable business. In that role, he led a global organization of more than 5,000 people and captured growth opportunities in the PC market.

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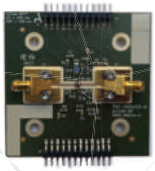

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Around the **Circuit**

▲ *Mark A. Skoog*

Jump Aero Incorporated announced the addition of autonomous aircraft systems expert, **Mark A. Skoog**, to the Jump Aero Advisory Board. Skoog was the principle investigator for Autonomy Research at NASA's Armstrong Flight Research Center prior to joining the Jump Aero board of advisers. Skoog will provide strategic guidance regarding the development of autonomous systems on the Jump Aero eVTOL aircraft. Skoog has led a collaborative effort between NASA, the Federal Aviation Administration and the Department of Defense and industry to develop certification methods for autonomous vehicles. Most recently, he was the lead for the Resilient Autonomy project at NASA Armstrong where his team developed the Expandable Variable Autonomy Architecture system.

▲ *Reine Eriksson*

Reine Eriksson has been appointed as the new CEO of **CellMax Technologies AB**, as of February 1, 2022. Eriksson's long industry experience and track record building global business' towards the telecom sector will help CellMax to meet the significantly increased demands for high performing antennas. The operational experience and global industry knowledge will be a great asset in taking CellMax into its next expansive phase. Eriksson has held a number of executive positions in public and most recent a privately held company where he built a global business area for a SW as a service company.

Isola Group announced the hiring of **Jim Francey** as RF Business Development director, Europe. Francey will report directly to David Humby, vice president of Sales and OEM Marketing Europe, in the new role and will apply his industry background and considerable experience in the RF/microwave electronics industry to help Isola explore and expand new opportunities for high frequency circuit materials within printed-circuit boards in such applications as 5G cellular wireless equipment and autonomous vehicles. Francey brings an open and engaging personality and more than 30 years of high frequency industry experience in chemistry and PCB materials and development engineering to his new position.

▲ *Jim Francey*

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INVITED PAPER

Reinventing YIG Technology for Microwave Filter Applications

Bill Linstrom, Jackson Barnard and Jane Rogan
VIDA Products, Rohnert Park, Calif.

The RF industry needs a higher performing filter technology to improve S- and C-Band (i.e., 2 to 8 GHz) tunable filter performance and reduce cost. This article reviews existing filter technologies and describes a new generation of surface-mount, low-power, tunable filters using yttrium iron garnet (YIG) resonators.

The ever-increasing demand for bandwidth is driving the use of higher frequencies, resulting in more spectrum congestion and increasing costs. The wireless spectrum, one of the world's most valuable natural resources,[1] is increasingly crowded.[2,3] Demand is outstripping the supply. For example, the Department of Defense reported that unanticipated congestion is requiring increased avoidance planning.[4] Putting a value on the resource, in January 2021, the FCC auctioned 280 MHz of spectrum, formerly allocated to satellite users, for 5G cellular and netted $81 billion—over 3× the anticipated amount.[5] With global demand for internet data capacity growing at a 50 percent compound annual growth rate over the past three decades, it's no surprise to see the value of frequency bands skyrocket.[6,7]

As demand and costs grow, innovative approaches are required for the regulations governing how the spectrum is used, as well as the technologies used in the radios using the spectrum. Using underutilized frequency bands is an important tool to increase spectrum utilization, leading to the adoption of flexible software-defined radio systems and "cognitive radio." Cognitive radio is a capability for spectrum reuse, where licensed frequency spectrum can be used by non-licensed users on a "first come, first served" basis when it's not being used by the licensee. When the licensed user requires the frequencies, the "squatter" must immediately switch to other unused frequencies or cease broadcasting until the spectrum becomes available.

RF FILTER TECHNOLOGY

Key to implementing cognitive radio at S- and C-Band is a filter technology that is tunable and, at the same time, provides excellent isolation, low power consumption and small size. Four common technologies are used for RF filters: inductor/capacitor tank circuits, resonant cavities, acoustic (surface acoustic wave and bulk acoustic wave) devices and YIG-tuned filters. Each has strengths and weaknesses when comparing performance, cost, size and power. Since resonant cavity and acoustic filters operate over a fixed band and are not tunable, we only consider varactor (tunable capacitor) and YIG-tuned filters in this article. In some applications, filter banks are used to tune the frequency bands and bandwidth of a radio. However, they are not as flexible as

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a tunable filter and usually increase board real estate, overall development time and cost.[8] Tunable filters provide flexibility for cognitive radio systems and are preferable when they meet system requirements for performance and size.

The performance of a filter is primarily determined by the Q-factor of the resonant circuit, which will set the passband and out-of-band signal rejection. These parameters, in turn, will affect the system noise floor, sensitivity and susceptibility to interference. A higher Q circuit will enable a lower noise floor, yielding greater sensitivity and narrower passband, improving the isolation.

A varactor-tuned filter uses the relationship between the bias on a varactor diode and the diode's capacitance. Unfortunately, as frequency increases, a varactor's Q decreases, degrading the filter's performance. To understand, consider the resonant frequency of an LC circuit:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

The resonant frequency, f_r, is inversely related to the capacitance, C. To achieve a higher resonance, C must decrease. Yet, the Q-factor of the LC circuit is given by[9]

$$Q = R\sqrt{\frac{C}{L}} \quad (2)$$

which shows that as C decreases, Q also decreases. This confirms that as frequency increases, the performance of varactor-tuned filters will necessarily degrade. Varactor-tuned filters generally perform well up to 2 GHz. Above 2 GHz, the bandwidth of the filter increases appreciably with frequency, as shown in ***Figure 1***.

YIG TECHNOLOGY

With varactor-tuned filter performance degrading above 2 GHz, a tunable filter using a new generation of YIG resonators becomes interesting. YIG is a ferrite material that resonates at microwave frequencies when immersed in a magnetic field. Historically, YIG has been used to provide the best performing oscillators and filters, but at a cost. Traditional YIG-tuned oscillators and filters have been large, power hungry and expensive. The theory and construction of YIG-based components is why.

YIG resonators operate when a steady magnetic field, a DC H-field, is applied in one direction, such as the vertical Z direction, and an RF-varying magnetic field is applied from an orthogonal direction, such as X or Y. As with LC tank circuits, a YIG can be used as the resonator in either an oscillator or filter. In a filter, the resonant frequency is the center frequency of the filter, which is set by the strength of the DC H-field.

YIG resonators use polished YIG spheres to take advantage of spherical symmetry, since YIG is sensitive to variations in the magnetic potential across the surface. To minimize the effects of the sensitivity to field variation, each YIG sphere is typically placed in an isolation chamber (see ***Figure 2***). This enables each sphere to be adjusted and tuned without affecting other spheres; however, this isolation complicates the design of the electromagnet creating the H-field.

Magnetic power is coupled

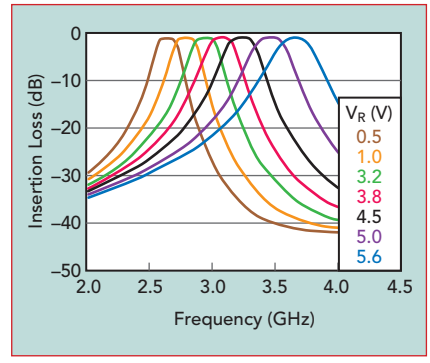

Fig. 1 Responses of a tunable filter using a varactor, showing wider passband as the center frequency increases.

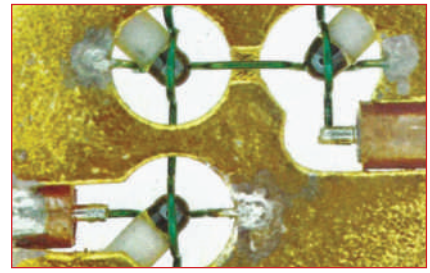

Fig. 2 Traditional YIG filter configuration, looking down on three YIG resonators configured as a three-pole bandpass filter.

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through magnetic media, i.e., a ferrite material. Conceptually, this is like power conducted via wires through electrical media. Extending the analogy, magnetic power is dissipated when the magnetic field encounters "reluctance" in the same way electric power dissipates when current encounters resistance. The geometrical design of the YIG filter requires a YIG sphere to be inserted in the gap of a toroidal electromagnet (see ***Figure 3***). The width of the air gap in the toroidal electromagnet is directly related to the reluctance of the electromagnetic circuit. The wider the air gap, the greater the reluctance, the greater the magnetic loss in the circuit and the larger the supply required to generate the H-field.

As noted, traditional YIG components are large and consume a lot of power, a result of the geometry of the design. The frequency of operation, the number of YIG spheres with each sphere occupying its own chamber, the size of the air gap and the size of the electromagnet needed to tune the YIG to the desired frequency result in the large size and power consumption of traditional YIG designs. For frequencies in the 1 GHz range, the electromagnet can be relatively small. Tuning the YIG to 2 GHz requires twice the magnetic field strength and twice the number of turns in the electromagnet, the magnetic field strength and attendant size of the electromagnet increases with the operating frequency. Also, the complex assembly of the component, not amenable to mass production, increases the cost.

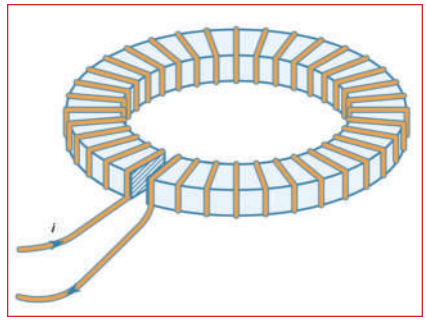

Fig. 3 **Toroidal electromagnet that surrounds the YIG sphere and generates the DC H-field.**

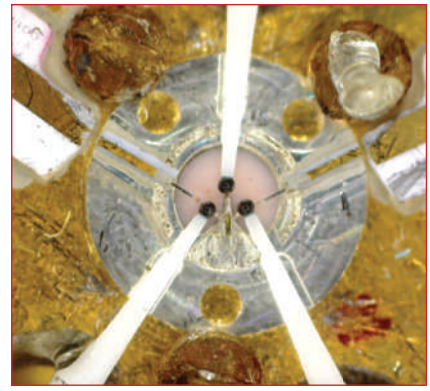

Fig. 4 **Three YIG resonators housed in a single resonant cavity.**

ADDRESSING THE SHORTFALLS

To address the downsides of traditional YIG components, VIDA Products has developed a new generation of YIG-tuned filters. The goals are maintaining YIG's high Q performance while decreasing the size and power consumption by up to 10× and significantly lowering the manufacturing cost. Lowering the power consumption would make YIG technology an option with battery-powered systems.

Reducing and eventually eliminating the air gap is the key to decreasing the size and power requirements of the YIG resonator. The approach involves the sphere-to-sphere coupling technique and adopting a single resonant cavity. The proprietary techniques for accomplishing both led VIDA Products to develop its "Next Generation" YIG filters. The design houses three YIG resonators in a single resonant cavity (see ***Figure 4***). The RF input and outputs are microwire loop-coupled, and the internal coupling is sphere-to-sphere.

Comparing the filter performance of this new YIG technology with varactors, varactor-tuned filters provide from 15 to 40 dB isolation at S- and C-Band, while YIG-tuned filters achieve more than 70 dB.[10] For a tuned center frequency of 4 GHz, the bandwidth of a varactor-tuned filter is between 120 and 400 MHz, from 3 to 10 percent, which increases with frequency (see Figure 1). Since the bandwidth does not remain constant with frequency, the system is more susceptible to noise and interference at higher frequencies.[11]

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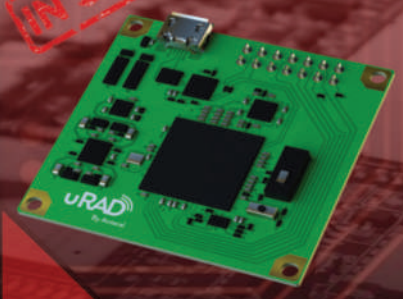

