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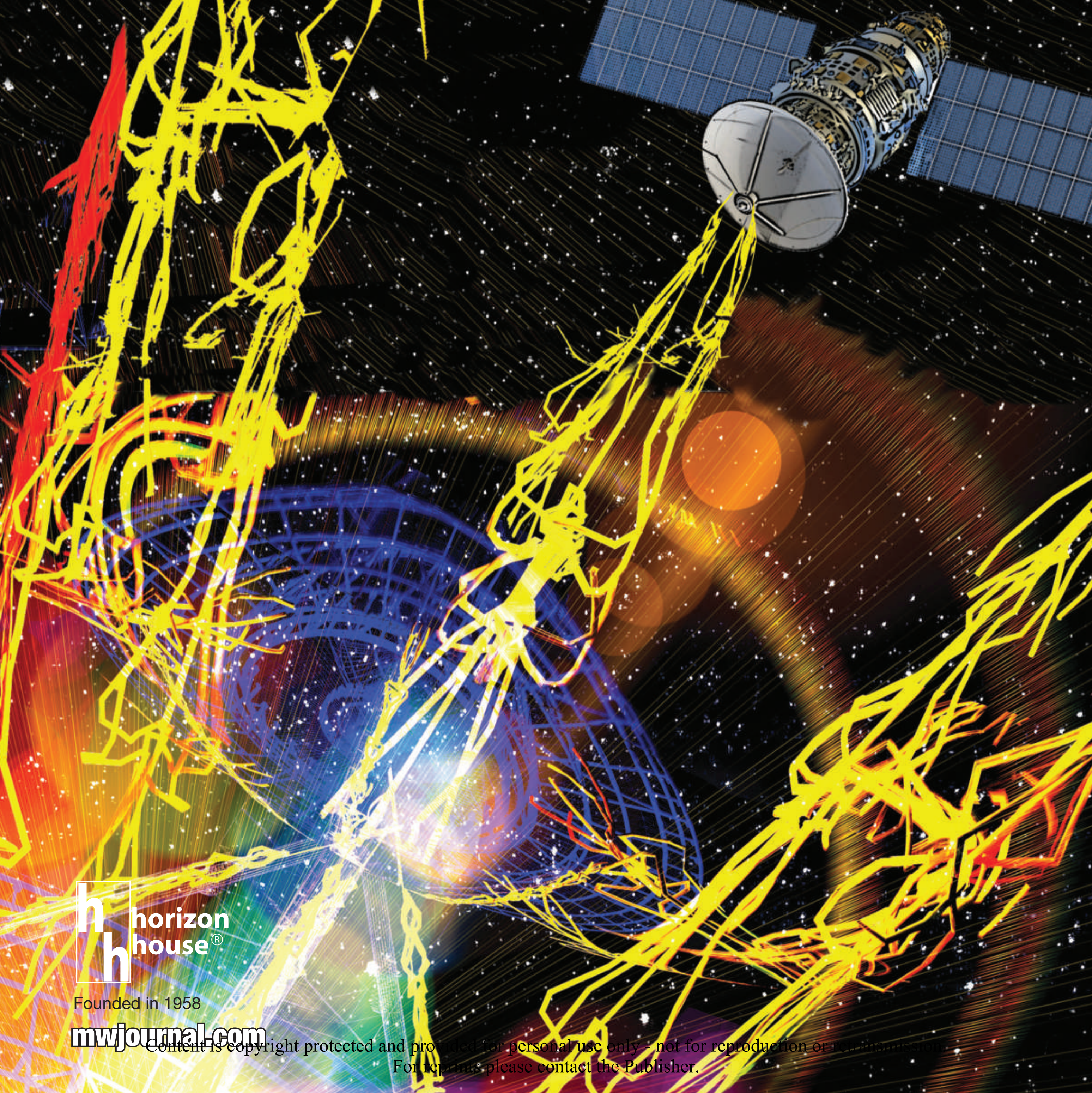
August 2021

Microwave Journal



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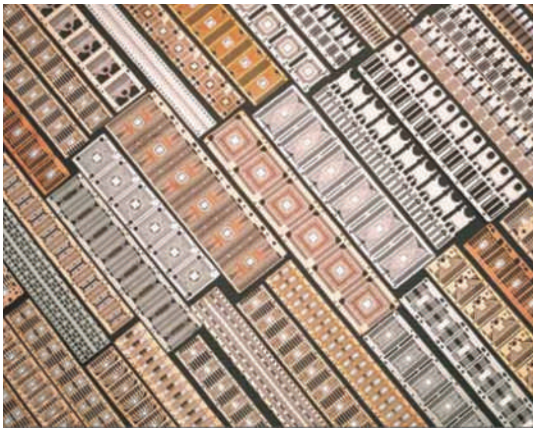

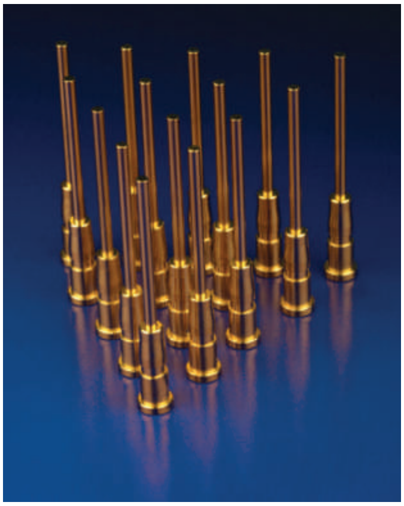

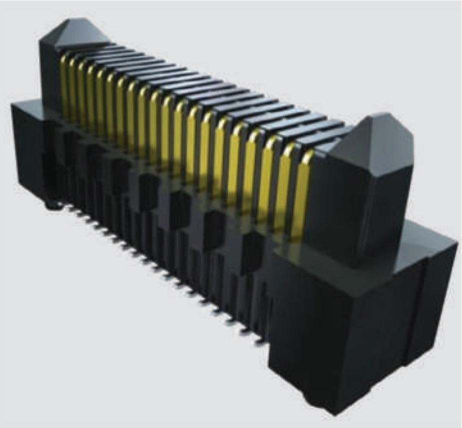

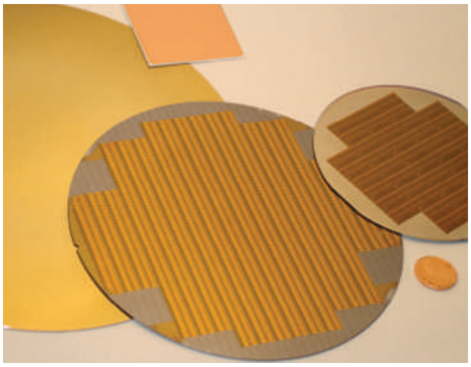

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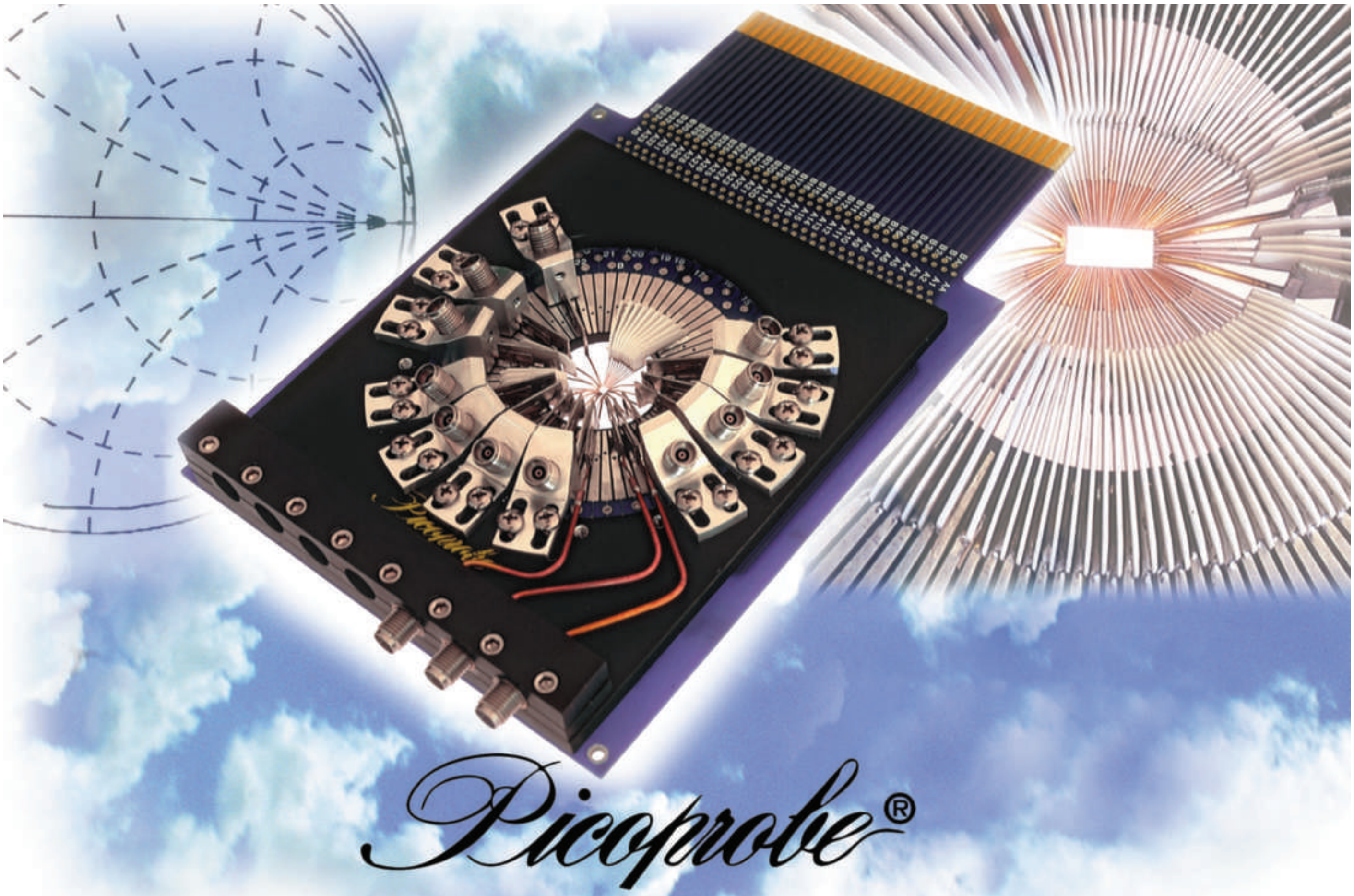

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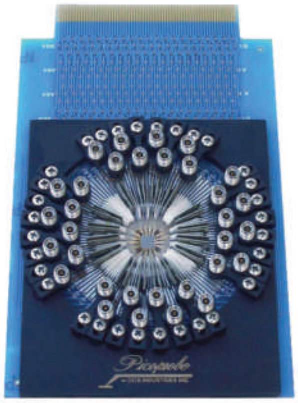

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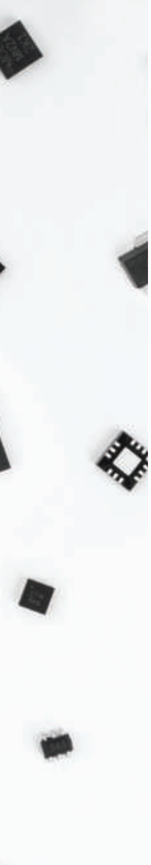