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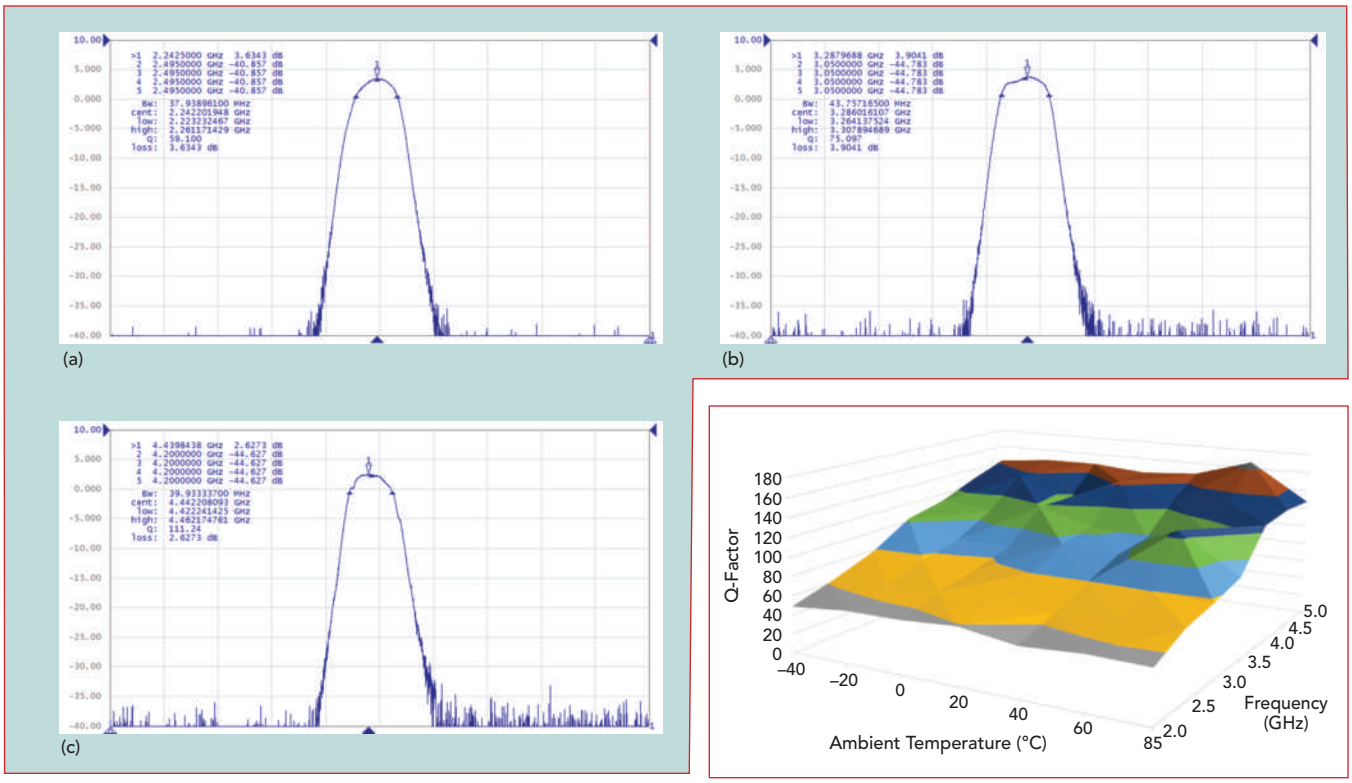

Fig. 5 Tunable YIG filter responses at 2.2 (a), 3.3 (b) and 4.4 (c) GHz, keeping the passband at approximately 40 MHz.

Fig. 6 Measured Q-factor vs. center frequency and temperature.

CHARACTERIZATION

One way to assess filter performance is measuring the passband, off-resonance isolation and Q-factor versus frequency. Three of these measurements, which were performed using a Keysight Technologies E5071C network analyzer, are shown in ***Figure 5***. Keeping the passband bandwidth constant at approximately 40 MHz, the Q-factor increases as the frequency increases, from 59 at 2.23 GHz to 75 at 3.3 GHz and 111 at 4.4 GHz. At 6 GHz, the Q reaches 160, confirming the performance of the YIG-based design is better than other tunable filter technologies. This characteristic of increasing Q with frequency is clearly seen in ***Figure 6***, which plots the measured Q-factor versus frequency and adds the effect of temperature, from -40°C to +85°C. The data shows Q-factor is stable over temperature.

Additional temperature characterization assessing the sensitivity of the 40 MHz filter bandwidth versus frequency is shown in ***Figure 7***. The passband bandwidth is stable across temperature and frequency. ***Figure 8*** plots the offset of the cen-

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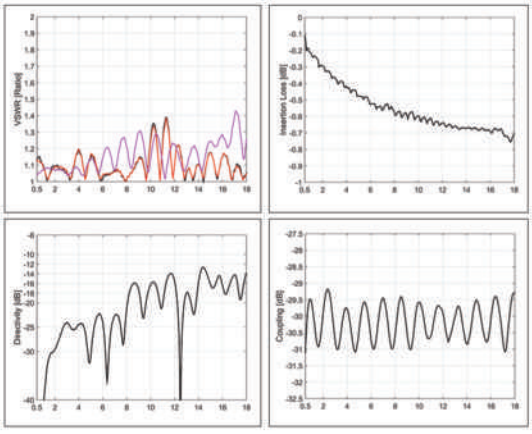

Frequency Range (GHz)	P/N	Coupling Max.(dB)	Main Line VSWR Max.(1:1)	Coupling VSWR Max.(1:1)	Insertion Loss* Max.(dB)	Flatness Max.(dB)	Directivity Min.(dB)	Power Max.(W)	Unit Price** (USD)
0.5-6	D30H005060	30±0.7	1.3	1.3	0.6	±1	15	600	1276
	D40H005060	40±0.8	1.3	1.3	0.6	±1.1	15	600	1276
0.5-18	D30H005180	30±1.2	1.5	1.6	1	±1.2	10	400	1899
	D40H005180	40±1.2	1.5	1.6	1	±1.4	10	400	1899
0.7-6	D30H007060	30±0.7	1.3	1.3	0.5	±0.9	15	600	1195
	D40H007060	40±0.7	1.3	1.3	0.5	±0.9	15	600	1195
1-6	D30H010060	30±0.7	1.3	1.3	0.5	±0.9	15	600	1073
	D40H010060	40±0.7	1.3	1.3	0.5	±0.9	15	600	1073
1-18	D30H010180	30±1.2	1.5	1.6	0.8	±1	10	400	1417
	D40H010180	40±1.2	1.5	1.6	0.8	±1	10	400	1417
2-6	D30H020060	30±0.7	1.3	1.3	0.4	±0.7	15	600	931
	D40H020060	40±0.7	1.3	1.3	0.4	±0.7	15	600	931
2-8	D30H020080	30±0.8	1.4	1.4	0.4	±0.7	14	600	1033
	D40H020080	40±0.8	1.4	1.4	0.4	±0.7	14	600	1033
2-18	D30H020180	30±1.0	1.5	1.6	0.6	±0.8	10	400	1215
	D40H020180	40±1.0	1.5	1.6	0.6	±0.8	10	400	1215
6-18	D30H060180	30±1.0	1.5	1.6	0.5	±0.7	10	400	972
	D40H060180	40±1.0	1.5	1.6	0.5	±0.7	10	400	972

* Theoretical I.L. Included
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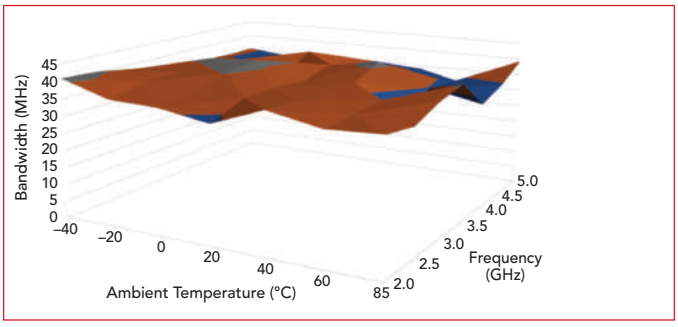

Fig. 7 Tunable filter bandwidth vs. center frequency and temperature.

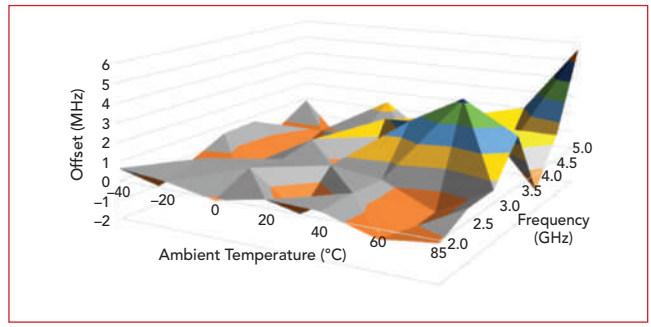

Fig. 8 Center frequency tuning offset vs. center frequency and temperature.

ter frequency from the intended frequency as a function of the center frequency and temperature. The goal is 0 MHz offset, which is achieved over most of the graph, although the offset increases as the temperature increases.

A surface-mount demonstrator of the Next Generation YIG-tuned filter has been developed to enable customer evaluation (see ***Figure 9***). ***Table 1*** summarizes its performance.

SUMMARY

Continued demand for increased bandwidth shows no signs of slowing, nor the demand for smaller, lower power and higher performance filters, particularly at S- and C-Band. Next-generation YIG technology has the potential to meet this need and is ready for production. VIDA Products is working with early adopters to develop custom designs for their programs.

This new YIG-tuned filter technology achieves the long-recognized performance of YIG resonators without the drawback of their large size, high power consumption and high cost. By integrating the YIG spheres into a single resonant cavity and reducing the complexity, size and power of the magnet, this new design approach can achieve up to a 10× reduction in size and power consumption compared to traditional YIG designs. VIDA's technology roadmap envisions moving from today's YIG spheres to a nano-film technology that could yield another 10x reduction in size and power.

Considering the performance capabilities and benefits, YIG-based filters warrant consideration.[12] This new generation of YIG technology offers performance with reduced size and is more economical than

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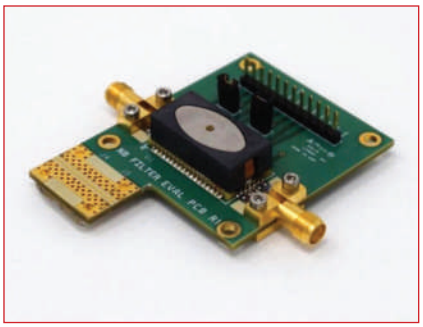

Fig. 9 **Surface-mount tunable YIG filter demonstrator.**

TABLE 1

TUNABLE-YIG FILTER DEMONSTRATOR PERFORMANCE

Passband Bandwidth Specified When Ordering

	Min.	Typical	Max.
Tunable Frequency Range (GHz)	2		5
3 dB Passband Bandwidth (MHz)	20		80
Passband Insertion Loss Variation (dB)		1.0	
Noise Figure (dB)		4.5	

historic YIG design. It provides a solution for systems that need to increase performance while reducing footprint and decreasing cost. ■

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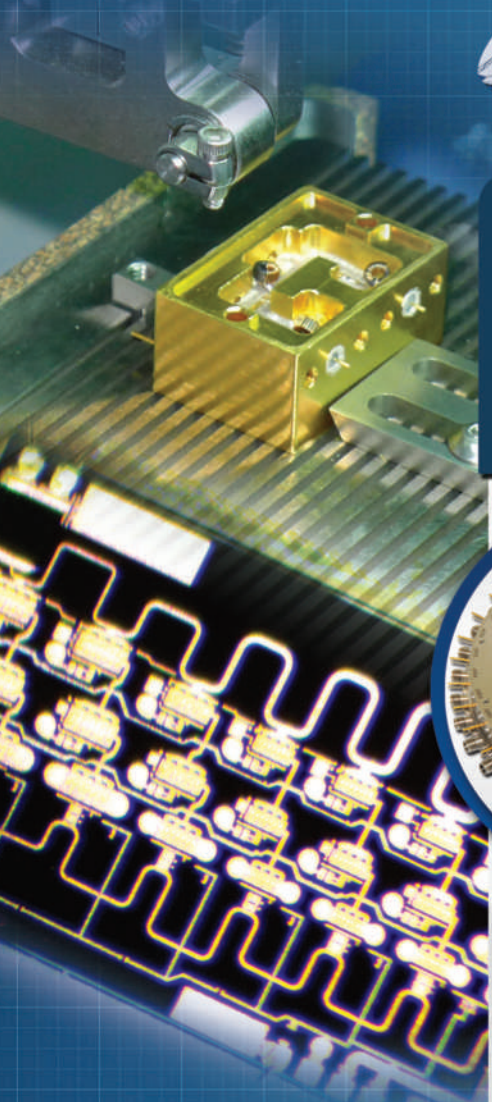

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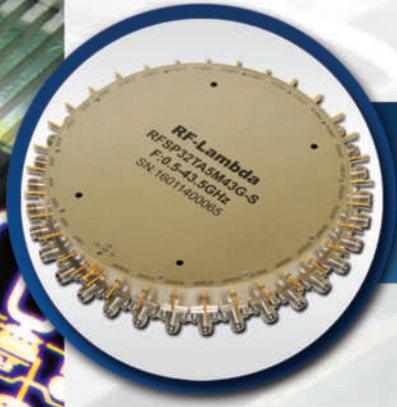
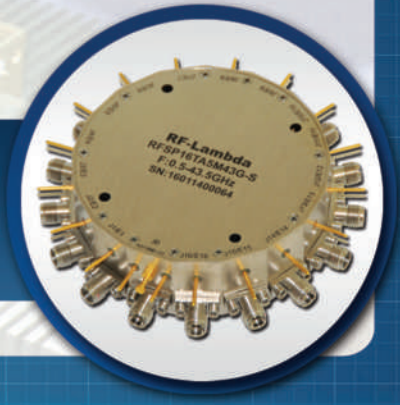


PN: RFSP32TA5M43G
SP32T SWITCH 0.5-43.5GHz

PN: RFSP16TA5M43G
SP16T SWITCH 0.5-43.5GHz



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INVITED PAPER

Addressing mmWave Challenges with Dielectric Resins and 3D Printing

Philip Lambert
Fortify, Boston, Mass.

A 3D printable photopolymer resin and 3D digital light processing printing technology enable the fabrication of a high gain, V- and W-Band dielectric lens antenna prototype.

There are a slew of market forces and technology trends driving the development of wireless communication and sensing systems designed to operate in frequency bands previously only used in satellite communication, backhaul and military radar. Examples include the recently released and licensed 5G and Wi-Fi frequency bands beyond 6 GHz, the extension of V-Band allowing unlicensed use to 71 GHz and new automotive short-range radar applications from 77 to 81 GHz. With growing spectrum congestion below 6 GHz, many applications are seeking to operate in higher spectrum regimes to avoid interference.

There are also other attractive features of operation at mmWave frequencies, namely that the size of many RF electronics scale in proportion to wavelength. mmWave components and devices can often be fabricated in much smaller form factors than lower frequency components and devices (i.e., smaller antennas and other RF hardware). Examples include mmWave 5G gNodeB and antenna arrays, as well as mmWave sensing devices such as imaging systems and radar.

This is a double-edged sword, however, as the relative size of mmWave hardware shrinks, manufacturing tolerances and precision material requirements become more restrictive due to a variety of phenomena (e.g., skin effect and high RF losses). Although the promise of broad swaths of available spectrum at mmWave frequencies seems attractive, the phenomena and fabrication considerations that come into play at these frequencies are often either negligible or able to be ignored at lower frequencies.

There are some emerging technologies whose benefits cannot be realized below mmWave frequencies, such as dense active/advanced antenna arrays (AAS). Now is the dawn of mmWave technology emerging from the shadows into mainstream use, along with the accompanying design and fabrication challenges that require designers to consider new solutions.

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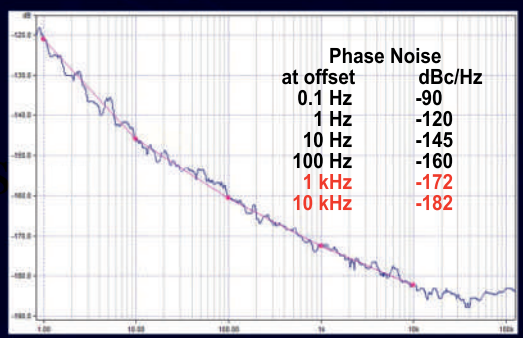

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FABRICATION CHALLENGES

Conductors are formed of metals, which can generally be reliably deposited, sputtered, formed and plated to reasonably high tolerances. They are also readily measurable. Dielectrics, however, are most often ceramics, glasses or polymers, which present nuanced production and manufacturing challenges.

The most significant electrical characteristics of conductors at mmWave frequencies are generally at the surface. This can depend on conductor thickness and the relative depth of the carrier concentration. Conductors can be plated or otherwise coated with gold or other noble metals to provide higher conductivity and a more conformal surface.

For dielectrics, which are often used to support, separate or load conductive structures, surface and bulk properties are critical and the electric field typically penetrates into, or entirely through, the dielectric material. As the electric field passes through a dielectric, some energy is absorbed (dielectric loss tangent or its reciprocal, quality factor) and converted to heat. For many dielectrics, a relatively small change in temperature can affect overall dielectric performance and dimensional stability. Consequently, dielectrics with extremely low loss tangents, less than 10^{-4} at 1 kHz and 10^{-3} at mmWave frequencies are desirable.[1]

Conformality of dielectric properties and dimensions of a dielectric are critical, as even small variations or gradients of a material's dielectric performance can change the behavior of the electric field passing through it. Spatially layering or mixing of dielectric materials results in generally difficult-to-determine dielectric effects, which may result in the effective permittivity of a given dielectric structure being much different than that of the constituent dielectrics.

In a parallel plate capacitor, for example, the direction of the dielectric layers with respect to the capacitive plates determines the effective permittivity of the overall dielectric. For perpendicularly stacked dielectric layers, the effective permittivity is essentially additive, where parallel stacked dielectric layers (perpendicular to the electric field with equal charge) result in an effective permittivity which is the sum of the reciprocals of each layer's dielectric constant (see ***Figure 1***). For more complex 3D structures, this computation becomes increasingly complicated, and thus hard to analytically determine using effective medium theory.

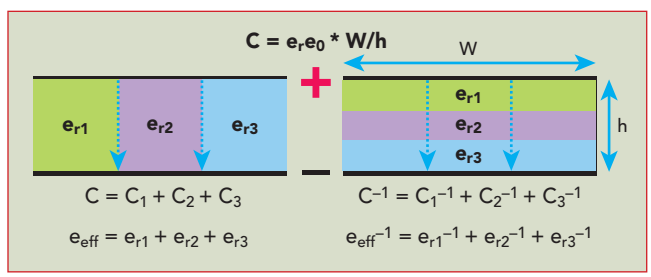
Dielectrics for mmWave applications must be machined, deposited, developed or layered with exacting precision. The degree of precision that can be achieved is a limiting factor in determining what materials and fabrication processes are viable for a given mmWave frequency.

METASTRUCTURES

A new class of electromagnetic metastructures (e.g., metamaterials, metasurfaces, meta-atoms, metalfilms and metascreens) can be made to behave in ways that traditional dielectrics in nature, or as conformal bulk structures, cannot. Within a dielectric medium, dipole moments are induced by electric polarization of the embedded scatterers when exposed to an electric field.[2] By volume averaging the dipole moments into a polarization density (P) with electric field (E), the result is an electric displacement vector (D) and permittivity (ε) as shown in Equation 1.

$$D = \varepsilon_0 E + P = \varepsilon E \quad (1)$$

Although natural dielectrics and materials have only positive values for permittivity, man-made materials with special properties or structures have since been made/arranged in such a way as to yield negative



▲ Fig. 1 **Parallel plate capacitor with series (left) and parallel (right) dielectric layers.**

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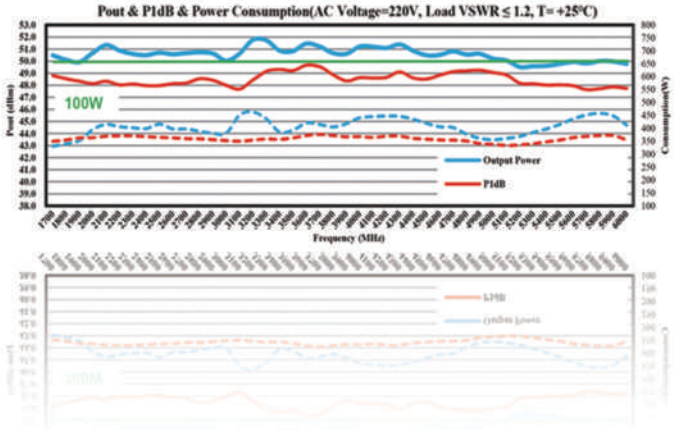

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refractive indexes, or negative permittivities. This is also the case for classes of magnetic metastructures that impact magnetic permeability.

The non-traditional permittivity behavior is frequency dependent, where frequencies outside the operational range of the metastructure interact with it in more traditional ways; but, within its frequency range of operation, these composite/engineered materials dramatically change the structure's electrical performance.

Creating a gradient of refractive indices within a dielectric volume, for example, can result in behavior that physically resembles that of optical lenses, but affecting electromagnetic radiation well below that of visible light. Gradient refractive index (GRIN) structures can be designed to act as complex optical structures that yield desired radiation patterns different from that of traditional lenses with more complex and nuanced behaviors.

Other mmWave metastructures can be fabricated that enable amplitude and phase manipulation, near-field interactions and even nonlinear behavior depending on the design and materials involved. A main advantage of mmWave metastructures is the enhanced degrees of freedom and more compact dimensions that can result from periodic, unit cell or fractal metastructure design methods.

Manufacturing process precision is intrinsically significant with 2D and 3D mmWave metastructures, as they require feature sizes on the order of fractions of a wavelength and tolerances of a few percent of the minimum structure size; otherwise, they would operate less efficiently, or even fail to function as intended. This is a particular challenge with dielectrics, as there are limited manufacturing processes that can produce ceramic and glass structures with such small dimensions, conformally and with tight tolerances.[1-5] Furthermore, to achieve other performance goals, these metastructures must be constructed of materials with extremely low dielectric losses (low loss tangents), which rules out many polymers and other materials.

Composite materials can be produced with the desired behaviors and assembled through additive manufacturing approaches. There are few additive manufacturing processes, however, that are compatible with complex dielectric composite materials capable of producing relatively large dielectric structures, on the order of centimeters, with high-resolution features on the order of tens of microns.[6] There are some promising new composite materials and fabrication approaches that use innovative manufacturing methods to produce structures on such scales that may be useful well into the mmWave frequency range.[7]

INTEGRATION CHALLENGES

To benefit from a dielectric metastructure it must be designed as a key feature of an AAS or as an enhancement add-on. Either way, the design and fabrication must generally be customized. This is because virtually every physical dimension of the dielectric metastructure must be designed for a specific function. Unlike a radome, which is designed primarily for the protection of a radar/communication antenna, but does not necessarily benefit its function, a dielectric metastructure is a key component designed to critically change the behavior of the electric fields within or radiated/received by the mmWave system.[8,9]

Integration of a dielectric metastructure, in most cases, requires full electromagnetic (EM) simulation and optimization of the entire mmWave system to fully determine the end-design. This is due to the impact of design integration and fabrication of the integrated assembly on the radiation and electric field behavior within a device and from its antenna structure. This type of simulation is computationally expensive for mmWave structures of any size or complexity, as the mesh refinement and resolution required to achieve accurate simulation results is quite sophisticated. Optimization of a dielectric metastructure may require a substantial amount of time for iterative simulation refinement. It is also likely necessary to characterize the behavior of the lens feed system for a dielectric lens antenna, or the placement and fixture tolerances within the assembly housing.[10,11]

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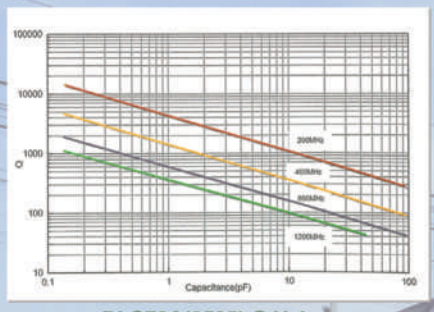

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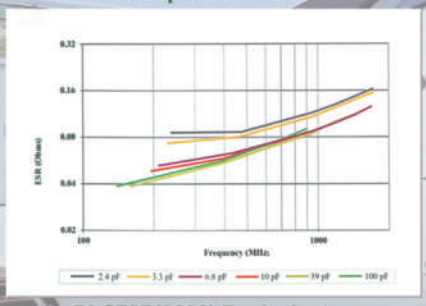

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Manufacturing dielectric metastructures for integration with mmWave systems using traditional layered, cast/molded or CNC subtractive manufacturing approaches may also incur significant expenses for the development of tooling, dies and molds. Consequently, there is a tradeoff between the time and resources spent on design optimization and manufacturing optimization, both of which have their own expense considerations, risks and unknowns. It is therefore desirable to have access to flexible manufacturing methods that can maintain tight tolerances. This is achievable with recently developed dielectric materials and digital light processing (DLP) 3D printing technology.[12]

DIELECTRIC RESINS & 3D PRINTING

Additive manufacturing technologies have revolutionized many industries, have created new ones and have enabled the fabrication of materials in 3D shapes that were previously impractical to manufacture in all but prototype quantities. This is true for RF dielectric structures as well. Until recently, however, there has been a gap in pseudo-scalable additive manufacturing processes that can yield structures out of low loss RF materials with adequate resolution to perform well at mmWave frequencies.

Traditionally, mmWave dielectrics have been manufactured by layering sheets, forming in molds, extruding to a linear shape or machining to shape from bulk dielectric materials. With additive manufacturing, dielectric structures can now be made in 3D layers with many more degrees of freedom and design flexibility. Additive manufacturing methods, however, come with their considerations.

For example, with fused filament fabrication (FFF), a thermoplastic is forced through a narrow nozzle, similar to an extruding process. The diameter of the nozzle, heating element design, speed of the nozzle translation and thermoplastic behavior dictate quality, repeatability and other manufacturing considerations. One important aspect of FFF is that the diameter of the nozzle heavily influences the final part resolution, but the diameter is also a key determinant in how long a part takes to be deposited (often measured in millimeters per second). For mmWave scale resolutions and surface finish, geometric requirements may necessitate the use of either much smaller diameter nozzles (0.1 mm), precision machining or other post-processing.