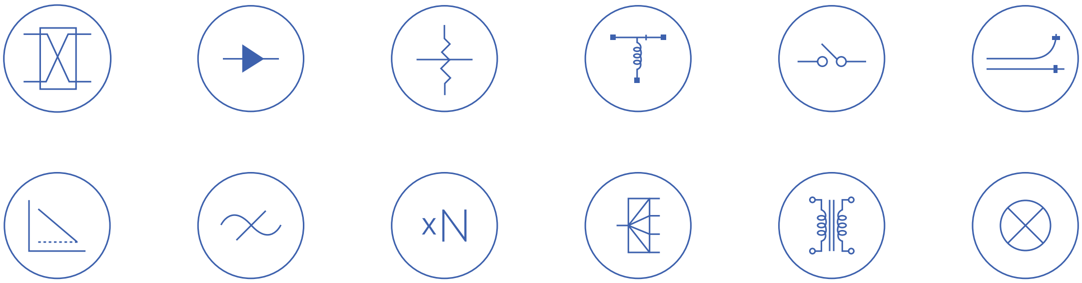

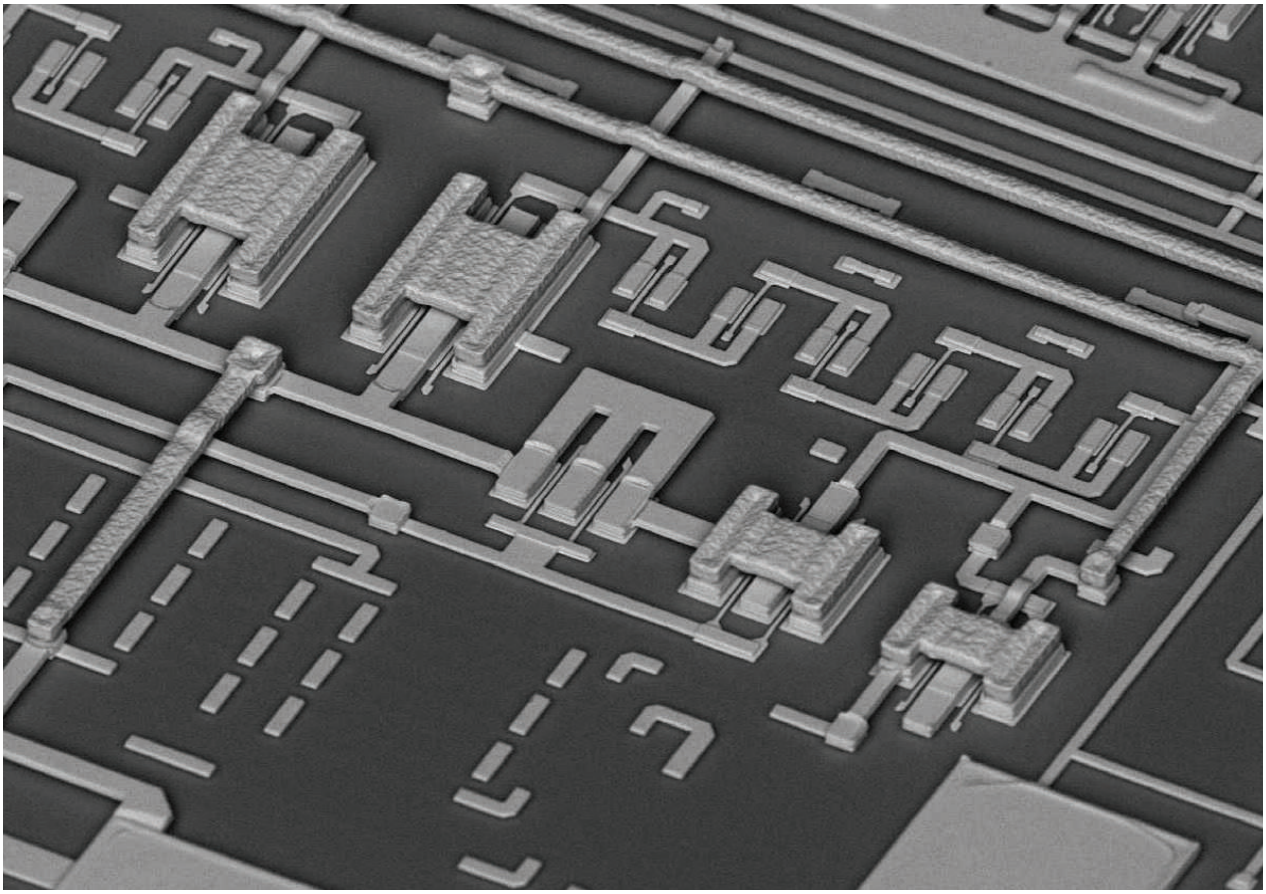

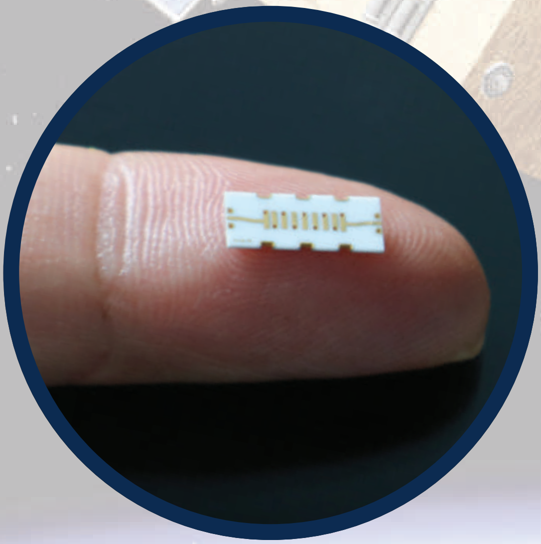

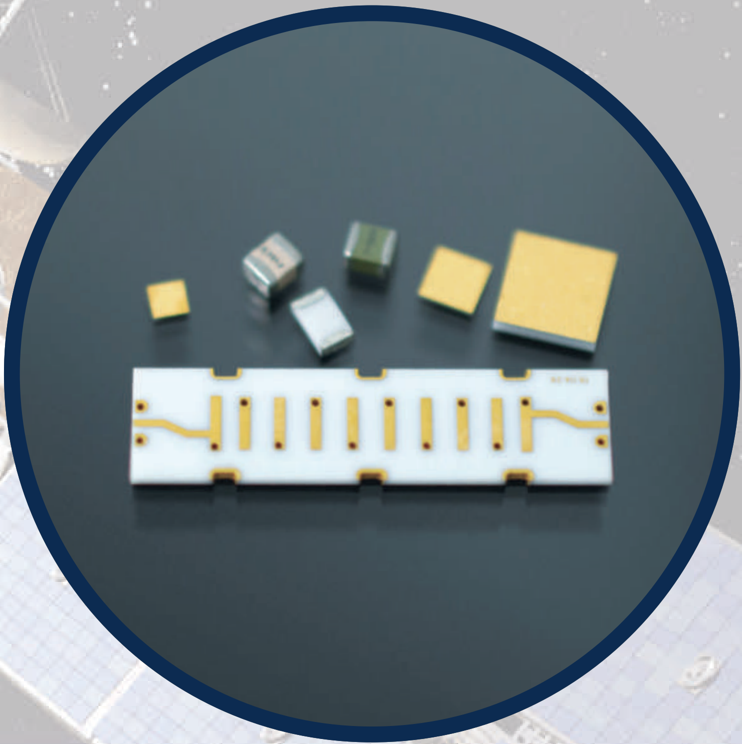

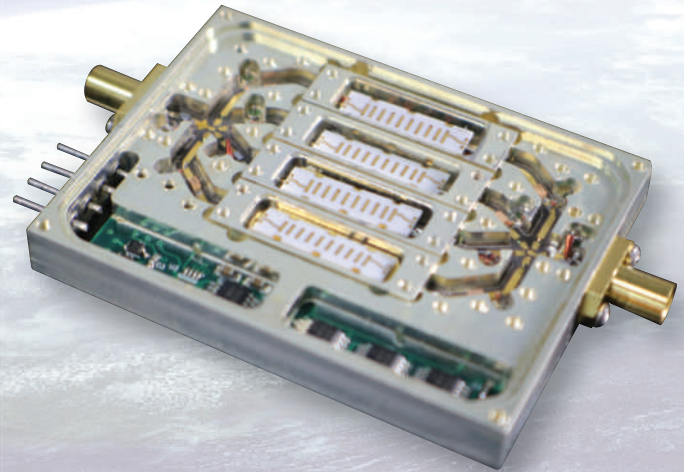

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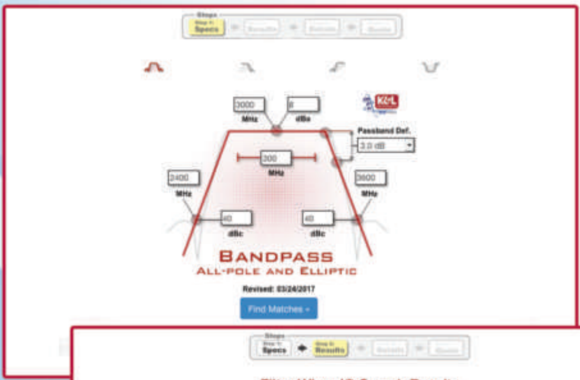

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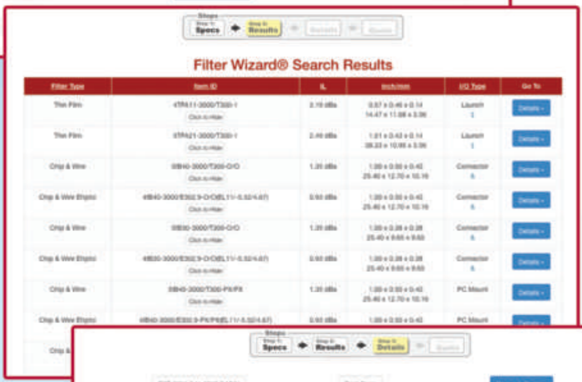

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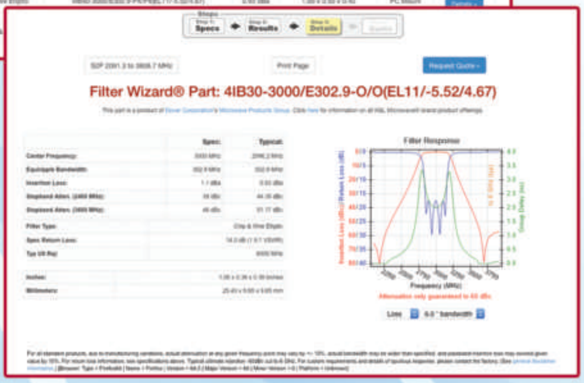

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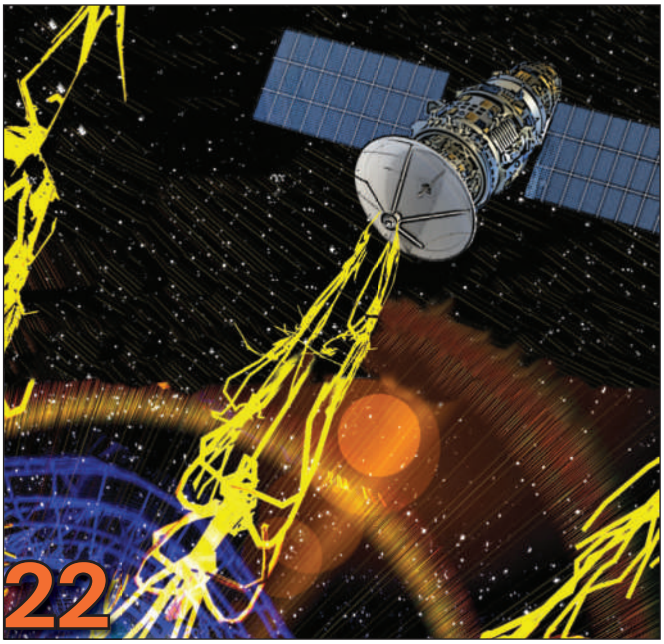

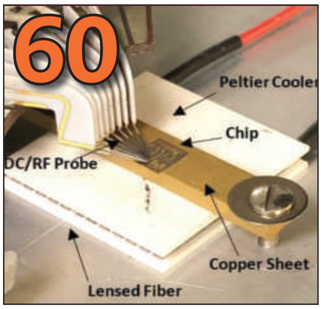

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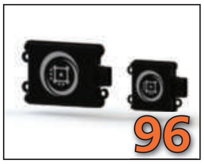

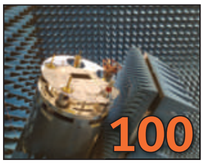

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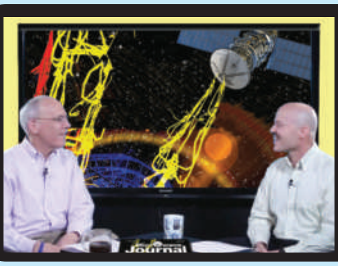

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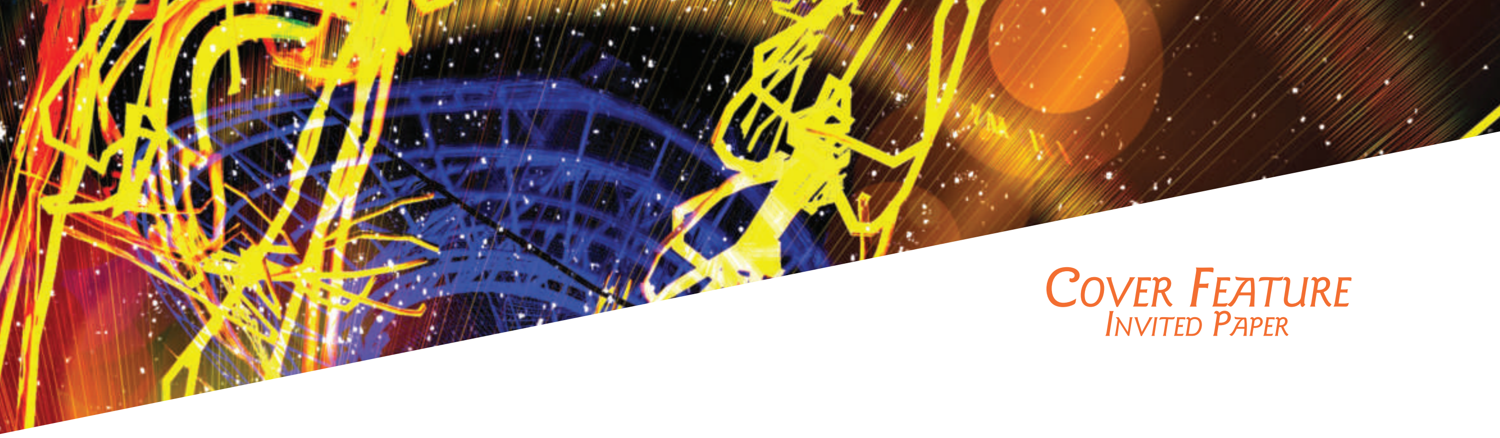

Cover Feature
Invited Paper

Using E-Band for Wideband Satcom: Opportunities and Challenges

Sam Morrar
Hughes Network Systems, LLC, Germantown, Md.