With liquid vat photopolymerization methods, such as stereolithography (SLA) and DLP, reaching mmWave scale resolutions is less challenging. Depending on the size of the printer, it is possible to process several parts on a single build plate with the potential for much greater repeatability and finer resolution. With DLP, repeatability and resolution of the developed layers are enhanced with the use of a projector as opposed to a laser in SLA or a nozzle in FFF, which are limited as the patterning with these methods is performed over a point path. A major drawback to vat photopolymerization printing (SLA or DLP) methods has been the lack of

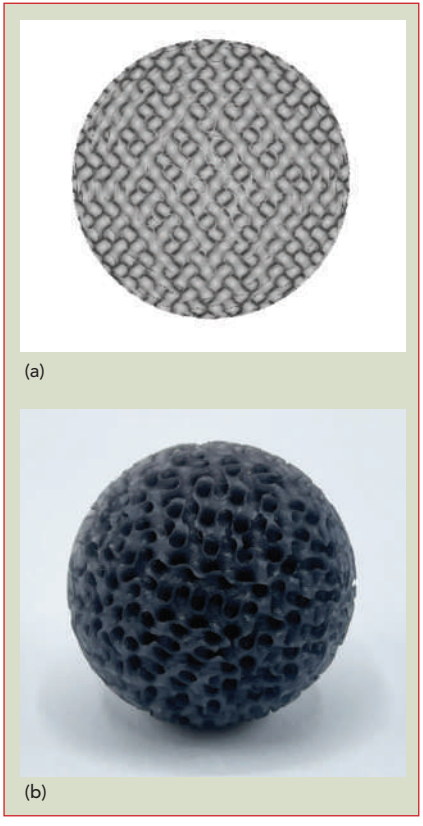

Fig. 2 Spherical dielectric GRIN lens model (a) and 3D-printed spherical GRIN lens fabricated with Rogers Corporation Radix 2.8dk printable polymer dielectric using a Fortify Flux Core DLP 3D printer (b).

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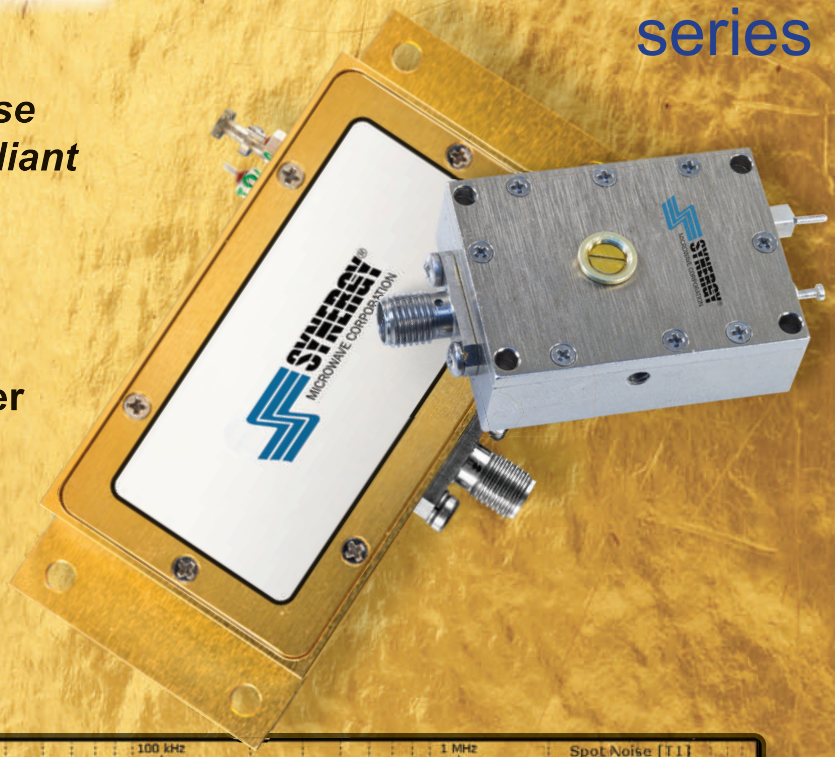

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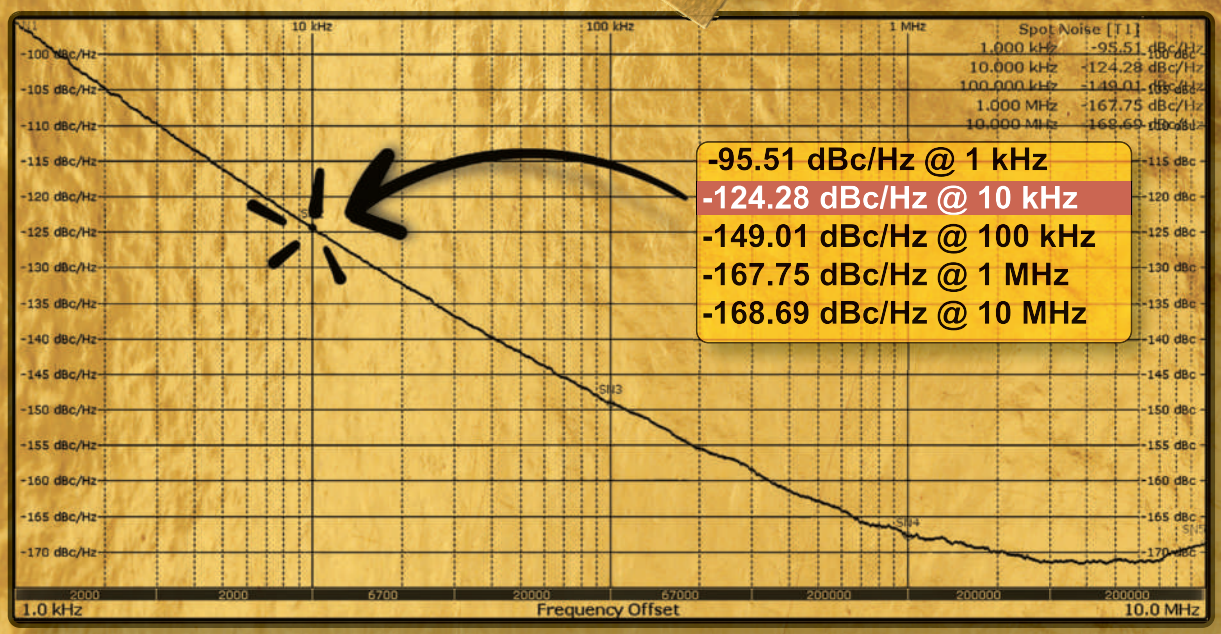

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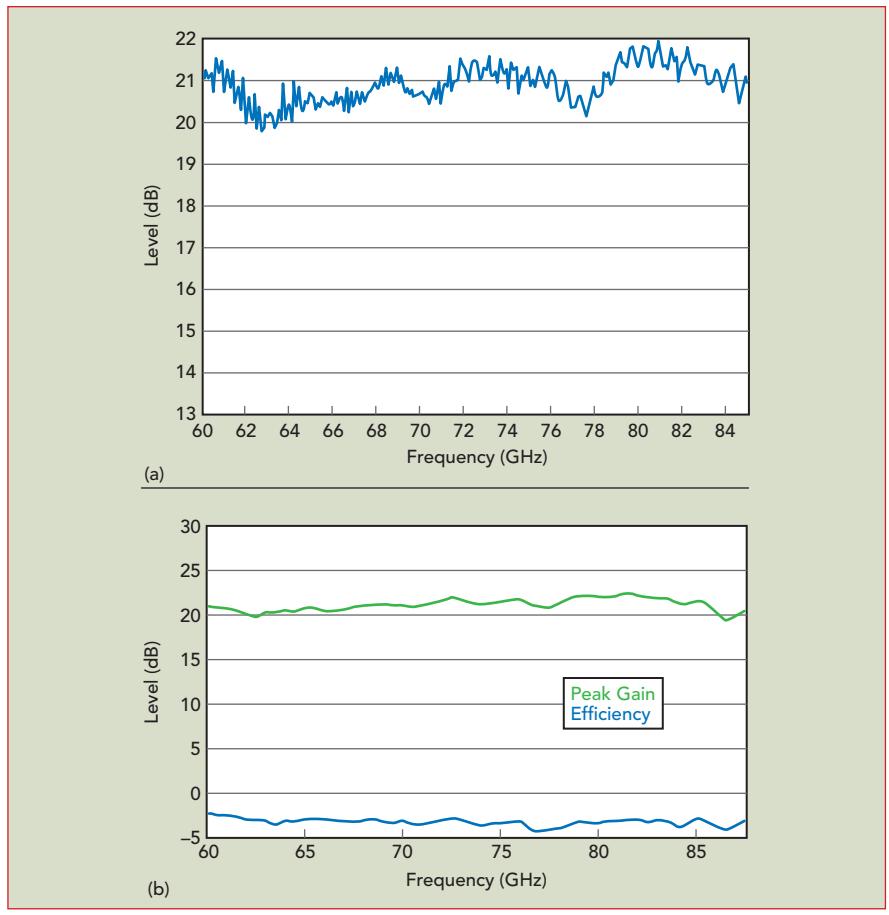

Fig. 3 **3D-printed, Luneburg-style lens measured gain at boresight (a) and peak gain and efficiency vs. frequency at any angle for the complete dielectric lens antenna (b).**

available photopolymer resins that exhibit a combination of desirable dielectric constant and low loss tangent, along with low moisture absorption.

An example of these dynamics can be found in the fabrication of dielectric metamaterial lenses, such as the mmWave Luneburg-style GRIN lens. A GRIN lens can be fed by switched antennas for beam steering, can enhance a phased-array antenna or otherwise act as a dielectric antenna for a variety of use cases. It can be made by designing air gaps within the structure to effectively reduce the overall dielectric constant within a region using cubic, Kelvin, octet or gyroid unit cell geometries. The design must ensure that the structure is both mechanically stable while providing the effective permittivity range needed to yield dielectric lens properties within a desired volume. In some cases, this may result in feature sizes as small as a fraction of a millimeter (required for mmWave operation) with some low effective permittivity regions requiring very thin and high aspect ratio connecting structures.

LUNEBERG STYLE GRIN LENS DEMO

A DLP projection-based manufacturing method using a photopolymer resin with a suitable dielectric constant and low loss tangent combined with a refined structural design can produce a Luneburg-style GRIN dielectric lens that operates to V- and even W-Band frequencies. The lens is composed of gyroid structural elements that enable fine dielectric gradients while maintaining high structural integrity. Putting these concepts to the test, a joint effort by Fortify and Rogers Corporation has produced a GRIN dielectric lens designed to enhance the directivity and gain of a directional antenna pointed at its center (see ***Figure 2***).

In this case, a coaxial to wave-

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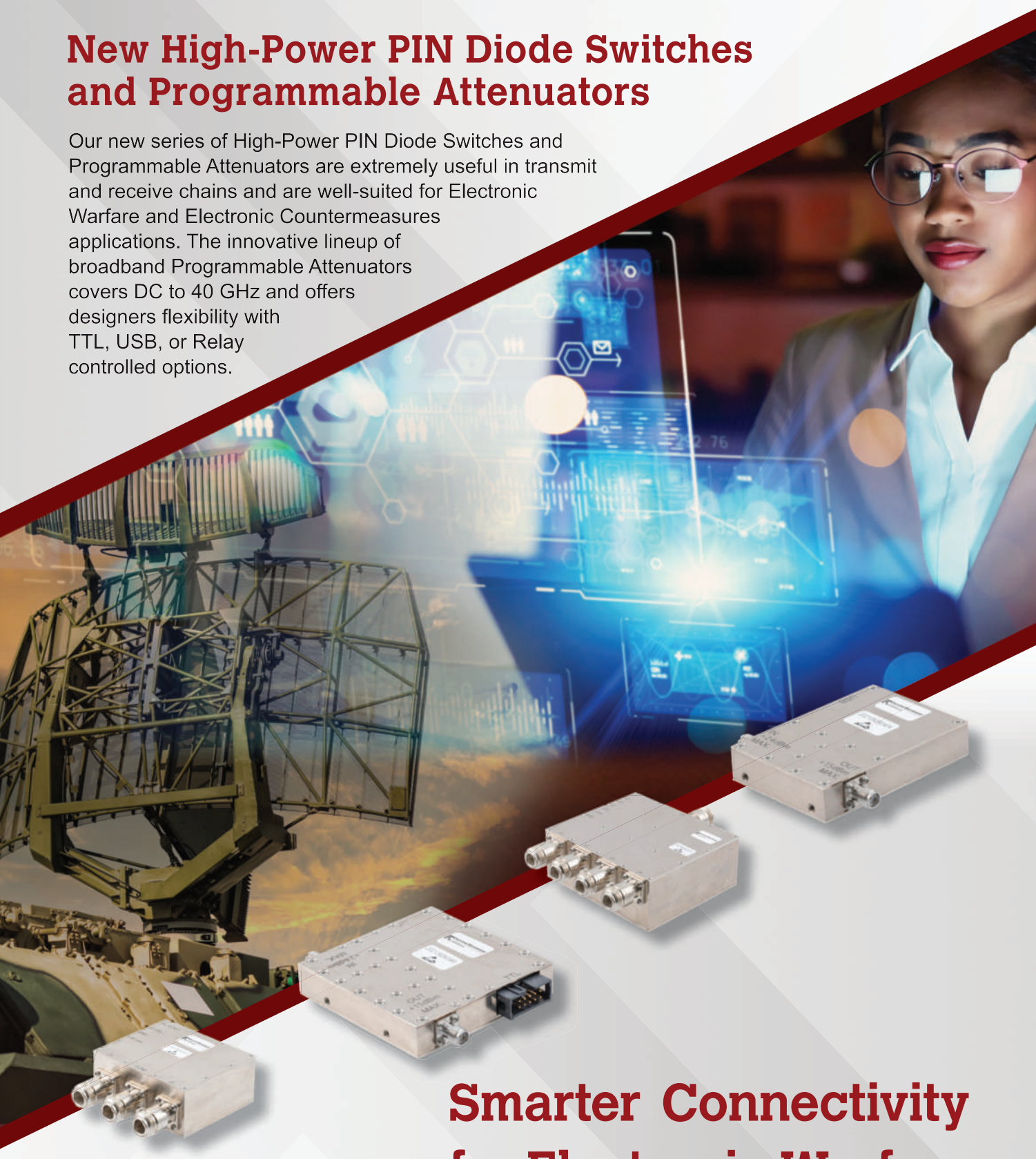

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guide adapter (WR12) is used to feed the spherical GRIN lens fabricated with a Rogers photopolymer resin material using Fortify's advanced 3D printing technology to ensure tolerances are met and to enable the advanced structural design.