The growing volume of data traffic to and from wireless devices calls for high bandwidth to connect users to the internet. Two 5 GHz frequency bands are available in E-Band for commercial very high throughput satellite (VHTS) communication systems. However, adopting these high frequencies makes RF component and subsystem development challenging for the satellite communications (satcom) system as well as the test and measurement (T&M) equipment and setups for working in E-Band. At these frequencies, propagation and atmospheric attenuation require higher power and lower noise figure components for the communication links. The mmWave components and subsystems developed for the ground gateway and spacecraft are significantly more complicated at E-Band because RF components suitable for satcom links need to be developed and qualified for the space portion of the system. Signal generation, adequate linear RF power in the band, fade mitigation techniques, the physical sizes of the RF components and regulatory challenges are a few of the elements to be examined.

This article discusses the RF advantages and complexities of operating wide bandwidth satcom systems in the lower and upper E-Band (i.e., 71 to 76 and 81 to 86 GHz, respectively). For this discussion, wide bandwidth refers to channels with instantaneous modulation bandwidth of 500 MHz to 2 GHz, which are needed to support Tbps satcom. Hughes Network Systems (HUGHES®), a leader in broadband satcom systems, is currently researching VHTS operation in E-Band, and this article is based on this work, supported by component and T&M suppliers.

MOTIVATION TO USE E-BAND

Systems designed at 70 and 80 GHz can tap 10 GHz of bandwidth —far more than is currently available at the lower point-to-point transmission frequencies from 4 to 51 GHz. Antennas at these higher frequencies create highly directive pencil beams that provide high gain, to compensate for high path loss, and high discrimination, enabling gateways to be tightly packed into favorable rain zones without suffering from co-frequency interference. Existing Q-, V- and Ka-Band systems are spectrally crowded, with limited bandwidth available and suitable for VHTS communication systems.[1]

To use E-Band, licensees only pay a reasonably small administrative fee to the regulating authorities. This "light" licensing model provides full interference protection and makes the economics of Tbps connectivity attractive for commercial VHTS communication systems. This, along with the antenna advantages mentioned, has spurred research into the commercial viability of using E-Band to provide Gbps connectivity at a level complementing fiber optic cable.

Figure 1 compares several mmWave frequency bands considered for VHTS communications links. E-Band is the logical candidate for gateways, Q-Band for the forward downlink:

- 5 GHz contiguous blocks have no known regulatory constraints
- E-Band is the logical next band for feeder links after V-Band
- Q-Band is logical next band for user links after Ka-Band.

Table 1 shows the characteristics for the feeder (gateway) and user (terminal) links for Ka-, V-, Q- and E-Band. The disjointed uplink and downlink at Ka-Band add excessive hardware to the system, which increases spacecraft mass, occupies panel space and lowers system reliability.

While E-Band is attractive because of the available bandwidth and light licensing, it poses significant complexities for the uplink and downlink:

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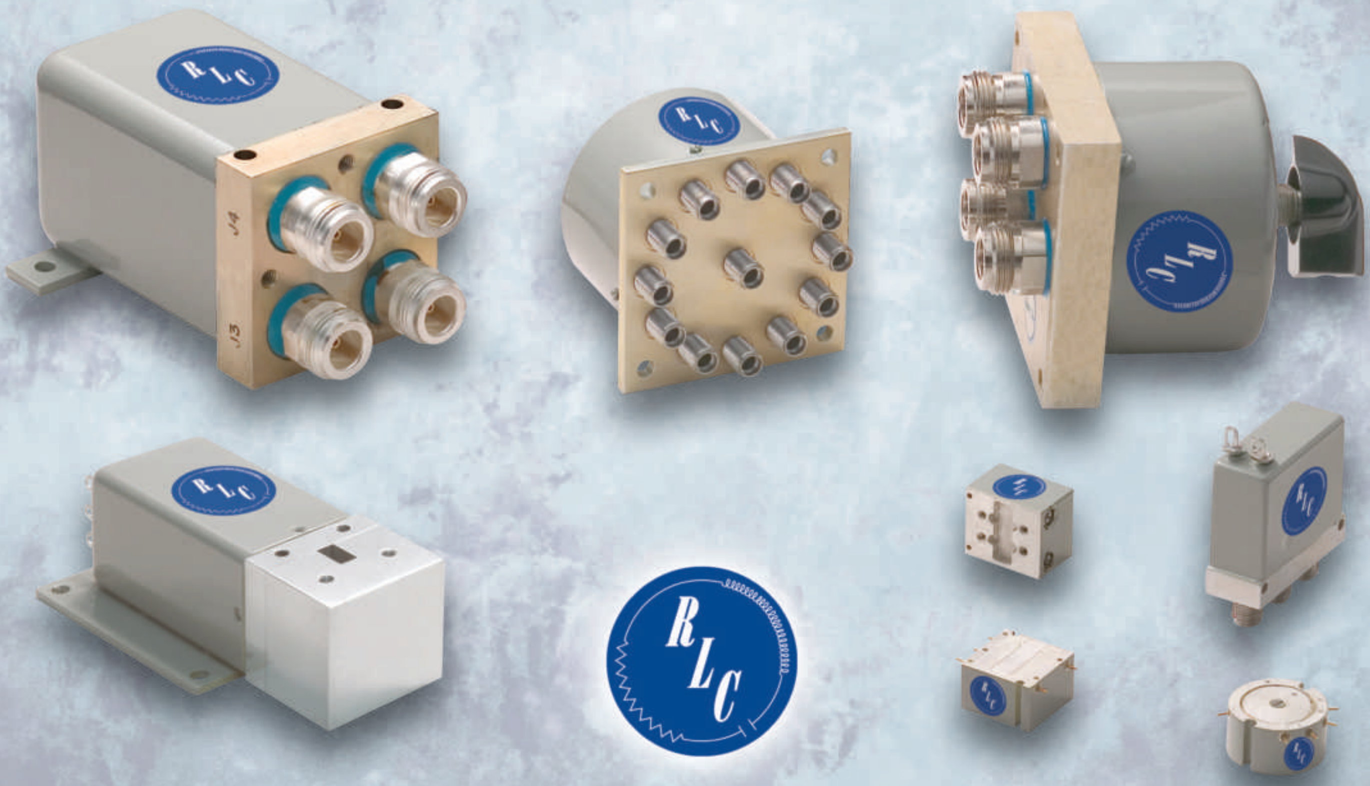

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COMPONENTS AND SUBSYSTEM CAPABILITY

The state of E-Band technologies for commercial Tbps satcom systems is a fundamental question. Although many E-Band components have been developed for automotive radar and cellular infrastructure, they are not space-qualified. E-Band semiconductor and passive components must be qualified for spacecraft—in some cases redesigned for satellites—and a viable supply chain developed to support this. For the gateway, some existing RF components will work; however, the high power amplifier (PA), antenna and feed losses will be challenges that need to be addressed for commercial Tbps systems, particularly increasing the output power and ensuring a mature technology.

As noted, a significant issue will be whether suppliers will participate in the E-Band satcom arena, despite supplying the automotive radar, EMC and military market segments with commercial components in the 60 to 90 GHz range. The challenges are meeting the satcom link performance requirements and qualifying the technologies and components for space.

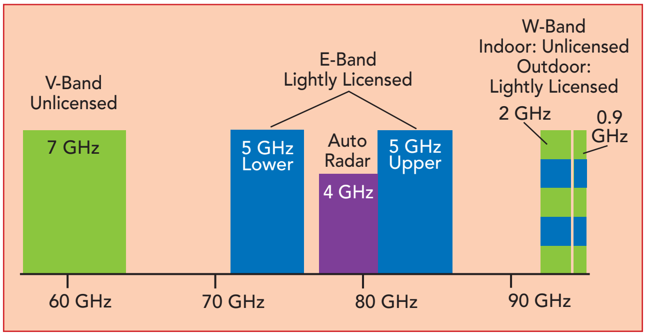

Fig. 1 V-, E- and W-Band frequencies. Source: Rohde & Schwarz.

TABLE 1

FREQUENCY BAND CHALLENGES

Ka-Band Feeder Link	V-Band Feeder Link	E-Band Feeder Link	Ka-Band User Link	Q-Band User Link
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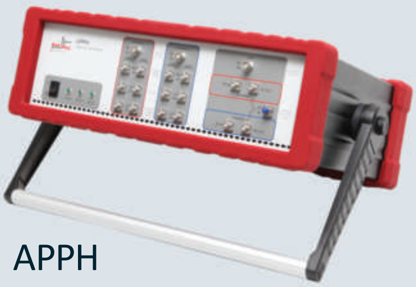

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A few suppliers do market space-qualified E-Band subsystems because there is some demand for such components. Because of the wavelengths at E-Band, the components typically use WR-12 waveguide requiring precise cavity dimensioning and fabrication. The gap transition tolerances must be extremely small to avoid excessive VSWR and insertion losses. ***Figure 2*** shows a couple of typical E-Band subsystems, integrating filters, amplifiers and waveguide sections.

We predict that InP low noise amplifier (LNA) technology or some exotic heterojunction high bandgap materials with super low noise figure will be required in both the spacecraft and gateways for E-Band systems. Hughes' estimates a 2 to 3 dB noise figure is needed in the gateway, possibly relaxed to 4 dB in the spacecraft. Based on the component and antenna requirements, the technologies being proposed for the PAs and LNAs at both ends will be tube based, possibly some solid-state PAs. High-power, linear tubes will be considered, and GaN may play a role in the PA, depending on timing. Hughes is currently conducting detailed tradeoffs to determine the best technologies and the manufacturers able to support space-qualified E-Band Tbps systems.

This same assessment process applies to the gateway and spacecraft antennas. Composite materials with very low surface roughness are feasible for the antennas as long as the tolerances are precise.

PROPAGATION LOSSES

The free-space path loss (FSPL) is

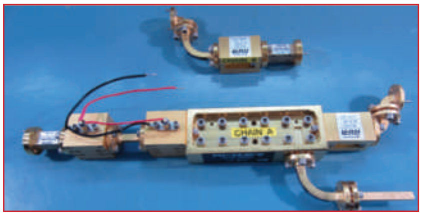

Fig. 2 Example of an E-Band signal chain.

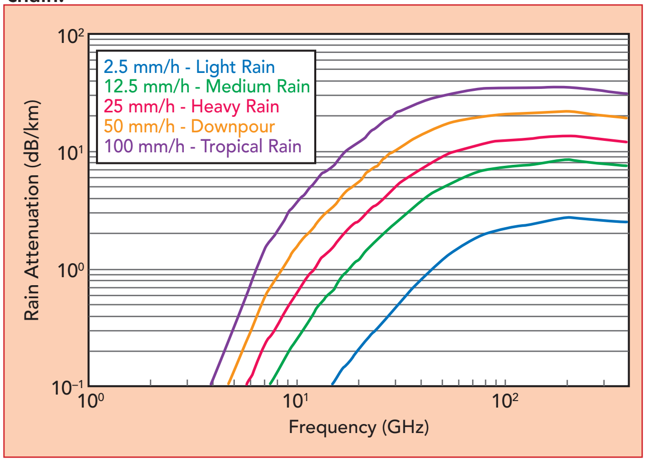

Fig. 3 Rain attenuation vs. rainfall vs. frequency.[2]

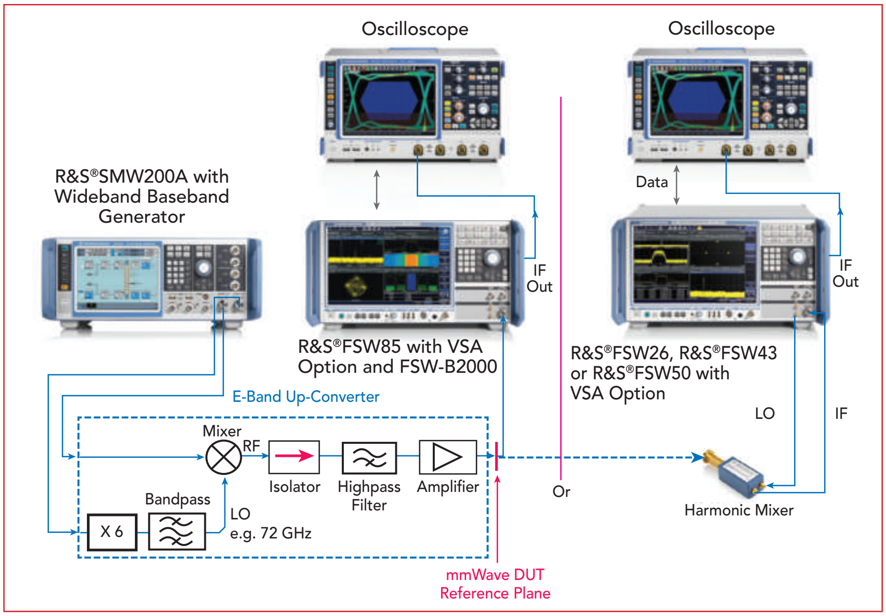

Fig. 4 Test setups for E-Band component characterization.