The approximately 24 mm diameter E-Band lens is fabricated with wall thicknesses as small as 200 microns (see Figure 2b). The lens is tested using standard methods within a Rohde & Schwarz antenna test chamber with foam gasket fixturing to measure gain at boresight, as well as peak gain at any angle, and efficiency versus frequency.

The 3D printed dielectric lens exhibits a relatively flat gain of between 20 and 22 dBi at boresight from 60 to 85 GHz (see ***Figure 3a***). The average gain of the lens antenna is relatively constant throughout the entire band. Gain fluctuations at boresight likely result and/or are exacerbated due to calibration errors within the setup or slight variations in peak gain angle.

The efficiency data plotted in ***Figure 3b*** includes the interconnect loss from coaxial cables, male/female coaxial adapters and the coaxial to waveguide adapter. Additional losses from the test setup are not included. It is expected that the lens antenna efficiency would improve if these losses were included. Additionally, the peak gain trends slightly upward at higher frequencies, which can be attributed to the increased aperture size relative to frequency.

CONCLUSION

The ability to fabricate complex 3D dielectric structures with the necessary accuracy and precision to achieve adequate performance at mmWave frequencies has historically been limited. The need for advance mmWave dielectrics has driven recent advances in electromagnetic metastructure design and materials development. These advancements have resulted in a 3D printable photopolymer resin and 3D DLP printing technology with performance characteristics that have enabled the fabrication of a high gain V- and W-Band dielectric lens antenna prototype. ■

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Beamformer RFICs Meet Commercial Space Screening

Analog Devices, Inc.
Wilmington, Mass.

The electronic content of space vehicle payloads is expanding in all missions, including deep space, traditional geostationary (GEO) satellites and low Earth orbit (LEO) satellite constellations. With the LEO category, one space subsystem seeing an architectural transition is the adoption of electronic beamforming antennas. These antennas transmit RF signals via antenna beams to the desired ground terminals, and they receive the uplink signals from these same ground stations, albeit at a different frequency. Because LEO satellites are constantly orbiting the planet, the antenna beams must be steered to maintain coverage over a given area, with the capability to hop to another point on the planet as ground coverage switches among satellites. Electronic beamforming antennas can create multiple beams and support dynamic steering and beam hopping. Despite the complexity of these new antenna solutions, they must meet the size, weight, power and cost requirements of the LEO constellations.

To support the adoption of these antennas on LEO satellites, Analog Devices has released the ADAR3000S and ADAR3001S beamformer ICs (BFICs), space screened versions of the ADAR3000 and ADAR3001. These four beam BFICs integrate 16 channels of amplitude and phase control into a single package while minimizing power consumption. The ADAR3000S covers 17 to 22 GHz, and the ADAR3001S covers 27.5 to 31 GHz.

COMMERCIAL SPACE GRADE

Analog Devices has applied decades of knowledge building space grade parts to ensure their ICs are suitable for these new space missions, creating two screening grades:

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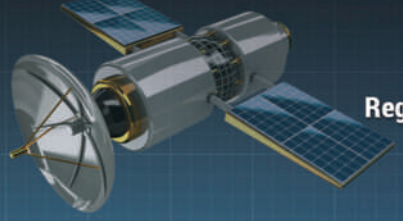

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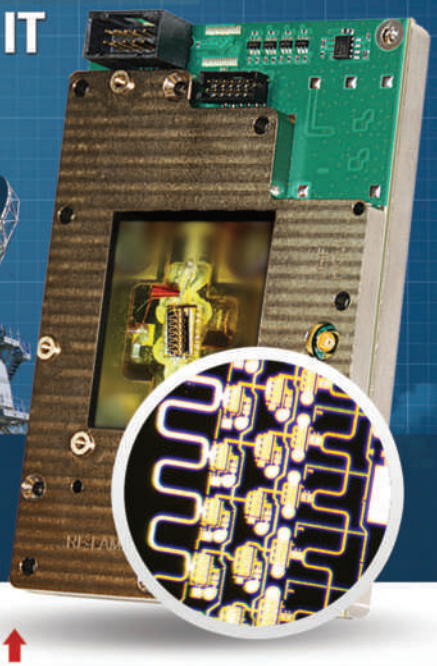

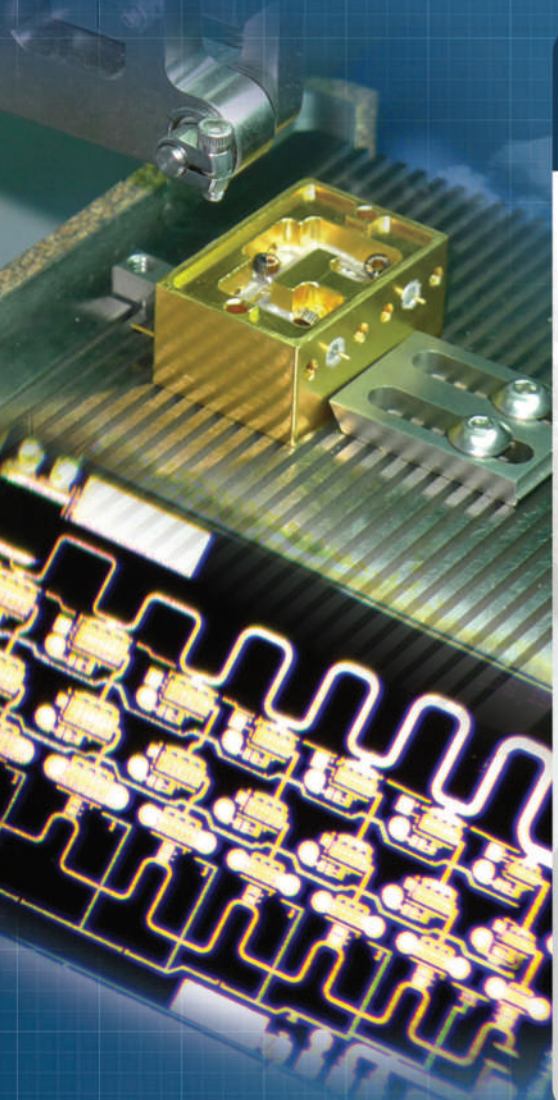

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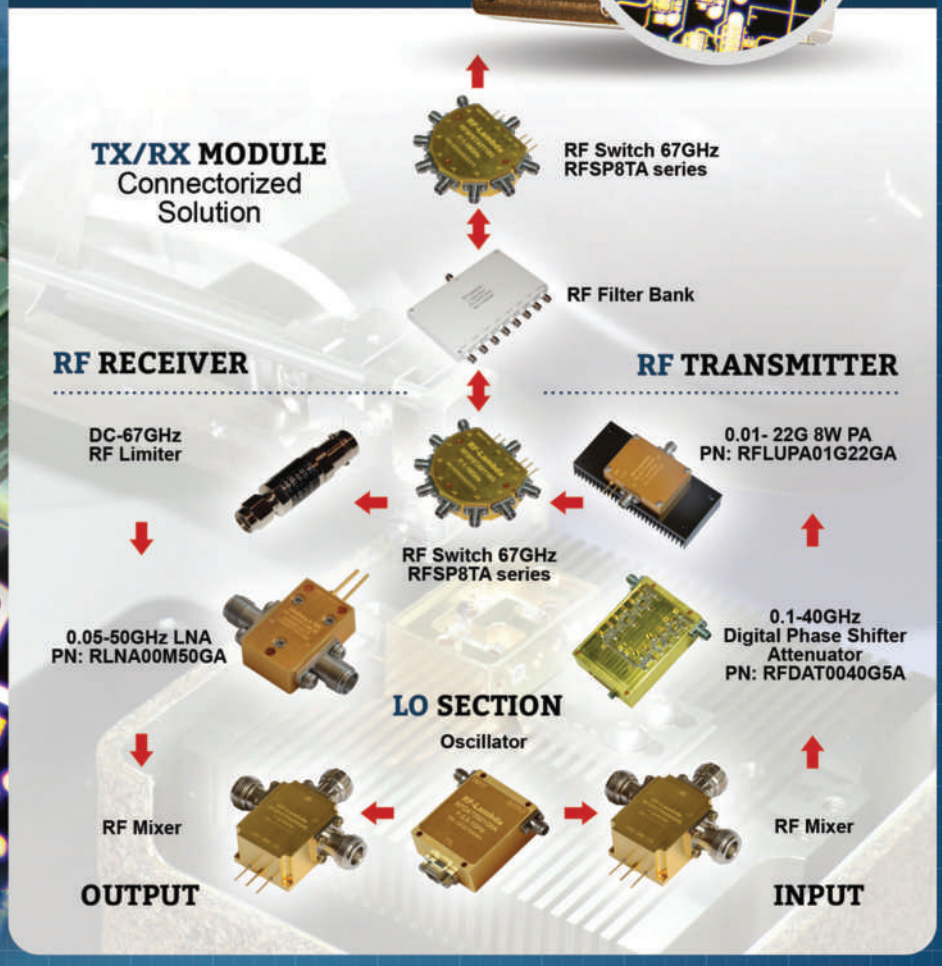

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TABLE 1
CSL SCREENING
Actual Operating Temperature Range Set By Maximum Junction Temperature

Package Type	Plastic	Ceramic
Primary Application/Mission Type	LEO Constellations	
Applicable High Reliability Standards	SAE AS6294, NASA PEM-INST001, MIL-STD-883, JEDEC-STD	
Homogeneous Wafer Lot	Yes	
Wafer Lot Acceptance Test (WLAT)	No	
Cu Wire Bonding	No	
Serialization	No	
Pure Sn Lead Finish	No	No (Au)
Target Operational Temperature Range	-55°C to +125°C	
Group Electrical Testing	No	
Reliability Screening	No	
Outgassing Test per ASTME E95	Yes	N/A
Burn-in Test per Wafer Lot	No	
Life Test (HTOL) per Wafer Lot	No	
Temperature Extreme Electrical Testing	No	
External Visual Inspection	Yes	
Destructive Physical Analysis	No	
Radiation -TID Target	<=30KRad	
Radiation - SEL/SEE Target	30MeV-cm²/mg	
Radiation Lot Aceptance	Benchmark data	
Online Data Sheet	Yes, CSL	
Data Report (per Shipment)	Yes, Generic	

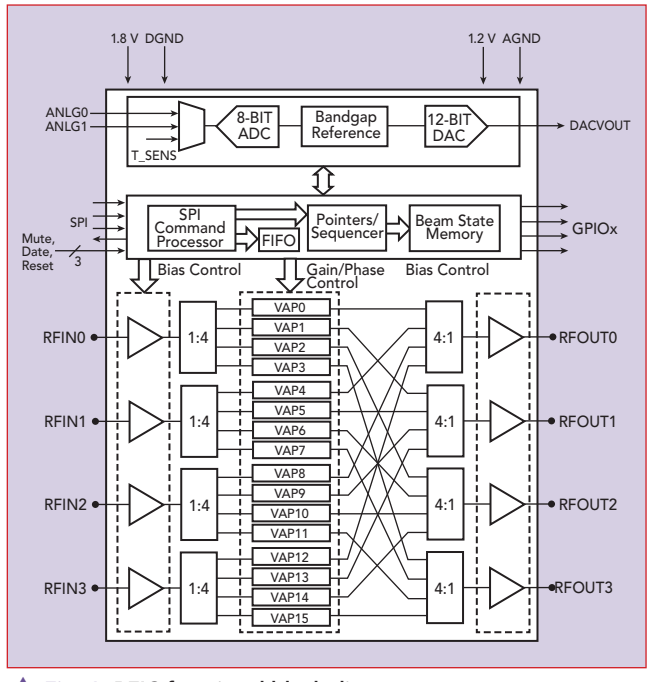

Fig. 1 **BFIC functional block diagram.**

- **Commercial Space High** provides the highest screening and qualification, used where no hermetic packaging option is available. It is equivalent to QML-V using SAE AS6294 as a guideline.
- **Commercial Space Low** (CSL) provides basic testing and screening suitable for LEO constellations or other space applications with high volume and cost are important. CSL provides wafer lot uniformity and traceability, radiation monitors and enhanced testing and screening that are not offered with a commercial grade product (see ***Table 1***).