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8SFB-250M20G-CD-SFF


7SFB-950M18G-CD-SFF

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5SFB-DC26G-CD-SFF https://www.pmi-rf.com/product-details/5sfb-dc26g-cd-sff	0.1 to 26	10 dB	500 ns	5	2.7" x 3.0" x 0.75" SMA (F) Removable
6SFB-HF-CC-100M18G-MAH-RX-TX https://www.pmi-rf.com/product-details/6sfb-hf-cc-100m18g-mah-rx-tx	0.1 - 18	0 dB of Gain	100 ns	5	4.8" x 3.08" x .0365" SMA (F) & SMPM
8SFB-250M20G-CD-SFF https://www.pmi-rf.com/product-details/8sfb-250m20g-cd-sff	0.25 - 20	8 dB	100 ns	10	1U / 19" Rack SMA (F)
7SFB-950M18G-CD-SFF https://www.pmi-rf.com/product-details/7sfb-950m18g-cd-sff	0.95 - 18.05	9 dB	100 ns	8	4.33" x 5.1" x 0.98" SMA (F) Removable
6SFB-1G20G-LP-AMP-SFF https://www.pmi-rf.com/product-details/6sfb-1g20g-lp-amp-sff	1 - 20	20 dB of Gain	200 ns	6	5.5" x 3.0" x 0.75" SMA (F) Removable
4SFB-2G18G-CD-SFF https://www.pmi-rf.com/product-details/4sfb-2g18g-cd-sff	2 - 18	8 dB	200 ns	4	3.0" x 2.6" x 0.75" SMA (F) Removable
16SFB10G-16G-CD-SFF https://www.pmi-rf.com/product-details/16sfb10g-16g-cd-sff	2 - 18	7 dB	2 µs	16	8.6" x 6.0" x 0.9" SMA (F) Removable
SFB-6G18G-2CH-6DB-500NS-SFF https://www.pmi-rf.com/product-details/sfb-6g18g-2ch-6db-500ns-sff	6 -18	6 dB	500 ns	2	3.0" x 2.0" x 0.75" SMA (F) Removable
2SFB-8G26G-CD-SFF Rev C https://www.pmi-rf.com/product-details/2sfb-8g26g-cd-sff-rev-c	8 - 26.5	5.5 dB	100 ns	2	1.5" x 0.8" x 0.5" SMA (F) Removable


6SFB-1G20G-LP-AMP-SFF


4SFB-2G18G-CD-SFF


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the expected attenuation of an electromagnetic wave as it travels away from the source. In the far field, it increases proportional to the square of the frequency:

$$\mathrm{FSPL} = \left(\frac{4\pi df}{c}\right)^2 \quad (1)$$

where d is the distance, f the frequency and c the speed of light.

The satellite and ground antenna gain also increases proportional to the square of the frequency:

$$G = k\left(\frac{\pi Df}{c}\right)^2 \quad (2)$$

where G is the gain expressed as a ratio, D is the antenna diameter and k is the antenna efficiency factor. Since there are two antennas in the gateway link—at the satellite and on the ground—as frequency increases, the increase in the gain of one antenna will compensate for the FSPL increase. The increase in the other antenna's gain will at least partially compensate for the increased loss due to rain (see ***Figure 3***). At E-Band, light rain will add 2 dB/km atmospheric attenuation, while links in tropical regions must be designed for approximately 30 dB/km.

Although antenna gain increases with frequency, surface imperfections will degrade the gain, also proportional to the square of the frequency. This change in gain can be estimated by Ruze's equation:

$$\Delta G = -685.81\left(\frac{\varepsilon f}{c}\right)^2 \quad (3)$$

where ΔG is the change in gain in dB and ϵ is the RMS surface imperfection.

It may seem that the higher antenna gain at higher frequencies can be used to reduce antenna size, but the higher gain is needed to overcome higher atmospheric loss. In dB, the FSPL can be expressed as

$$\mathrm{FSPL(dB)} = 20\log(d) + 20\log(f) + 32.44 \quad (4)$$

Equation 4 is the free-space attenuation calculation for point-to-point microwave transmission in the frequency bands permitted by ITU-R, from ITU-R P.525. Comparing the FSPL values for Ka-, V- and E-Band:

- For a 36,000 km geostationary (GEO) orbit at Ka-Band (27 GHz), the FSPL is 212 dB
- For the same GEO orbit at V-Band (50 GHz), the FSPL is 217 dB
- For the same GEO orbit at upper E-Band (86 GHz), the FSPL is 222 dB.

The E-Band FSPL is 5 dB greater than the value at V-Band and 10 dB above the Ka-Band level. To maintain similar link margins, one option is to increase the power of the PAs at both the ground station and satellite. Unfortunately, high-power E-Band PAs for ground gateways and commercial satellites are virtually nonexistent. With satellite power being a precious resource and ground-based PAs already as large as practical to minimize antenna size, other solutions are needed.

T&M COMPLEXITY

Generating wideband, digitally modulated signals at V-Band and above is challenging and typically requires multiple instruments. The

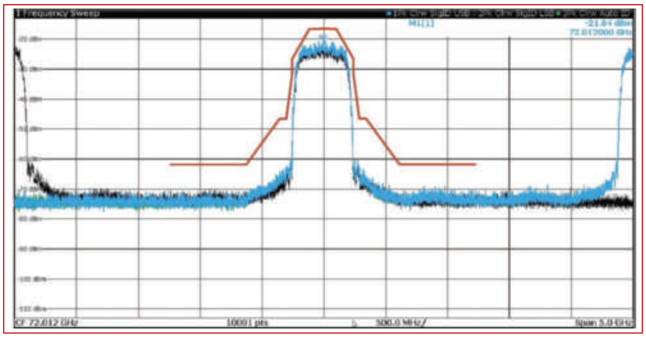

Fig. 5 500 MHz bandwidth signal at 72 GHz, showing the image offset by 2.6 GHz.

latest signal and spectrum analyzers, like the Rohde & Schwarz FSW67 and FSW85, are the first to operate in V-Band (up to 67 GHz) or in E-Band (up to 86 GHz), respectively, without using external frequency conversion.

One possible setup for E-Band signal generation and analysis for wideband satcom channels is shown in ***Figure 4***. For E-Band signal generation, an up-converter using discrete components was employed, comprising a ×6 multiplier because of its commercial availability and other components operating at E-Band. ***Figure 5*** shows a 500 MHz bandwidth E-Band input signal using the FSW signal and spectrum analyzer and the FS-Z90 harmonic mixer. The input and image frequency signals are 2.6 GHz apart. With this spacing, measuring the spectrum mask or analyzing modulation quality of wider bandwidth signals is straightforward. The bandpass filter after the multiplier must be chosen to eliminate the higher harmonics generated by the multiplier from appearing at the mixer local oscillator port, which will cause spurious signals in the up-converter's output.

ONGOING R&D

E-Band satcom is becoming more suitable due to the growing demand for users to connect to the internet at higher data rates, which requires higher data capacity from commercial VHTS systems. Of the available satcom spectrum, E-Band offers the highest feasible data rates. This article has described some of the challenges to be addressed, such as the frequency plan, availability and performance of RF components and T&M complexities.

To evaluate the feasibility of E-Band for commercial VHTS systems, Hughes is investigating the following:

- Modeling links using commercially available and custom components
- Analyzing the RF conversation signal flow in the gateway and spacecraft.
- Researching solid-state and traveling-wave tube PA technologies.
- Researching antenna system requirements and design options.
- Testing E-Band gateway and spacecraft links with modems to demonstrate link closure.
- Characterizing wideband modulated signals suitable for high capacity links.

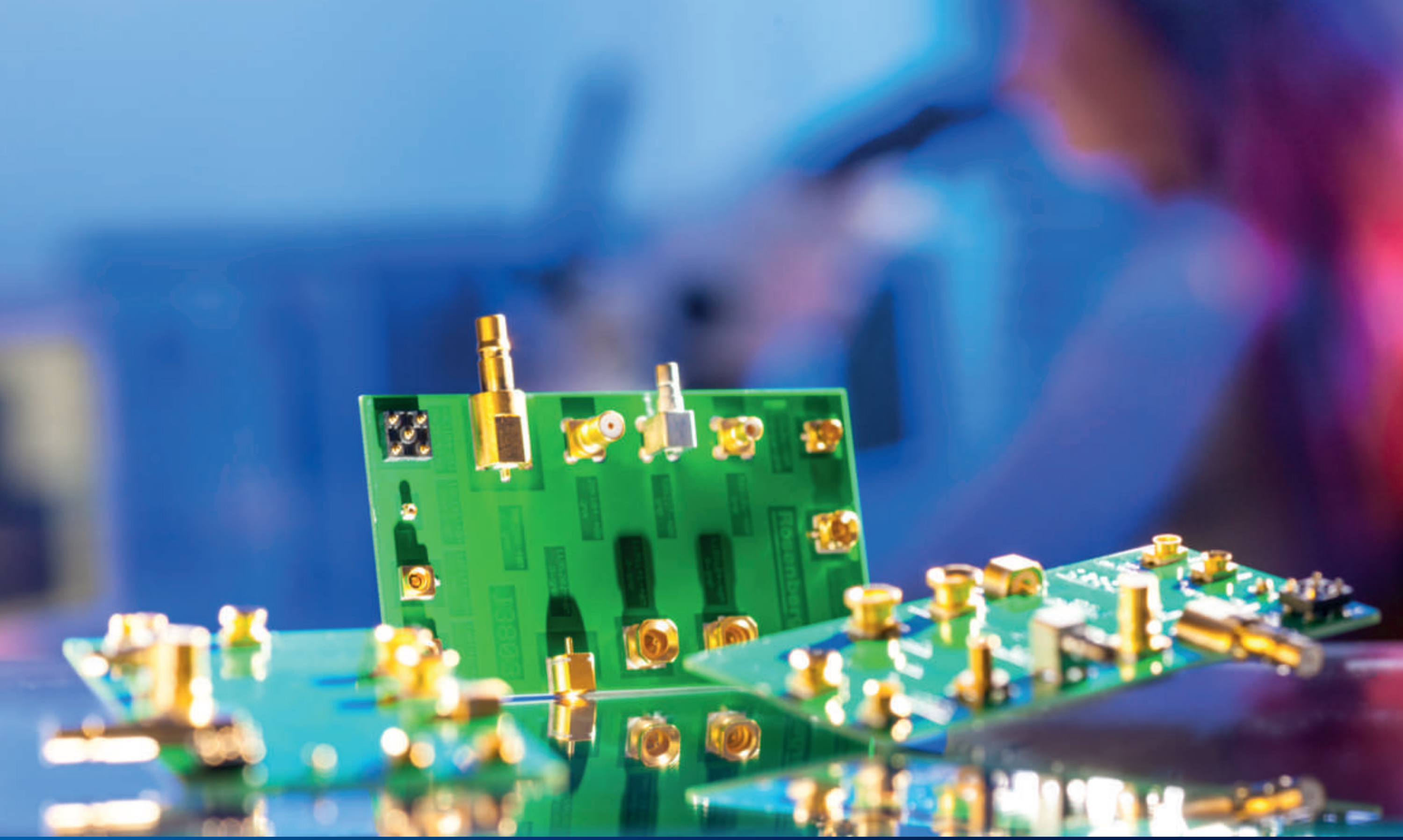

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Table 2 shows a preliminary E-Band link budget. This is being refined as Hughes models the gateway and spacecraft forward and return paths and performs studies and benchtop tests with RF components from various suppliers. As noted, these studies are evaluating conversion schemes, various modulation and 1 to 2 GHz instantaneous bandwidth channels. Noise figure, output power, link gains and losses, phase noise, spurious, EVM and other communication system metrics are being measured, with the results used to update the link budgets and system architecture. Hughes plans to provide a future article for *Microwave Journal* readers, reporting on the results of these studies.