Balancing reliability with cost to reach an acceptable level of risk is important for this new era of space, where many missions have shorter life cycles and less radiation exposure than traditional GEO satellites. CSL bridges between commercial product screening and full, space-qualified, hermetic, QML-V screening.

The ADAR3000S and ADAR3001S are the first commercially released BFICs available either in standard commercial or CSL grades.

BFIC PERFORMANCE

The capability to steer multiple beams is essential for LEO satellites, typically requiring 12 to 24 analog beams. Adding digital beams creates an antenna with hybrid beamforming. To support these configurations, the ADAR3000 and ADAR3001 support four beams with 16 channels of programmable time delay and attenuation for beam steering, with internal memory for storing the beam positions (see ***Figure 1***). A programmable sequencer enables quick and efficient beam state selection, including beam hopping and raster scanning. The beam commands can be updated, reset or muted via the BFIC's pins or the four-wire serial peripheral interface, which provides 16-chip parallel addressability.

The BFICs are full duplex and can be configured for either transmit or receive, i.e., used for the ground terminals or on the satellite. Control is by the beam and element rather than direct, which enables the registers to load the beam weights in either transmit or receive modes.

The ADAR3000 and ADAR3001 consume very low power. The semiconductor process used for the designs enables the beamformers to dissipate less than 12 mW per channel, summing to total power consumption less than 195 mW for the entire BFIC. The power consumption can be reduced via the programmable bias for the RF amplifiers.

Highly integrated, the ADAR3000 and ADAR3001 BFICs are rich in features, including integrated analog-to-digital converters for temperature sensing and general analog inputs.

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Software-Defined Imaging Radar Aids the Awareness of Intelligent Systems

Zadar Labs
San Jose, Calif.

As automated and intelligent systems advance to take on new workloads and applications, their detection requirements have evolved beyond simple data to awareness of the surrounding complex and dynamic environment. This presents two challenges for radar. First, conventional 24 and 77 GHz designs cannot readily achieve the data quality and density to support artificial intelligence (AI) and machine learning (ML) processing techniques. Second, the application space is growing rapidly and requires "open box" designs for deeper and flexible integration with more systems.

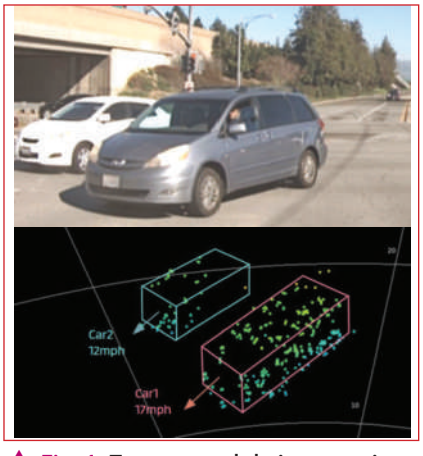

Fig. 1 Two cars and their respective zPRIME radar point clouds. The color reflects target elevation.

zPRIME from Zadar Labs closes these gaps by combining the latest RF Si technology with a software-defined architecture that elevates the performance of the radar from hardware into software to create a software-defined imaging radar (SDIR). Zadar Labs sees SDIR as the foundation enabling broad and quick expansion of radar applications.

In nearly all applications for intelligent systems, the objective is to create a "digital twin" to perceive and model the environment with enough accuracy, precision and recall to be useful for an automated workload. To do this, the sensor array—typically composed of a combination of radar, LiDAR, camera and location sensing—will actively and passively collect feedback from the surrounding environment. To do this intelligently, meaning with awareness of context, the sensors must dynamically respond to understand and optimize for the current scenario. zPRIME uses real-time processing to update the radar configuration within milliseconds, optimizing for the current scenario. Linking the processing and sensor is unique to SDIR and requires higher performance than the typical radar; the data from the radar must be of sufficient quality and density to feed the algorithms used with a cognitive radar.

SDIR PERFORMANCE

Zadar Labs' zPRIME is currently leading by demonstrating the potential of SDIR: zPRIME detects vehicles out to 800 meters with 0.4-degree resolution in azimuth and elevation. While Zadar uses available hardware and components like other 4D imaging platforms, its patented algorithms and software provide significantly better performance. With deep access to the processing chain, the platform is versatile and powerful

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▲ Fig. 2 Point clouds of a LiDAR sensor (left) and the Zadar sensor (right).

enough for critical radar applications. The Zadar team developed a proprietary processing stack named zVUE that manages both the signal and data processing, using AI/ML algorithms for dynamic operation and advanced radar features. These include object tracking, classification, simultaneous location and mapping and segmentation. Able to tap into data at any point in the processing chain, Zadar's solution supports almost any form of sensor fusion. Further, zVUE's capabilities for higher level data processing are independent of the hardware, meaning they can be applied to other radar platforms with relatively little tuning.

The zPRIME platform fulfills the stringent radar requirements for fully autonomous operation, called L5 autonomy. zPRIME's state-of-the-art resolution produces a LiDAR-like point cloud that reveals the outline of a target, whether human or vehicle (see ***Figures 1*** and ***2***). The radar covers a wide field of view of approximately ±65 degrees in azimuth and ±12 degrees in elevation and has demonstrated vehicle detection out to 800 meters in a suburban environment. zPRIME uses a unique chirp-coding waveform for unambiguous Doppler detection per scan to greater than 220 MPH. It is also near immune to interference: if interference is detected, zPRIME frequency hops and adjusts timing to eliminate continuing exposure. All this capability is packaged in a form factor of approximately 15 × 12 × 3 cm.

FROM DATA TO INFORMATION

zPRIME was designed to house most of Zadar's SDIR processing at the edge; zVUE provides significantly higher data quality and information to the upper-level system. For autonomous mobility, the data is typically used for perception and navigation. Zadar divides the processing chain into kernels, applying bespoke algorithms to provide advanced information based on their respective locations in the chain. This information includes the following:

- Estimated vehicle odometry without GPS or inertial measurement unit data
- Static-dynamic detection performed on each scan to differentiate between static and moving objects
- Prediction, comprising a tracked object list with optimized cluster and track data
- Online calibration and tuning. The radar has intrinsic and extrinsic online calibration, and the

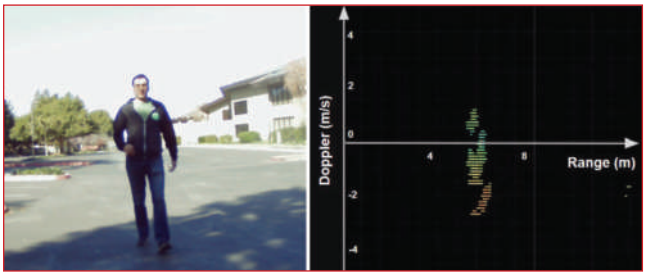

Fig. 3 Range-Doppler profile of a person. The signature of the relative hand movements can be used to classify the object as a person.

Fig. 4 Range-Doppler profile of a moving sedan, showing a clear difference in the speed of the wheels vs. the vehicle body.

SDIR software stack adaptively tunes the RF front-end and signal processing kernels to the environment, providing enhanced precision and recall

- Object classification using the AI radar algorithms in zVUE. Using the detection signatures of the detected objects (see ***Figures 3*** and ***4***), in addition to temporal characteristics, Zadar's algorithms use a detection profile for classification.

ONE PLATFORM, MANY APPLICATIONS

zPRIME can provide up to 20,000 useful detections per scan. When combined with the Zadar SDIR, the platform greatly reduces computational workload, enabling adaptation to support many applications in multiple industries.

zPRIME's resolution, feature set and post-processing kernels set a development model for Zadar's current and future platforms. The Zadar SDIR has the performance to support demanding autonomy applications, yet it remains flexible as a platform to enable adaptation and optimization. The SDIR can be used for applications from autonomous vehicles and trucks to heavy equipment and infrastructure.

Zadar's vision is to help build a future where the quality of life is radically improved through safer and more effective machine sensing and cognition using radar vision. Seeing the trend toward SDIR, Zadar has developed a platform to realize SDIR's resolution, flexibility and scalability.

Zadar Labs
San Jose, Calif.
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0.8 to 3.2 GHz, 1 kW Pulse, Solid-State, Dual-Mode Power Amplifier

Exodus Advanced Communications has developed a solid-state power amplifier (PA) for automotive, communications, electronic warfare and general radiated susceptibility testing, such as EMI-Lab and RS103. With a response from 800 MHz to 3.2 GHz, the AMP2103P-LC dual-mode amplifier covers both automotive testing ranges, meeting the pulse and CW requirements for the 300 V/m and 600 V/m automotive testing requirements defined by the Society of Automotive Engineers.

The AMP2103P-LC produces at least 1000 W of pulsed power across the band or 500 W CW with 3 dB peak-to-peak power flatness. To support the linearity requirements of all modulations and industry standards, the PA uses a class A/AB design, enabling it to achieve -20 dBc harmonics at the rated output power and -30 dBc two-tone intermodulation with two 47 dBm tones 1 MHz apart.

The dual-mode PA provides extensive control and monitoring capabilities, with monitoring using a 7-inch color display or via a remote connection. Automatic leveling with > 20 dB gain range can be controlled using the screen or the remote interface. The color touchscreen shows the forward and reflected power, providing VSWR in real time; system voltages and currents; and the operating temperatures of the PA module heat sinks and internal system temperature. Exodus offers an option to calibrate the power monitoring accuracy to within ±0.2 dB.

A unique feature of the AMP2103P-LC is its compact size: 7U, the smallest and highest power offered for this frequency range. The PA uses type N female connectors for the RF input and optional RF sampling ports. To handle the high power, the RF output uses a 716 female connector.

In addition to PAs, Exodus designs low noise amplifiers, modules and multi-band systems spanning 10 kHz to > 51 GHz.

VENDORVIEW

Exodus Advanced Communications
Las Vegas, Nev.
www.exoduscomm.com

18 GHz, High-Power Electromechanical Switch Family for EW

RLC Electronics has released a family of high-power electromechanical (EM) switches with frequency coverage to 18 GHz. The series expanded from the original single pole double throw switch, released in 2015, to include SP3T through SP6T versions. Developed for an electronic warfare (EW) system, the switches have insertion loss <0.5 dB and isolation >80 dB, and they handle 125 W incident power at 18 GHz. Switch performance improves at lower frequencies, with 1000 W power handling at 100 MHz. VSWR in a 50 Ω system is specified at 1.6:1 maximum at 18 GHz and 1.25:1 below 7 GHz. Switching time is less than 20 ms.

The switches have type N female RF connectors, with power and control connections via solder terminals, D-Sub or MS connectors. Additional options are failsafe or latching operation, 5 to 30 V DC coil voltage, a TTL driver and indicator circuitry. The switches can be customized further to meet a program's unique requirements. To create multi-function assemblies, RLC can integrate discrete components into a multifunction platform.

According to RLC, it is the only company supplying this combination of power handling and frequency coverage in a multi-throw EM switch. Nonetheless, anticipating future program needs, RLC is focused on increasing the power handling capability of the switch family to 175 W at 18 GHz.

Formed in 1959, RLC Electronics designs and manufactures coaxial and surface-mount microwave components, including coaxial switches, filters, attenuators, couplers, power dividers, detectors, bias tees, pickoff tees, phase trimmers and terminations.

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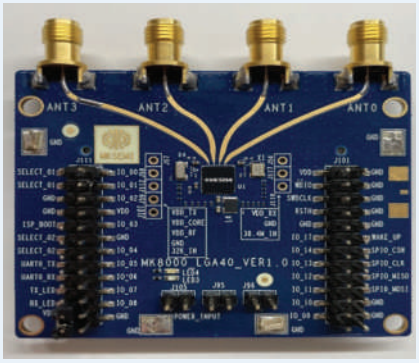
Mount Kisco, N.Y.
www.rlcelectronics.com



Low-Power, Highly Integrated UWB SoC

Ultra-wideband (UWB) technology has become a significant short-range wireless standard in the smartphone ecosystem, following its adoption by consumer electronics manufacturers like Apple, Samsung and Google. UWB is also being adopted by standard bodies such as the Car Connectivity Consortium®, with its Digital Key 3.0 release, and the FiRa™ Consortium, which recently announced its first certification program for UWB device interoperability.

To meet the growth in UWB for ubiquitous high precision sensing, Mauna Kea Semiconductors (MKSemi) has introduced the MK8000 SoC, which MKSemi says is the world's lowest power and highest integrated chip solution. Drawing 43 mA at 3 V bias in receive mode, the MK8000 has 2x lower power consumption than other SoCs. For full ranging and angle of arrival measurement, it integrates an ARM Cortex M0 microcontroller with multiple RF channels: four receive (Rx) and one transmit (Tx), including the Tx/Rx switch and matching network. This integration lowers the bill of materials cost and reduces printed circuit board footprint.

Supporting the widest frequency band, from 3.1 to ~ 9 GHz (UWB bands 1 and 2), the MK8000 meets all global UWB standards and is backward compatible. It handles data rates of 110 and 850 kbps and 6.8, 27 and 54 Mbps, supporting many applications and ensuring futureproofing. Applications for the SoC range from the location solutions being integrated into smartphones and automobiles, as well as consumer and industrial IoT applications from smart homes and cities to cars and hospitals.

For automotive, MKSemi has partnered with Infineon Technologies and ThinkSeed Systems to develop secure ranging and location solutions for IoT applications, jointly developing a design that pairs the Bluetooth Low Energy microcontroller from Infineon with the MK8000.

Mauna Kea Semiconductors (MKSemi)
San Jose, Calif.
www.mk-semi.com

Non-Signaling RF Test Platform for Validation and Production Test

Designed to be a flexible platform for RF testing, the NOFFZ Universal Wireless Tester (UWT) covers the cellular and connectivity standards (e.g., C-V2X, 5G, 802.11ax, Bluetooth Low Energy and ultra-wideband) for non-signaling verification. Additional waveform generation capabilities for global navigation satellite systems and broadcast radio expand the technology coverage for test applications.

The UWT is based on modular PXIe hardware from NI that provides high speed, reliable testing. Instrument sharing and scheduling of measurement tasks are enabled through the NOFFZ Universal Switch Matrix (UMX), which extends PXIe instruments to 32 bidirectional RF ports, with additional DC load emulation and voltage/current measurement capabilities. The UWT is scalable to up to four individual vector signal transceivers and four UMXs, covering 128 RF channels.

For higher throughput or faster test time, the system can be upgraded with additional analyzers and generators. During calibration or repair, the test stations can continue to operate at lower throughput; transceivers can be serviced one at a time, minimizing downtime.

Wireless standards are increasingly integrated in vehicles, smart homes and industrial IoT applications, this demands parallel testing solutions with high channel counts. From sub-6 GHz to mmWave frequencies, the UWT covers the essence of test requirements in one system, providing flexibility, scalability and long-term support.

VENDORVIEW

NOFFZ Technologies GmbH
Toenisvorst, Germany
www.noffz.com

MAKING WAVES

Industrial Wireless Connectors and the Factory of the Future

Read how ADI are reducing factory downtime, lowering runtime costs and enabling maintenance-free solutions for industrial robotics through the removal of physical connectors.

Analog Devices Inc.
www.analog.com/en/signals/articles/industrial-wireless-connectors.html

New 50 Ohm Component Brochure from JFW Industries

JFW has introduced numerous new products to support testing the full range of frequencies allotted by Wi-Fi 6E. Learn more in their new brochure.

JFW Industries
www.jfwindustries.com

Test Solutions Product Guide 2022

Mini-Circuits' innovative line of test solutions has helped hundreds of customers improve efficiency and reduce cost in their test setups. Check out this complete guide for some ideas about how we can help you do the same!

Mini-Circuits
www.minicircuits.com/pdfs/Test%20Solutions%20Brochure_11-2-21_DIGITAL.pdf

Defining Near/Far Field Regions Within EMC Testing

Antenna specifications can be misinterpreted or confusing. Where are near/far field regions and what do they imply? Read, "Antenna Far Field Distances," to learn more.

AR RF/Microwave Instrumentation
https://bit.ly/3JW0kKF

All Things 5G Episode 12: 6G

Roger Nichols, head of Keysight's 6G program, gives an update on the status of the sixth-generation wireless communication technology including what he envisions for it, where it stands today and what the development roadmap looks like.

Keysight Technologies
https://bit.ly/36FknyD

ALL THINGS 5G PODCAST

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Use NEL's new product finder function to determine the right frequency control solution for your needs. Select the product category, then choose your requirements and specs to find the best model.

NEL Frequency Controls, Inc.
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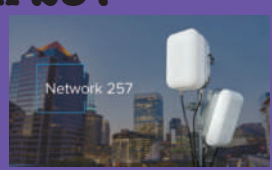
Signal Hound's Spike™ Adds LTE Analysis Mode at No Cost

Spike's LTE features provide solutions for network coverage testing, cell discovery and monitoring, network verification, antenna characterization and more. Free update with Spike V3.5.21 or newer.

Signal Hound
https://signalhound.com/spike/

New Video: Wilson Network 257

The Wilson Network 257 with dielectric waveguide antennas is the ideal repeater solution extending 5G mmWave outside cellular coverage on any mobile network.



Wilson Electronics
https://bit.ly/3vgB7qg

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COMPONENTS

Beamformer and IF Up-/Down-Converter ICs

VENDORVIEW

Anokiwave Inc. introduced its fourth generation high efficiency multi-band Si IC family. The new IC family greatly pushes the levels of performance and cost to a point where network operators can start to accelerate the builds of greener, lower cost and smaller form factor mmWave 5G radios, for every 3GPP FR2 band. The ICs in this family are the 24 to 30 GHz AWMF-0221, a dual-quad channel, dual polarization beamforming IC and the AWMF-0210, a wideband IF up-/down-converter IC.
Anokiwave Inc.
www.anokiwave.com

Waveguide Pressure Windows

VENDORVIEW

Fairview Microwave's new series of Waveguide Pressure Windows, in stock and available for same-day shipping, are ideal for sealing and isolating pressurized components from non-pressurized components within a waveguide system. These Waveguide Pressure Windows provide protection against contaminants such as debris, moisture and dust entering your waveguide system and degrading its RF performance. They are manufactured to endure applications found in the most demanding environments.
Fairview Microwave
www.fairviewmicrowave.com

DC to 70 GHz, 1 W, 50 Ω, 1.85 mm Termination

VENDORVIEW

MIcable TM01-185MH ultra-wideband 50 Ω termination is built up with 1.85 mm high precision male connector and firm stainless steel configuration. They have excellent VSWR 1.5: 1 maximum over the DC to 70 GHz frequency range which can absorb up to 1 W CW power. The rugged configuration gives the unit an extended life of use.
Fuzhou MIcable Electronic Technology Group Co., Ltd.
www.micable.cn

mmWave Controlled Components

General Microwave Corp. is a key partner with major OEMs and primes, having been chosen for broad and comprehensive understanding of mmWave Controlled Components. General Microwave offers a wide range of mmWave products operating in the 18 to 40 GHz frequency range including catalog attenuators, switches and phase shifters as well as integrated microwave assemblies. If it's a standard catalog unit or a highly customized mmWave product designed specifically for high performance, General Microwave can provide products to support your requirements.
Kratos/General Microwave Corp.
www.kratosmed.com

5 to 700 MHz Return Path Transformers

Whether you are expanding return path to 210, 300 or 700 MHz BW, MiniRF offers a myriad of return path solutions. The new MRFXF5R16 and MRFXF5R17 are 1:1 transformers that provide low IL loss 0.4 dB at mid-band with 25 dB IRL typical and ± 0.2 dB amplitude balance. They both provide 400 mA DC bias tap in the S20 package.
MiniRF
www.minirf.com

24 to 30 GHz Wideband Cavity Filter

NIC introduces a 24 to 30 GHz wideband cavity bandpass filter spanning from K-Band to Ka-Band. The filter is designed for low insertion loss, sharp close-in attenuation of > 60 dB and can withstand harsh military environmental requirements, making it a perfect fit for airborne, ship-mount or vehicle mount applications. Custom designs are available from 100 MHz to 30 GHz.
Networks International Corp. (NIC)
www.nickc.com

Larger Case Size Capacitors

Passive Plus Inc. (PPI) offers a series of larger case size capacitors with a high Q, high RF current/voltage with low ESR/ESL and ultra stable performance characteristics. These capacitors can be used as bypass, coupling, tuning, impedance matching or DC blocking components for HF/RF power amplifiers, transmitters, antenna tuning, plasma changes and medical equipment applications.
Passive Plus Inc.
www.passiveplus.com

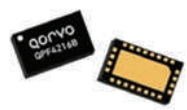
SP1T Absorptive Switch

VENDORVIEW

PMI Model No. P1T-DC40G-65-T-24FM-1NS is an absorptive, single pole single throw Pin diode switch that operates from DC to 40 GHz with isolation of 65 dB, insertion loss of 5.5 dB, VSWR of 2.0:1, input power of +17 dBm and switching speed of 5 ns, rise/fall time of 0.9 ns. This model uses DC voltage of +8 to +15 V at 15 mA, -8 to -15 V at 40 mA, incorporates a TTL compatible driver for ease of system integration and has 2.4 mm female connectors in a housing measuring 1.30" × 1.20" × 0.50".
Planar Monolithics Industries
www.pmi-rf.com

Wi-Fi 6 FEM

VENDORVIEW



RFMW announces design and sales support for a Wi-Fi (802.11n-ax) front-end module (FEM). The Qorvo QPF4216B FEM delivers higher power and better throughput in Wi-Fi 802.11ax systems than competing devices. Integrated matching minimizes layout area and the device is pinned out so external filtering can be added in the optimal position. Performance features include 22 dBm Pout (at -43 dB DEVM) and 26 dBm Pout (at MCSO HT20). Transmit gain is 32 dB while receive noise figure is 1.8 dB. 5 GHz signals are filtered with 15 dB rejection.
RFMW
www.rfmw.com

SP9T/SP10T Higher Power Handling Switch

RLC Electronics Inc. has recently launched a new SP9T/SP10T higher power handling switch series. These switches operate from DC to 6 GHz (minimum) and will handle upwards of 150 W cW (previous designs limited power to 75 W cW). Units exhibit low loss (0.25

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dB), high isolation (> 70 dB) and are designed to operate in severe environmental conditions. Switch to RLC for your Electro-Mechanical switch needs, from DC-65 GHz, SP2T-SP12T.
RLC Electronics Inc.
www.rlcelectronics.com

CABLES & CONNECTORS

General Purpose Between-Series Adapters

VENDORVIEW

Introducing HASCO MCX to SMA general purpose between-series adapters. The bulkhead, T and straight coaxial adapters offer performance from DC up to 6 GHz. These general purpose adapters come in male to female or plug to jack configuration, featuring a VSWR of 1.20:1 and impedance of 50 Ohms. HASCO's general purpose adapters are RoHS compliant, in stock and ready to ship daily.
HASCO Inc.
www.hasco-inc.com

NMD Adapters

VENDORVIEW

Pasternack's new addition of NMD Adapters feature a rugged design and are ideal for stabilizing test port cables when attached to the front of vector network analyzers or other test sets. These 50 Ohm adapters are precision manufactured to RF components industry specifications and are available in 3.5, 2.92 and 2.4 mm configuration options. They are perfect for use in the testing of various RF components.
Pasternack
www.pasternack.com

AMPLIFIERS

U-Band Amplifier

VENDORVIEW

With typical small-signal gain of 30 dB and a 1 dB compression point of +26 dBm, U-Band power amplifier model SBP-4035533026-1919-E1 spans the frequency range of 40 to 55 GHz. DC power is +8 V at 1850 mA. The mechanical configuration offers an in-line structure using WR-19 Uni-Guide™ waveguide connectors for the input and output ports. Other port configurations such as 1.85 mm connectors are also available.
Eravant
www.eravant.com

1 kW Pulsed Solid-State Power Amplifier

VENDORVIEW

The AMP6030P-1KW is a solid-state power amplifier (SSPA) that operates from 33.5 to 35 GHz. It delivers a pulsed output power of 1 kW with a gain of more than 60 dB. This Class A/AB linear amplifier has a pulse width of 100 µs and has a maximum duty cycle of 10 percent. The SSPA has spurious levels of better than -60 dBc and harmonics of -20 dBc. The amplifier is ideal for pulsed EW, EMI/RFI, communications, pulse/HIRF, EMC/EMI MIL-STD 461/464 and radar applications.
Exodus Advanced Communications
www.exoduscomm.com

Coaxial Amplifier Powers

VENDORVIEW

Mini-Circuits' model ZHL-2425-250+ SSPA capable of 300 W (+54.8 dBm) typical CW or pulsed output power across the ISM band from 2.4 to 2.5 GHz. It provides 42 dB typical gain with 60 percent typical power-added efficiency but measures just 6.750 × 2.20 × 0.80 in. (171.450 × 55.880 × 20.320 mm) with MCX input and N-type output connectors. The rugged 50 Ω amplifier has simple TTL control and draws 16 A at 32 VDC.
Mini-Circuits
www.minicircuits.com

SYSTEMS

Next-Generation PCIe Digitizers

VENDORVIEW

Two new digitizer cards from Spectrum Instrumentation raise the standard of PC-based instrumentation performance: The cards are capable of streaming acquired data over the PCIe bus at an impressive 12.8 GB/s—nearly twice as fast as any other PCIe digitizer currently on the market. It means they can continuously run at their maximum sampling rate of 6.4 GS/s, with 12-bit resolution, streaming this massive data to CPUs or CUDA GPUs for real-time processing.
Spectrum Instrumentation GmbH
www.spectrum-instrumentation.com

SOURCES

Vibration-Isolated OCXO

The vibration-isolated AXIOM210 series is AXTAL's high-runner offer very low phase noise under vibration. The unique internal vibration absorbers are proven in many

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applications since 2013. The module comes in a compact connectorized 50 x 50 x 30 mm package. Standard frequencies are 100 and 120 MHz, other frequencies between 50 and 130 MHz are available. Several options for phase noise under vibration can be chosen. A smaller version in 38 x 38 mm package can be offered.
AXTAL GmbH & Co. KG
www.axtal.com.