A natural question is, "What is the potential timeline for using E-Band for Tbps communications satellites?" Today, Hughes estimates five to 10 years based on the availability and viability of space-qualified E-Band components, supplier participation and leveraging benefits from terrestrial 5G systems.■

TABLE 2 INITIAL LINK BUDGET ESTIMATES

Uplink Band	**E-Band**
Path Loss	222.6 dB
Atmospheric Losses	3.6 dB
EIRP	69.0 dBW
G/T	33.1 dB/K
Aggregate C/I	25.1 dB
C/N	21.1 dB
NPR	25.0 dB
C/(N+I)	18.5 dB
Downlink Band	**Q-Band**
Path Loss	216.0 dB
Atmospheric Losses	1.7 dB
G/T	24.4 dB/K
EIRP	72.6 dBW
EIRP CF	11.2 dBW
Downlink Power Flux Density	-124.6 dBW/MHz/m^2
Aggregate C/I	16.2 dB
C/N	14.8 dB
C/(N+I)	12.4 dB
Es/No	11.5 dB
Implementation Margin	1.5 dB
Forward Es/No with Margin	10.0 dB

References

1. Y. Antia, D. Roos and S. Morrar, "The Hughes JUPITER System: Powering a Connected Future," *Microwave Journal*, October 2019.
2. Recommendation ITU-R P.618-12, "Propagation Data and Prediction Methods Required for the Design of Earth-space Telecommunication Systems," July 2015.

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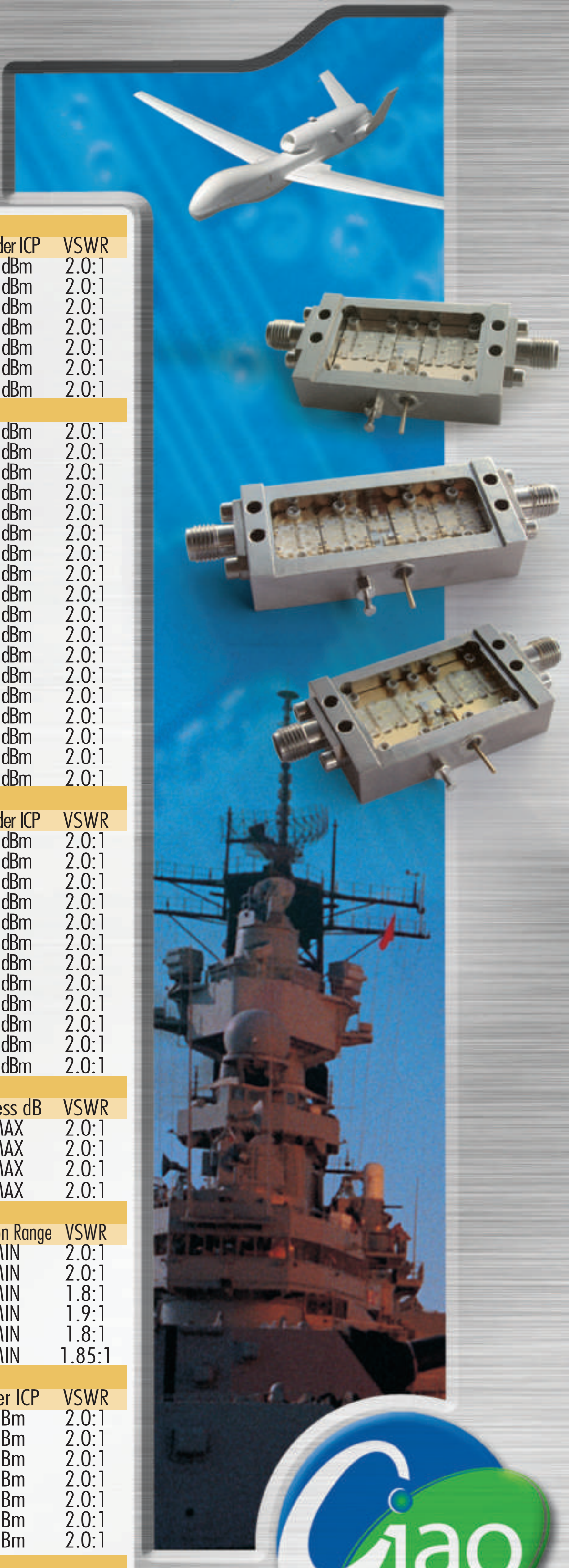

OCTAVE BAND LOW NOISE AMPLIFIERS

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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NGC Flight Tests Digital Wideband AESA Sensor

Northrop Grumman Corporation (NGC) has successfully flight demonstrated its new Terracotta sensor—a fully-digital open mission systems (OMS)-compliant wideband active electronically scanned array (AESA).

The flight test was a follow-on to successful ground and flight demonstrations of Terracotta conducted last fall. This most recent flight verified Terracotta's ability to simultaneously perform active and passive RF capabilities. Terracotta's nearly 200 wideband digital channels can be molded cooperatively or segmented for unique purposes, including electronic warfare, airborne early warning radar, active and passive sensing and communications.

Terracotta (Source: Northrop Grumman Corporation)

"As a fully-digital multifunction sensor with a wide operating bandwidth, Terracotta can seamlessly provide adaptive spectrum maneuverability," said Paul Kalafos, vice president, surveillance and electromagnetic maneuver warfare. "The sensor's architecture is easily scaled and configured for many applications and systems across all domains. It represents a key enabling technology for joint all domain operations."

Unlike traditional sensors, multifunction apertures consolidate multiple capabilities into a single sensor, decreasing both the number of apertures needed and the size, weight and power requirements for the advanced capabilities. Sophisticated multifunction apertures like Terracotta can deploy several functions simultaneously.

OMS compliance offers an interface solution based on open architecture design allowing customers to rapidly add new or improved capabilities, regardless of supplier, at a reduced cost. Northrop Grumman plans to integrate a combination of OMS/Open Communication Systems sensors and software-defined radios across multiple platforms, networks and nodes to address driving mission needs and ensure multi-domain interoperability.

Filtering Out Interference for Next-Generation Wideband Arrays

DARPA has spent decades advancing technologies that provide enhanced situational awareness, perhaps most notably phased arrays. Having the ability to detect and monitor adversarial movement or communications provides significant advantage to U.S. military operations. For pilots in air-to-air combat, for example, advanced radar capabilities arguably give a more decisive edge than a higher maximum speed.

The current leading edge of phased arrays is the AESA. Unlike their passive counterparts, where all the antenna elements are connected to a single transmitter and/or receiver, AESAs employ a matrix of hundreds or thousands of tiny antenna elements, each with their own transmitter and receiver. This allows you to electronically steer a beam of radio waves in different directions, instead of physically moving the antenna to point at a target.

Over the past decade, there has been increased interest in wideband AESAs with digital-at-every-element architectures. Wideband AESAs are more versatile and robust because they allow for operation at different frequencies, as opposed to narrowband arrays that are tuned for a specific use and frequency. Digital-at-every-element architectures allow AESAs to perform beamforming in the digital domain, enabling the collection of many beams simultaneously. However, the implementation of wideband, digital-at-every-element receivers in AESAs currently comes with significant trade-offs.

"Wideband, digital-at-every-element AESAs are particularly compelling for applications like advanced radar, electronic warfare and communications," said Dr. Benjamin Griffin, a program manager in the Microsystems Technology Office. "However, high bandwidth receivers often have a limited dynamic range, leaving them vulnerable to electronic jamming. Further, digital-at-every-element exposes each element to interferers and requires filtering at the element level, leaving very little room to integrate conventional filter technologies."

To address the challenges hampering the use of wideband AESAs in congested RF environments, DARPA developed the COmpact Front-end Filters at the ElEment-level (COFFEE) program. COFFEE aims to develop a new class of integrable, high frequency RF filters for next-generation wideband arrays. The COFFEE filter technology will address the combination of size, performance and reproducibility to enable protection at every element of a wideband AESA.

"Essentially, we want to build integrable filters that operate over a wide range of frequencies that are also small enough to fit behind each element of the phased array," said Griffin. "COFFEE aims to develop filters that are on the analog front-end, making the array more robust and resistant to interference before digital processing on the back-end."

The key to this research will be the development of filter technology that can address all microwave frequencies of a wideband AESA's bandwidth without sacrificing performance. Further, the target filters must be

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physically small compared to the element area as the available space for element-level integration decreases significantly as AESA bandwidth increases. Finally, to ensure uniformity the COFFEE filters should be manufacturable with reproducible performance at each of the array elements.

COFFEE is a part of DARPA's Electronics Resurgence Initiative (ERI)—a five-year, upwards of $1.5 billion investment in the advancement of the U.S. semiconductor industry. The program addresses part of ERI's focus on revolutionizing communications for the 5G era and beyond.

First-Ever Series of Interception Tests Employing an Airborne, High-Power Laser System

The Directorate of Defense R&D in the Ministry of Defense (MoD), together with Elbit Systems and the IAF, has successfully intercepted several UAVs using an airborne high-power laser (HPL) weapon system. The UAVs were intercepted at various ranges and flight altitudes.

The test series was conducted under the leadership of the Directorate of Defense R&D in the Israel MoD.

HPL (Source: Israel MoD)

During this series, a HPL system was installed on an aircraft and was tested in several scenarios. It successfully intercepted and destroyed all UAVs that were launched throughout the test. The ability to intercept and destroy airborne threats in the air is groundbreaking and offers a strategic change in the air defense capabilities of the State of Israel.

Israel is among the first countries in the world to achieve and demonstrate such capabilities employing an airborne, HPL system. This test series is the first phase in a multi-year program led by the Directorate of Defense R&D and Elbit Systems to develop a laser system against a variety of long-range threats.

This method of airborne interception has many advantages, including a low cost per interception, the ability to effectively intercept long-range threats at high altitudes regardless of weather conditions, and the ability to defend vast areas. The airborne, HPL system will complement Israel's multi-tier missile defense array, which include the Iron Dome, David's Sling and Arrow missile interceptor systems.

5G: Take it or Leave it?

"A sharp transition toward 5G is ongoing in mobile devices." asserted Cédric Malaquin, technology and market analyst, RF Devices & Technology at Yole Développement. "The number of 5G phones will more than double in 2021 compared to 2020. This is a significantly faster penetration rate than the LTE standard 10 years ago. And 5G is leading to an unprecedented increase in content of RF devices, while previous radio standards still need to be supported."

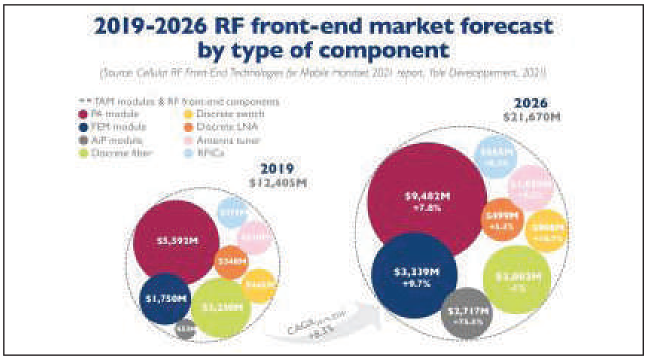
As a result, hundreds of RF components must be fitted into handheld format devices. This is now impacting mid-tier and entry-level phones, not only flagships. 5G features implemented in handsets focus on improving download speed and making the uplink more robust. In addition, there is an entirely new radio path created at mmWave frequencies, though this only applies to flagships right now.

The first use cases of the technology have matured and mobile network operators (MNOs) are proposing new services to the consumer. MNOs are strongly motivated to invest more resources and to demonstrate 5G's added value to the consumers, as 5G is not the first thing they are thinking about. In addition, MNOs have developed advantageous commercial 5G packages, particularly in China, adding some more motivation to consumers to upgrade. In this context, 5G has strongly penetrated the smartphone market in 2020 and is expected to further grow as the network expands in China, Europe and the U.S.

A 5G phone is relatively more complex than a 4G phone at the RF front-end. Therefore, it is worth analyzing the technical trends and anticipating future changes to understand this complex market better. Indeed, as for every new air standard, 5G represents a significant opportunity for industry players to differentiate, innovate and win the market in the end. "The Cellular RF Front-End Technologies for Mobile Handset 2021" report gives Yole's view on the RF front-end market evolution and its associated ecosystem.

Yole estimates the RF content at US$5-US$8 higher in a 5G phone compared to a 4G version and an additional US$10 for a mmWave version. Therefore, the RF front-end market is booming. It should reach US$17 billion by the end of 2021, up from US$14 billion in calendar year 2020. From there, RF front-end market growth should slow. Average selling price erosion will be stronger when 5G is mainstream and competition grows further. Overall, analysts expect an 8.3 percent CAGR between 2019, the year of 5G's introduction and 2026, leading to a US$21 billion RF front-end market.

The introduction of 5G adds complexity to phones along with RF content. Building 5G phones using discrete components while keeping an acceptable form factor is a challenge, driving more integration.



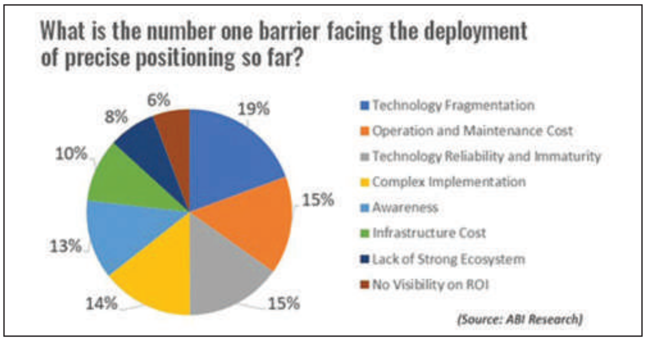
RF Front-End Market Forecast (Source: Yole Développement)

Survey Reveals 5G Positioning in Demand as Enterprises Struggle to Deploy Real-Time Location Systems

While numerous existing real-time location system (RTLS) technologies, including Bluetooth, Wi-Fi and UWB, have been available for a few years now, they have failed to capture the market potential so far. In fact, according to a new survey conducted by global tech market advisory firm ABI Research, 87 percent of enterprises said they have not yet deployed RTLS technology within their business, primarily because of the significant barriers to adoption facing existing RTLS solutions.

Most of the barriers to deployment mentioned in ABI Research's survey point to the fragmentation of existing solutions, which impacts the total cost of ownership, the complexity to implement, operate and maintain them and the uncertainties around their reliability and their maturity level. "All the barriers identified by the survey are currently constraining the RTLS ecosystem from developing and flourishing. Current solutions addressing this market today are struggling to generate scale as they are not ticking all the commercial and technology requirement boxes of end-users," explained Malik Saadi, vice president of Strategic Technologies at ABI Research.

According to the ABI Research survey results, which



RTLS Deployment Barriers (Source: ABI Research)

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polled decision-makers from more than 210 medium to large enterprises across key industry verticals, 56 percent of respondents selected 5G positioning, among several alternative technologies, as the preferred RTLS solution they are willing to adopt despite the fact the technology will not fully mature before 2025, at the earliest.

"5G positioning will mature incrementally through the commercial introduction of 3GPP Release 16, Release 17 and Release 18 between 2022 and 2025," said Andrew Zignani, research director at ABI Research. "In the meantime, while there is clear demand for 5G positioning, there are still many limitations that need to be addressed before we see the technology widely deployed. The 5G supply chain must come together to deliver improvements on accuracy, reliability, scalability, terminal power consumption and cost, and many other key metrics demanded by the varied RTLS use cases."

5G Service Now Reaches 1,662 Cities Worldwide

VIAVI Solutions Inc. released new research demonstrating the accelerating pace at which 5G is growing, with coverage extending to an additional four countries and 301 cities worldwide since the beginning of this year. The new total—1,662 cities across 65 countries—represents an increase of more than 20 percent during 2021 to date, according to the latest edition of the VIAVI report "The State of 5G," now in its fifth year.

The top three countries that have the most cities with 5G coverage are China at 376, the U.S. at 284 and the Philippines with 95, overtaking South Korea which is now in fourth position with 85 cities. The APAC region remains in the lead with 641 cities, closely followed by EMEA at 623. The Americas region lags at 398 cities.

With the launch of commercial 5G services in four additional countries—Cyprus, Peru, Russia and Uzbekistan—well over a third of the world's countries now have at least one live 5G network. However, the quality and speed of connectivity can vary significantly from region to region depending on available spectrum.

"Although we are seeing a significant jump in the number of networks being rolled out, not all 5G technologies are created equal," said Sameh Yamany, chief technology officer, VIAVI. "Networks operating in lower, mid and upper band frequencies perform very differently in terms of reach and throughput, increasing the importance of network assurance and optimization to consistently fulfill the promise of 5G."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

The **Rohde & Schwarz** technology group will now be active in the field of quantum computing. The July 1, 2021 acquisition of **Zurich Instruments AG**, a technological leader in test and measurement, will help Rohde & Schwarz further expand its Test & Measurement Division. The Swiss company Zurich Instruments AG will be run as a full subsidiary. The test and measurement market for quantum computing holds enormous potential for both companies. Operating and maintaining a large-scale quantum computer requires numerous, specific T&M solutions. Thanks to their complementary products, Rohde & Schwarz and Zurich Instruments will provide complete solutions in the future.

Maury Microwave announced that it has been acquired by **Artemis Capital Partners**, a Boston-based private equity firm. Maury will continue to operate as an independent company from its headquarters in Ontario, Calif., with customers and team members across the globe. Maury has served as a trusted test and measurement partner for many of the industry's leading manufacturers in the wireless technology chain. Maury's comprehensive suite of products span frequencies from RF through THz and includes calibration, measurement, modeling and interconnect technologies—from turnkey measurement and modeling device characterization solutions for semiconductor technology development, IC design and design-validation test, to reliable cables assemblies and adapters designed to reduce measurement uncertainties and deliver confidence in measurements and models.

Microwave Techniques LLC and N.H.-based **Ferrite Microwave Technologies** announced that they have acquired all of the assets and IP of Raleigh, N.C.-based **Industrial Microwave Systems LLC** (IMS) from Laitram, LLC. These two long-time leading microwave systems brands are recognized worldwide for innovative and robust designs and reliability. The merging of the brands, IP and products related to IMS's single-mode continuous Fluid and Solid Processing Systems and Ferrite's multi-mode batch and continuous tempering and drying systems into the Microwave Techniques portfolio offers customers a one-stop source for lab and commercial scale microwave systems.

Communications & Power Industries has successfully completed the purchase of **TMD Holdings Limited** and its subsidiaries, including **TMD Technologies Limited** and **TMD Technologies LLC**. Consisting of approximately 170 employees in facilities in the U.K. and the U.S., TMD is a designer and manufacturer of technologically advanced microwave, RF and high voltage equipment for radar, electronic warfare, communications, medical, EMC testing and scientific applications. TMD brings new products and technological capabilities to CPI's established portfolio of electronic components and subsystems focused primarily on the defense and communications markets.

Abracon announced the successful acquisitions of **ProAnt AB** and **Proant Asia Limited**, privately held antenna suppliers headquartered in Umeå, Sweden, and Hong Kong, respectively. Both companies will now operate under Abracon's new ProAnt brand. Abracon will retain facilities in both Sweden and Hong Kong. Abracon is an industry leader in passive components, providing frequency control & timing devices, RF & antenna products, and inductor & connectivity solutions. Over the last few years, they have acquired a number of component brands that include AEL Crystals, Ecliptek, Fox, ILSI, MMD and Oscilent.

COLLABORATIONS

MIT and **Ericsson** are collaborating on two research projects that seek to help build a new network infrastructure needed to empower the revolutionary use cases the next generation of mobile networks will bring. The new mobile network generations bring ultra-fast speed, low latency and superb reliability to the end user. Ericsson is working to research cognitive networks, which rely on artificial intelligence (AI) to enable a secure, highly automized, data-driven network operation. To improve the compute power, speed and energy efficiency of cognitive networks, Ericsson Research and the MIT Materials Research Laboratory are collaborating to research new designs in lithionic chips enabling neuromorphic computing, offering exponentially more energy efficient AI processing.

Gapwaves has entered into a licensing and development agreement with time limited exclusivity for corner and side radar with **HELLA**, one of the largest manufacturers of radar in the automotive industry. As part of the agreement, HELLA will also invest 182,3MSEK in Gapwaves in a directed new issue of 3,100,000 B shares, the investment covers approximately 10 percent of Gapwaves' capital. Gapwaves will in addition provide development services to HELLA. Over the past year, HELLA has evaluated Gapwaves' technology through several design and prototype projects. By entering into this licensing agreement, HELLA receives the right to use Gapwaves' patented technology for waveguide-based antennas within specific applications. Gapwaves will cooperate with HELLA in the development of radar antennas with an expected start of production in 2024.

SAF Tehnika announced a collaboration project with the **Electronic Communications Office of Latvia** to develop a complete RF test and measurement solution mounted on unmanned aerial vehicles (drones). The development of the drone solution will create a more efficient process to address the ever-crowded RF spectrum in a variety of regulatory applications. The drone

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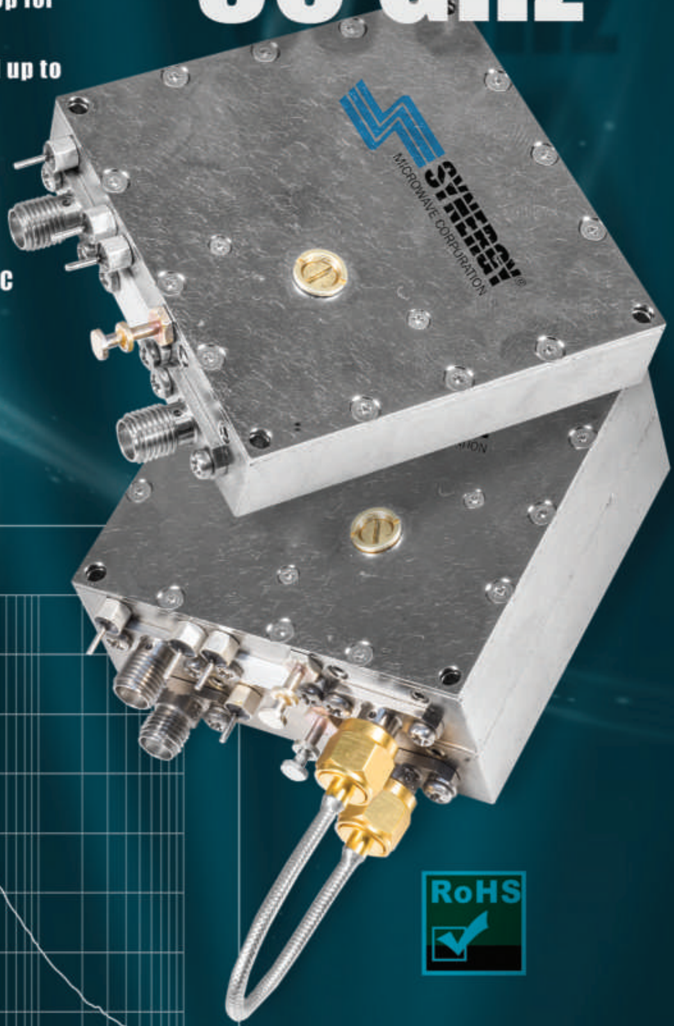

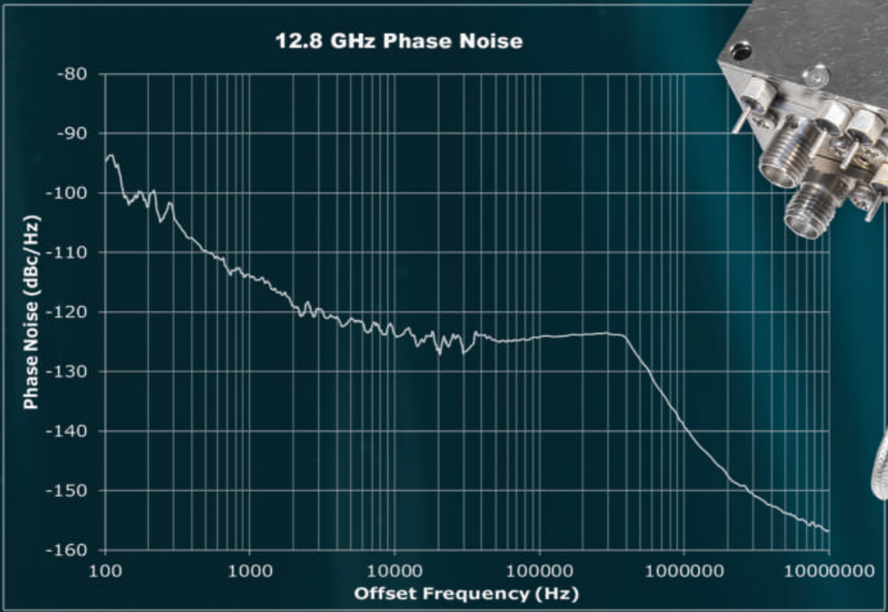

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solution will include SAF Tehnika's Spectrum Compact lightweight spectrum analyzer, as well as dedicated software for easy data collection, storage and analysis. It will help ensure RF spectrum control, which is an integral responsibility of telecommunications regulatory bodies to safeguard a consistent application of the regulatory framework.

Movandi announced a strategic collaboration with **Mavenir** to provide Movandi's BeamX 5G mmWave technology for the 5G mmWave Open Radio Access Network (RAN) smart city in Thailand. Mavenir's Open RAN radio units (RUs) for the smart city private network include Movandi's mmWave RF ICs and phased array modules that together enable an ultra-low-power RU solution delivering superior 5G performance in a smaller antenna array. Mavenir's cloud-native, open architecture-based private network solution enables service providers to deliver on the promise of 5G. The software-based platform transforms mobile communication private networks into a virtualized environment where devices, applications and services run on an automated network using open architecture, containers and AI.

Fujitsu Network Communications Inc. is collaborating with the **Telecom Infra Project (TIP) OpenRAN Project Group** to accelerate adoption of Open RAN infrastructure, helping service providers speed new 5G services to market at reduced costs. With commercial 5G deployments gaining momentum worldwide, an increasing number of network service providers are embracing Open RAN technologies to take advantage of greater component choice, reduced costs and improved network performance. The TIP OpenRAN Project Group strives to create a robust and sustainable ecosystem for open infrastructure compliant with 3GPP and O-RAN ALLIANCE specifications.