Innovative New 1 GHz OCXO

To meet the increasing demand for high frequency OCXOs with ultra-low phase noise, KVG's engineers have developed a 1 GHz OCXO. Using the advantages of a SC-cut crystal-based oscillator stage in combination with new analog frequency multiplication, the OXCO provides tight temperature stability and very good long-term stability. The 1 GHz OCXO comes up with excellent phase noise performance near the carrier with better than -112 dBc/Hz at 100 Hz as well as a very low noise floor below -155 dBc/Hz.
KVG Quartz Crystal Technology GmbH
www.kvg-gmbh.de

Pulse Generator

Pulse Genex announces its new mid-cost range pulse generator. Their engineers were tired of the over-complicated user interfaces on other pulse generators, so we came up with the Bulldog. It is designed for ease-of-use and offers four-channel output, ModBus communication and user defined fault limits to protect your equipment. It generates pulses with programmable relative timing and is capable of remote operation with a provided graphic user interface. The Bulldog is available in both benchtop and rackmount models.
Pulse Genex
Pulsegenex.com

TEST & MEASUREMENT

CMX500 One-Box Tester

VENDORVIEW

Rohde & Schwarz eliminates the complexities of 5G NR device testing by combining ease-of-use and superior performance in a single instrument. With its new one-box tester approach, the R&S CMX500 5G radio communication tester enables even complex test setups for all 5G NR deployments, supporting a large variety of the present and future 3GPP band combinations. The simplified setup in a single easy-to-use test platform results in an extremely small footprint in the lab.
Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

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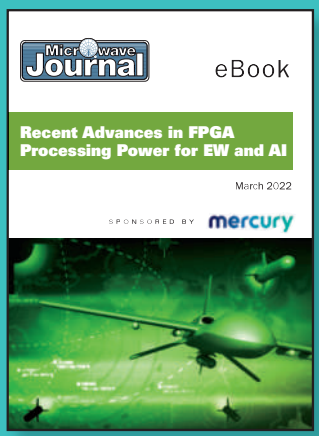

Bookend

Nonlinear Design: FETs and HEMTs

Peter H. Ladbrooke

Despite its continuing popularity, the so-called standard circuit model of compound semiconductor field-effect transistors (FETs) and high electron mobility transistors (HEMTs) is shown to have a limitation for nonlinear analysis and design: it is valid only in the static limit. When the voltages and currents are time-varying, as they must be for these devices to have any practical use, the model progressively fails for higher specification circuits.

This book shows how to reform the standard model to render it fully compliant with the way FETs and HEMTs actually function, thus rendering it valid dynamically. Proof-of-principle is demonstrated for several practical circuits, including a frequency doubler and amplifiers with demanding performance criteria.

Methods for extracting both the reformulated model and the standard model are described, including a scheme for re-constructing from S-parameters the bias-dependent dynamic (or RF) I(V) characteristics along which devices work in real-world applications and as needed for the design of nonlinear circuits using harmonic-balance and time-domain simulators.

The book includes a historical review of how variations on the standard model theme evolved, leading up to one of the most widely used—the Angelov (or Chalmers) model. This is a key resource for circuit designers, device measurement and characterization specialists and device manufacturers.

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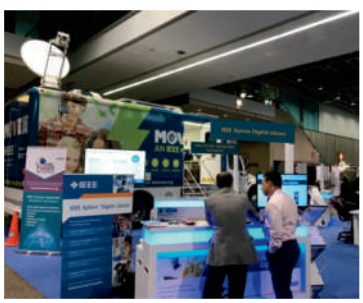

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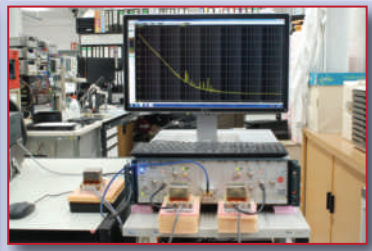
SSG-6001RC	Signal Generator	1-6000
SSG-6000RC	Signal Generator	25-6000

*SSG-30G-RC comes as a kit including SSG-15G-RC signal generator, FX-30G-RC frequency extender and all required accessories.

Mini-Circuits

KVG: The Hidden Champion of Quartz Crystal Technology



From a stately stone building in the heart of Neckarbischofsheim, Germany, KVG Quartz Crystal Technology pursues its long commitment to a technology at the heart of electronics. Any system with an oscillator or clock requires an accurate frequency reference, one that ideally introduces no phase noise or jitter and is stable with temperature and vibration. Quartz crystals have long been the predominant frequency reference for such sources, and KVG was one of the first companies to develop and commercialize the technology.

Formed in 1946 by physicist Kurt Klingsporn, Kristallverarbeitungsgesellschaft Neckarbischofsheim (translated as crystal processing company in Neckarbischofsheim), KVG has expanded its capabilities from crystals to designing and building the oscillators that use crystal technology, such as temperature compensated crystal oscillators (TCXO), oven-controlled crystal oscillators (OCXO) and voltage-controlled crystal oscillators (VCXO). KVG also develops crystal filters, typically Chebyshev or Butterworth designs with center frequencies between 5 and 200 MHz and bandwidths from 1.5 to 75 kHz.

Most KVG products are designed to meet customers' unique requirements, which reflects KVG's heritage of customer focus and taking on the most challenging problems. Known for low phase noise and low g sensitivity, KVG's oscillators are found in test and measurement instruments, telecommunications equipment, medical imaging and military systems, particularly suited for high vibration environments. To achieve the lowest phase noise, KVG combines its crystals with analog circuits designed using bipolar or CMOS transistors. The electrical design is complemented by mechanical and thermal designs that minimize performance variation caused by the environment.

As an example of the performance capability of its oscillators, KVG offers a 100 MHz OCXO that achieves a noise floor better than –185 dBc/Hz at 100 kHz offset. Phase noise is less than –180 dBc/Hz at 10 kHz offset and –138 dBc/Hz at 100 Hz offset. The dynamic g sensitivity of the OCXO is less than 1 ppb/g for all three axes, which is 10x better than standard OCXOs.

With an extensive library of oscillator designs between 10 and 150 MHz, KVG's R&D is focused on expanding the TCXO and VCXO products and offering higher frequency options, i.e., from 500 MHz to 2 GHz. As systems move to higher frequency bands such as mmWave, designers want higher frequency references to simplify their local oscillator chains.

KVG is largely self-contained. Its team occupies approximately 6000 m^2 in several buildings located at one site, including the founder's home, which first housed the company, and its larger headquarters, once the district court in Neckarbischofsheim. 1200 m^2 is devoted to manufacturing and test, with full environmental testing for vibration, mechanical shock, temperature shock, salt spray and altitude.

Despite the pandemic, KVG's business grew over the past two years, attributed to the critical applications its products support. While it is well known and highly regarded by the customers it supports, KVG sees itself as a "hidden champion" in the market. To continue growing, the team intends to increase its visibility to attract more customers with demanding requirements. No doubt its loyal customer base will grow as more companies become aware of its 75-year history, vertically integrated capabilities and the performance of its oscillator and filter products.

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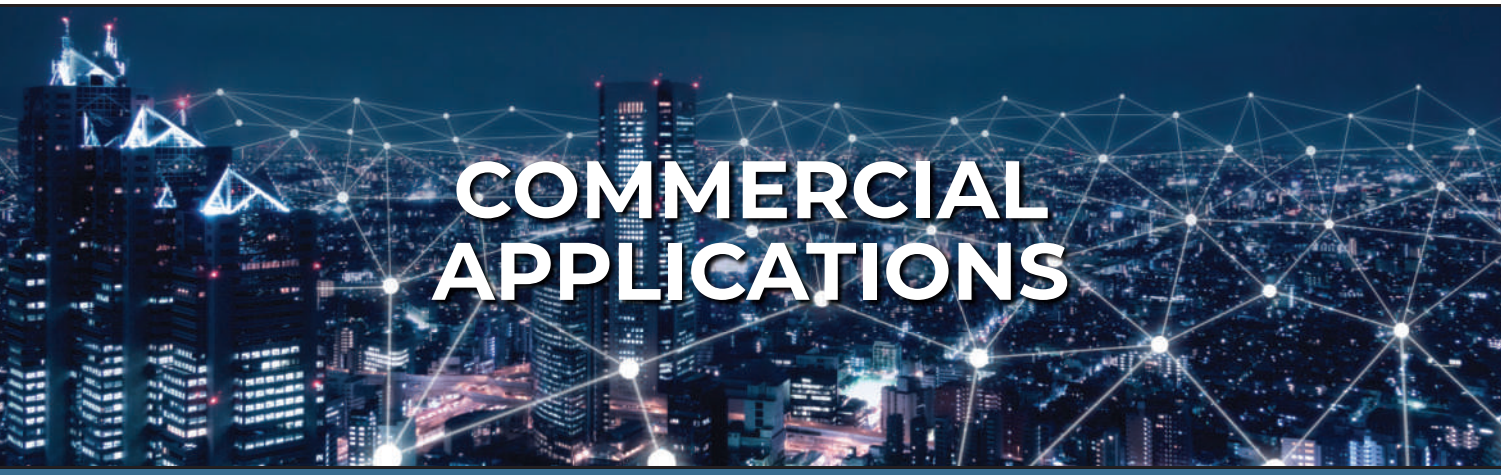

COMMERCIAL APPLICATIONS

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- **Werlatone Offers a Full line of RF Combiners, Dividers & Directional Couplers.**
- **Werlatone specializes in Commercial Transit Communication Systems.**
- **Our Solutions Cover Multiple Carrier Frequency Bands between 80 and 2400 MHz.**
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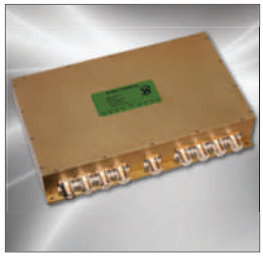

Even Isolated & Non-Isolated Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Isolation (dB)	Insertion Loss (dB)	Connectors	Size (inches)
D5875	4-Way	80-1000	150	Non-Isolated	0.80	N-Female	8.5 x 7.5 x 1.5
D7142W	2-Way	100-500	100	20	0.40	N-Female	4.4 x 4.3 x 1.29
D2542	2-Way	120-470	100	Non-Isolated	0.30	N-Female	2.5 x 1.75 x 1.5
D6295	2-Way	150-500	100	Non-Isolated	0.30	N-Female	1.75 x 1.75 x 1.5
D5877	2-Way	150-1000	350	Non-Isolated	0.50	N-Female	8.38 x 7.55 x 1.5
D5876	3-Way	150-1000	350	Non-Isolated	0.65	N-Female	8.38 x 7.55 x 1.5
D5944	4-Way	150-1000	350	Non-Isolated	0.70	N-Female	8.38 x 7.55 x 1.5
D5543	3-Way	400-470	100	Non-Isolated	0.20	N-Female	4.75 x 2.0 x 1.88
D6748	4-Way	470-860	250	18	0.35	N-Female	6.0 x 5.0 x 2.0
D5906	4-Way	470-860	500	15	0.40	N-Female	6.0 x 5.0 x 2.0

Uneven Splitters (Taps) & Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	Connectors	Size (inches)
C7141W	Uni	100-500	100	6	0.30	N-Female	7.0 x 5.0 x 1.8
C9270W	Uni	100-1000	100	6	0.60	N-Female	7.05 x 3.3 x 1.2
C8163W	Uni	100-1000	200	6	0.40	N-Female	7.0 x 5.0 x 1.8
C9534	Uni	100-1000	350	6	0.40	N-Female	6.75 x 3.0 x 1.2
C9271W	Uni	100-1000	100	10	0.50	N-Female	7.05 x 3.3 x 1.2
C2541	Tap	120-470	100	10 (Split)	0.75	N-Female	2.5 x 1.75 x 1.5
C6149	Tap	120-470	100	6 (Split)	0.75	N-Female	2.5 x 1.75 x 1.5
C5541	Tap	400-470	100	6 (Split)	0.20	N-Female	4.75 x 2.0 x 1.88
C6755	Dual	470-860	250	40	0.20	N-Female	3.0 x 3.0 x 1.09
C5560	Dual	470-860	500	40	0.10	N-Female	3.0 x 3.0 x 1.09
C6756	Dual	470-860	1000	40	0.20	N-Female	3.0 x 3.0 x 1.09

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