Anritsu Corp. has introduced a new solution for evaluating the video quality of 5G devices. This lab-based solution was developed in partnership with **Spirent Communications** and **TOYO Corp.** It uses Anritsu's SmartStudio NR Network Simulator and Spirent's Attero and Umetrix Video software, providing a new integrated 5G video quality system. The accelerating shift from 4G to 5G mobile communications, combined with increasing adoption of teleworking, are leading to more streaming of video content as well as greater use of online meeting tools. As a result, the quality of the video is a key factor in users' choice of 5G mobile operator and smartphone brand.

Qorvo has partnered with **Polarity** to develop integrated rack/hub-mounted solid-state power amplifiers (SSPAs) for radar and electronic warfare (EW) applications. Qorvo's newly released 2 to 20 GHz, 300 W Spatium® power amplifier is at the core of Polarity's newest broadband SSPA housed in an EIA-compatible three-unit height, rack-mountable chassis. This state-of-the-art SSPA solution incorporates a wide input range AC-DC power supply, fan-forced convective thermal management and an internal driver amplifier. The Spatium high-power amplifier is designed to operate in wideband testing, communications, radar or any application requiring capability for simultaneous power amplification of signals across the 2 to 20 GHz operational bandwidth.

NEW STARTS

Teaming up with industry titans including **Samsung**, **NVIDIA** and more, researchers at **The University of Texas at Austin** are launching 6G@UT, a new research center to lay the groundwork for 6G, the next generation of wireless technology. Founding 6G@UT affiliates Samsung, AT&T, NVIDIA, Qualcomm and InterDigital will each fund at least two projects for three years at the center. Researchers from the companies will work alongside University of Texas faculty members and students to develop wireless-specific machine learning algorithms, advanced sensing technologies and core networking innovations that will be the backbone of 6G.

Nano Dimension Ltd. announced that it has formed a partnership with **HENSOLDT AG**. The recently formed joint venture entity is named J.A.M.E.S GmbH (Jetted Additively Manufactures Electronics Sources). Nano Dimension is a manufacturer of intelligent machines which 3D-print additively manufactured electronics. HENSOLDT has been using Nano Dimension's DragonFly PRO and LDM® 3D-AME printer technology since 2018 to fabricate many innovative "first-of" designs, as 3D-printed circuit boards (PCB)/AME 3D high performance electronic devices (Hi-PEDs®). AME is a highly agile and customized method for development, prototyping and fabrication of electronic circuits, which results in a significant reduction of time and cost in the time-to-market process.

ACHIEVEMENTS

Guerrilla RF announced that it has surpassed the 100 million milestone for RFIC/MMIC deployments in less than six years after releasing its first product. Since opening its doors in 2013, Guerrilla RF has experienced incredible growth within the wireless infrastructure market. In 2020, the company was recognized by *Inc. Magazine* as being one of top 500 fastest growing companies in the country.

Signal testing is complete on the national **NSF PAWR COSMOS** testbed site for the DFT spread orthogonal frequency-division multiplexing (OFDM) with Harris Tapered Nyquist Filter, called the "spectralDSP SC-OFDM" waveform. This signal demonstrates an extraordinary peak-to-average power ratio (PAPR) improvement allowing a significant reduction of the power consumption of the power amplifier. The PAPR reduction improves cell coverage and increases the radiated transmit power. Increased power permits the use of a larger cell radius for the same transmission energy level as traditional OFDM, this translates to fewer cell sites to cover the desired area. This waveform benefits the true 5G mmWave and low latency/gigabit speeds.

Around the **Circuit**

CONTRACTS

The U.S. Army has awarded **BAE Systems** a contract worth up to $600 million for the sustainment and support of the Armored Multi-Purpose Vehicle (AMPV) over the next five years. The AMPV comes in five variants designed to execute a broad set of missions while operating on the front lines. BAE Systems is currently in low-rate production for the AMPV program and has delivered at least one of each of the five variants designed for the family of vehicles. This sustainment contract enables adding new capabilities and technologies on AMPVs throughout their time in service.

Comtech Telecommunications Corp., a leader in secure wireless communications technologies, announced that during its third quarter of fiscal 2021, its Santa Clara, Calif.-based subsidiary, **Comtech Xicom Technology Inc.**, a leader in high-power amplifiers, was awarded a contract valued at more than $3 million for Q/V-Band traveling wave tube amplifiers to support a new high speed satellite network. Comtech Xicom Technology, Inc. manufactures a wide variety of tube-based and solid-state power amplifiers for military and commercial satellite uplink applications.

PEOPLE


▲ *Kristijan Bauer*


▲ *Eric Küppers*

The technology company **Rosenberger** has succeeded in strengthening the company's management for the next step towards future growth. As of July 1, 2021, **Dr. Kristijan Bauer** has joined the management team of the Rosenberger Group as chief operations officer. Along with **Eric Küppers**, who already took up his position as chief executive officer in Fridolfing on May 1, 2021, they will work together to lead the organization to implement the Rosenberger Group's corporate strategy across the globe. The entrepreneurial and international experience that Mr. Küppers and Dr. Bauer bring to the Rosenberger Group will be a great asset for the expanding company.


▲ *Mike Elias*

CAES, a leading provider of mission-critical electronic solutions for aerospace and defense, announced the appointment of **Mike Elias** as senior vice president and general manager, Space Systems Division. In this role, Elias will oversee the company's space product portfolio including radiation hardened microelectronics, applications-specific integrated circuits, advanced packaging solutions, motion control and positioning technologies as well as division operations in Colorado Springs, Colo.; Plainview, N.Y.; Hauppauge, N.Y., and Gothenburg, Sweden. Elias joins CAES as an established leader in both military and space, as well as

commercial aerospace product development, strategic planning and customer interface.

REP APPOINTMENTS

Filtronic plc, a designer and manufacturer of RF, microwave and mmWave products for the wireless telecoms, mission-critical communications and defence applications markets, announced that it has signed an exclusive U.S. West Coast distribution agreement with **The Sales Group**. Founded in California in 1987, The Sales Group is a leader in the sales and distribution of critical communication products. Its existing portfolio includes two-way radio communications, communications centres and safety products that are primarily designed for use by government and enterprise emergency responders, public safety, 911, utilities, municipal, transportation, schools and similar applications.

Infinite Electronics, a global supplier of electronic components, announced that it has added **EPI Vietnam** as a distributor covering all of Vietnam. EPI Vietnam Technologies Co., Ltd. was founded in 2013 with a vision to be a market leader in electronic component distribution in Vietnam. In addition to providing access to thousands of components and assemblies, EPI offers engineering services to help its customers develop solutions from concept through the design process all the way to manufacture. EPI serves a wide range of industries and sectors including, industrial, consumer, automotive and telecom.

Richardson Electronics Ltd. announced an exclusive manufacturing and global distribution agreement with **Battery Street Energy** (BSE) to manufacture ultracapacitor-based engine start modules for use in various markets and applications including the wireless telecom industry and in critical facilities. In collaboration with BSE, Richardson Electronics will be manufacturing these modules using BSE's patent-pending technology in its 250,000 square-foot facility located in LaFox, Ill. These new ultracapacitor generator start modules are an eco-friendly drop-in replacement for hazardous lead-acid batteries used in backup generators and related equipment.

PLACES

LadyBug Technologies is making a move to a larger facility. This is their third move in response to consistent growth since their inception. With this move, they double their space, allowing for additional product design engineers and manufacturing employees. One of the main reasons for the expansion is the demand for new products. They are adding two members to their engineering team at the time of the move and plan to add additional personnel shortly thereafter. They plan to deliver new products at a significantly faster pace. This includes their new small form factor measurement system with wide bandwidth pulse measurement capability.

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INVITED PAPER

Contactless Waveguide Flange Enables Faster Measurements

Cornelius Mayaka, Yonghui Shu and Dhanraj Doshi
Eravant, Inc., Torrance, Calif.

Applications continue to expand for mmWave and THz frequencies in aerospace, military, industrial and consumer markets. The result is increasing demand for faster and more reliable methods of testing waveguide components. At these frequencies, a rectangular waveguide is commonly used to carry the signals between components and subassemblies, with standard and non-standard flanges as the predominant means for connecting waveguide sections. When joined, precisely machined flanges provide continuous electrical contact around the mated waveguide openings.

Unfortunately, measurements of waveguide components are easily compromised by poor connections. Common problems include waveguide cocking, which occurs when flange surfaces are not perfectly parallel. Small gaps between the mating flanges can lead to power leakage and poor return loss, causing unreliable and inaccurate measurements.[1,2] Repeated connections can also degrade the flanges used on waveguide test equipment such as vector network analyzers (VNAs), frequency extenders, power meter heads, frequency converters and calibration standards. Periodic replacement of expensive test system components is often required to maintain accuracy and repeatability.

Inadvertent gaps and surface damage may be minimized by carefully and evenly tightening the screws that provide mechanical contact between the waveguide flanges. However, this requires substantial training and skill to be performed correctly. When done repeatedly in a production environment, this work requires endurance and discipline. Ultimately, using traditional waveguide flanges in manufacturing operations limits how quickly and reliably components can be tested and sorted.

This article describes a contactless waveguide flange (CWF) that can be used without the flange screws mandatory with conventional flanges. When used with streamlined test fixtures, the CWF enables much faster mmWave and THz measurements while maintaining accuracy and reliability. The CWF was developed to preserve the electrical and mechanical integrity of both the device under test (DUT) and the test system, without sacrificing measurement results.

THEORY OF OPERATION

The CWF employs gap waveguide technology while applying the well-known principle of operation of the choke flange. The CWF choke is a recessed ring engraved into the flange at a nominal depth of $\lambda_g/4$ and a distance $\lambda_g/4$ from the waveguide walls, where λ_g is the guide wavelength. Gap waveguide technology has been thoroughly investigated and used previously in the design of antenna array feed structures and


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other passive components.[3] These studies demonstrate that when a perfect magnetic conductor (PMC) plate and a perfect electric conductor (PEC) plate are positioned so they are parallel to each other and the distance between them is less than $\lambda_0/4$, where λ_0 is the wavelength of the operating frequency in air, a cutoff condition is created. As a result, parallel plate transmission modes cannot propagate between the plates.

Further, textured surfaces formed by metallic pins attached to a ground plane can exhibit the electrical characteristics of a PMC, forming an artificial magnetic conductor (AMC) over a limited range of frequencies. Often referred to as a "bed of nails substrate," such an arrangement can be used to suppress dielectric surface waves in planar antenna structures. In the CWF, the choke ring is populated with concentric rings of small, pin-like structures to realize a high impedance AMC surface that approximates a PMC plate. Conversely, the mating surface on a conventional flange is flat, approximating a PEC plate.

The combination of a choke ring that controls the gap impedance and a band gap structure that suppresses signal leakage results in good signal transmission between the CWF and a conventional flange. In contrast to traditional flanges, no physical contact is required. Fast measurements can be performed without engaging the traditional waveguide connection screws that must be carefully tightened.

The CWF concept has been demonstrated with an E-Band design (see ***Figure 1***). It employs a standard waveguide flange modified by adding two concentric rows of pins to fill a choke ring engraved around the waveguide opening. The inner metal surface surrounding the waveguide opening has a nominal width of about $\lambda_g/4$ across the opening's two longer sides. Its purpose is to transform an open circuit into a short circuit at the waveguide opening. Along the two shorter sides of the waveguide opening, the inner metal surface is thinner to increase the connection bandwidth.[4,5]

Fig. 1 CWF implemented at E-Band.

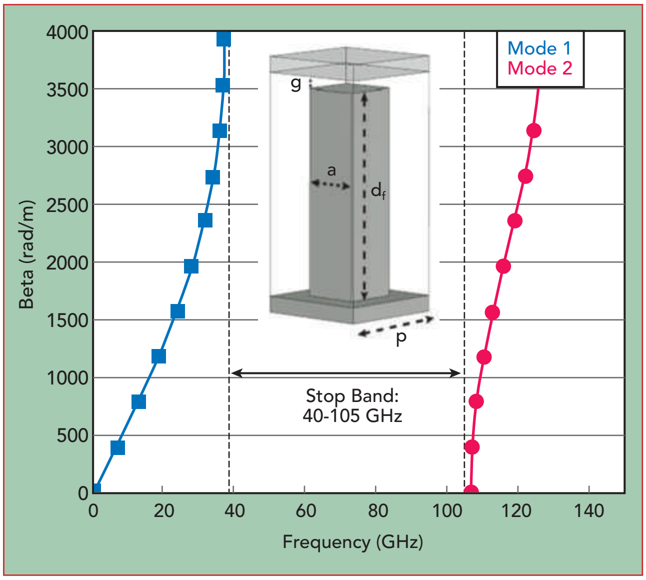

Fig. 2 Dispersion diagram for an infinite periodic pin unit cell, showing the stop band from 40 to 105 GHz.

DESIGN CONSIDERATIONS

The first step in the design process is determining the dimensions of the pins to provide the stop band over the desired frequency range in the gap between the flanges.[5] A unit element with periodic boundaries was used to calculate the stop band of the periodic electromagnetic (EM) band gap structure. The height of the pin surface is around $\lambda_0/4$

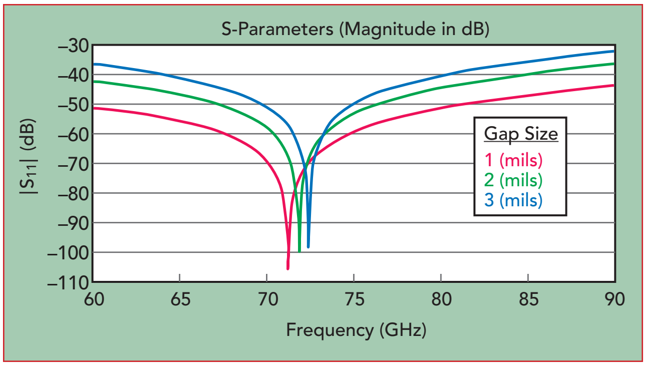

Fig. 3 Simulated $|S_{11}|$ vs. gap size, showing effect of reflections at the waveguide flange interface.

at the center frequency of 75 GHz. The pin width and the distance between the pins affect the stop band of the combined AMC and PEC surfaces. However, the stop band is also affected by the pin height and the resulting thickness of the air gap between the AMC and PEC surfaces; the bandwidth increases as the gap between the two surfaces decreases. The stop band also moves lower in frequency as the height of the pins increases, following an inverse relationship.[4]

CST Studio EM simulation software was used to model the design (see ***Figure 2***). The dispersion diagram shown in the figure applies to a unit element with an air gap (g) of 3 mils, pin height (d_f) of 35 mils, pin surface width (a) of 15 mils and pitch (p) of 25 mils. The stop band covers 40 to 105 GHz, covering all of E-Band (60 to 90 GHz).

Unlike previous designs, this design combines the functions of a choke flange with gap waveguide technology to suppress signal leakage and minimize reflections.[6-11] The two rows of pins form a circular pattern to ease the mechanical design and fabrication of the pins. The pins form an AMC surface that creates a parallel plate cutoff condition at the junction between the waveguide flange surfaces, reducing signal loss and reflection. The present E-Band gap adapter design has a fixed air gap of 3 mils, although smaller gaps can be used to achieve better performance.

The CWF design was refined by performing repeated simulation and iteration. The process involves trade-offs between the electrical

Fig. 4 To prevent damage to the pin surfaces, the front face of the CWF has an outer rim 3 mils thicker than the pin array.

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performance and manufacturability. In the present design, $|S_{11}|$ was evaluated for different gaps between the waveguide flanges (see ***Figure 3***). From 60 to 90 GHz, the simulated return loss is better than -30 dB for a 3 mil gap and -40 dB for a 1 mil gap, indicating that good electrical performance is achievable without requiring any physical contact between the flanges.

The rim surrounding the waveguide opening has the same height as the pins. Its short walls are 14 mils thick, while its long walls are nominally 45 mils thick across the longer dimension of the waveguide opening. Another rim with radial thickness of 47 mils surrounds the pin array that forms the AMC surface. This external rim protects the pin surfaces from damage and determines the minimum gap between the AMC and PEC surfaces (see ***Figure 4***). Guide pins are included to ensure proper alignment between the CWF and the conventional flange, adhering to standard flange definitions. By eliminating screws, measurements can be performed considerably faster, since the flanges only need to be aligned and pushed together.

MEASURED PERFORMANCE

The E-Band contactless flange was incorporated into a pair of VNA frequency extenders, which were mounted on sliding rails to create a fast measurement system (see ***Figure 5***). With this configuration, a DUT can be quickly inserted and removed for testing, offering the possibility for automated measurements when testing components in large quantities.

Using this measurement system, the E-Band CWF was used to measure the insertion loss of an isolator and two different directional couplers, and the results were compared with

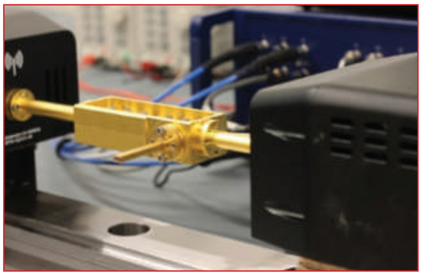

Fig. 5 Using the CWF with a pair of VNA extenders that slide on rails enables the DUT to be easily inserted and removed while maintaining test port alignment.

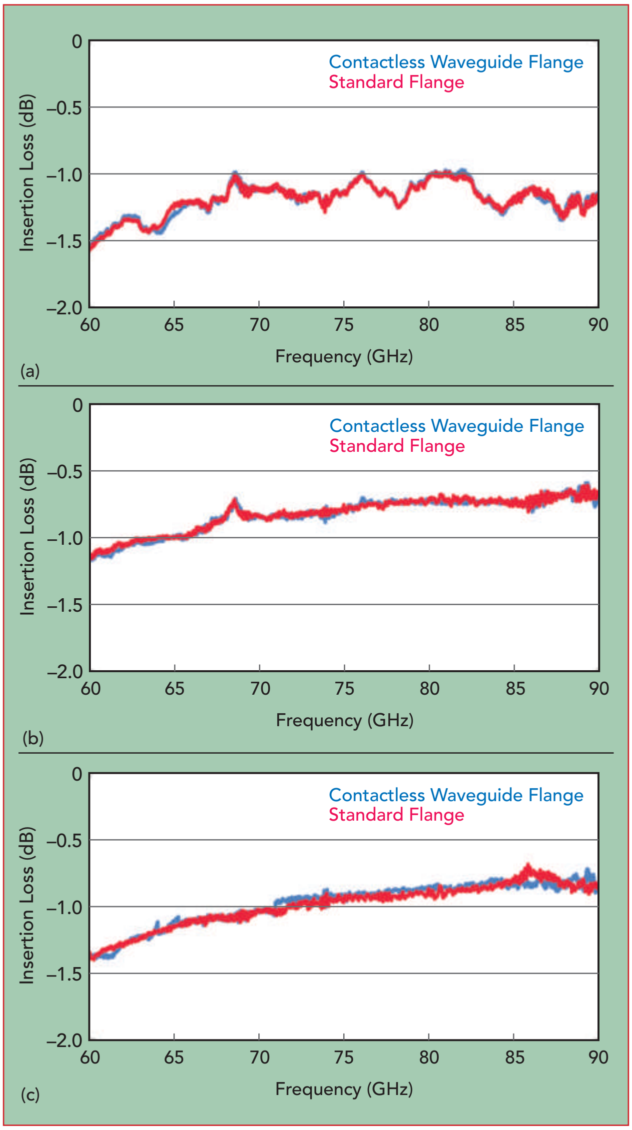

Fig. 6 Measured insertion loss of an E-Band isolator (a), directional coupler (b) and a different directional coupler (c).

the measurements made using conventional flanges (see ***Figure 6***). The results show differences of less than 0.1 dB between the two setups, confirming that CWF can achieve reliable measurement results. The insertion loss measurements were repeated five times, achieving the same results in all cases.

CWF designs are being developed for waveguide sizes ranging from WR28 to WR05, covering the waveguide frequency bands from 26.5 to 220 GHz. Increasing demand for waveguide components in greater quantities will motivate more manufacturers to adopt CWF for their test systems, to increase productivity and reduce operator fatigue and possible errors in high volume production environments.■

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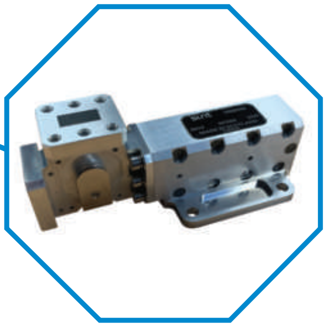

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INVITED PAPER

Compact and Highly Stable Frequency Synthesizers for Integrated RF Front-Ends

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Ulrich L. Rohde and Ajay K. Poddar
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Intermodal oscillation of multimode InGaAs/InP lasers at X-Band frequencies are stabilized using self-forced oscillation of self-injection-locked, triple-phase-locked loop (SILTPLL), self-mode-locking (SML) and a combination of SML and SILTPLL. As the number of SML modes are increased, lower phase noise close to the carrier is measured. With 201 modes with intermodal oscillation frequency of 10 GHz, a phase noise of -157 dBc/Hz at 10 kHz offset from a 10 GHz carrier is predicted, while any random phase error among self-mode-locked modes can be corrected using a self-forced oscillation technique. A compact realization is feasible using a heterogeneously integrated InP multimode laser (MML) on Si photonics, using low loss SiN resonators as delay elements and SiGe low noise RF electronics.

Low phase noise RF sources are important elements of coherent detection in many RF applications, such as terrestrial and space communications. One of the key technological challenges faced by efficient front-end electronics for reconfigurable wireless communication, sensitive electronic warfare, jamming resistant radar and diversified remote sensing systems is reliance on highly stabilized local oscillator frequency sources. The traditional method of generating stable RF signals by multiplying the frequency of a highly stable crystal oscillator[1] suffers from high power consumption, large size, poor AM noise and high AM-to-PM noise conversion, compared with forced oscillation techniques such as injection locking and phase-locked loops.[2] Alternatively, an optoelectronic oscillator has been developed and reported for X- and K-Band with a frequency resolution better than 50 kHz and phase noise better than -130 dBc/Hz at 10 kHz offset from the carrier.[3–5] A single chip design minimizes the environmental impact of temperature, vibration and radiation that influences long-term frequency stability. A small IC is preferred over its commercial 19 in. rack-mountable frequency synthesizer counterpart because of its smaller size, weight, power consumption and lower cost.

This article describes a compact chip-level integration using the intermodal output of a multimode semiconductor laser in the tens of GHz. While its performance using different frequency stabilization methods is reported elsewhere,[6-8] its salient points are reviewed here to provide an overview of the single chip design.

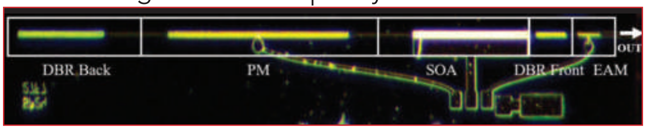


Fig. 1 Fabricated DBR-based multi-mode, multi-section, semiconductor laser on a 0.8 mm x 4.6 mm InP chip.

MML AS AN RF SOURCE

A distributed Bragg reflector (DBR) multimode, multi-section semiconductor laser for RF generation is shown in ***Figure 1***. It has no external reference and uses optical components fabricated with an InP process from the SmartPhotonics foundry.[9] The device has four major sections: semiconductor optical amplifier (SOA) for gain, phase modulator (PM) for RF frequency tuning, filtering DBR for lasing function at select wavelengths, and electro-absorption modulator (EAM) for mode number control using multi-quantum well InGaAs/InP for multi-mode laser (MML) operation at 1550 nm with intermodal RF signal of tens of GHz. The lengths of the DBR back and front mirrors are 600 and 200 µm, respectively, the phase section length is 1250 µm and the SOA length is 800 µm. To form the complete laser cavity, the sections are connected by shallow-etched waveguide. The total cavity length, including the connecting waveguide of approximately 4,000 µm, yields an intermodal oscillation frequency of about 11.5 GHz for multiple modes over the 80 GHz gain spectrum of the SOA. The external EAM, 200 µm long, is used to selectively suppress various modes. Electrical connections are placed on the chip to provide DC bias for the operation control of SOA, PM and EAM. A via connects the ground pad to the backside of the chip.

The microchip is mounted on a temperature-controlled surface (see ***Figure 2***) for static and dynamic characterization of MML in a constant temperature. A copper sheet placed under the microchip and mounted on a Peltier cooler maintains 20°C throughout testing, using a thermistor and temperature controller maintaining the fluctuation

to ±0.2°C. Mechanical probe stations provide electrical microprobes for the DC and RF input and the optical lensed fiber holder to collect the optical output. The optical output is monitored with an optical spectrum analyzer (OSA) through the lensed fiber optical coupler and photodiode. Its dynamic modulation has an important role in the phase-locking process of RF signals with greater than 50 MHz bandwidth. Intermodal oscillations are detected using an external high speed photodetector and displayed on an RF phase noise analyzer.

The EAM section controls the laser modes by shifting the quantum-confined Stark absorption edge. PM and EAM bias were initially set at 0 V, and the measured test of the integrated laser showed five dominant modes on the OSA. The fundamental mode was around -12 dBm at 1550.85 nm when the SOA injection current was 80 mA. The mode gap between each mode was around 11.5 GHz, which correlates with the estimated effective cavity length of 13.065 mm. The free-running intermodal output was around 11.5 GHz with about -10.6 dBm power at 11.5496 GHz. Poor phase noise of -5 dBc/Hz at 1 kHz offset from the carrier and -30 dBc/Hz at 10 kHz offset was recorded, as well as a 30 MHz center frequency shift over 10 minutes. Timing jitter was estimated to be 266.1 ps for 1 kHz to 1 MHz offset frequencies, before significant reduction using self-forced oscillation techniques.

The intermodal RF is tuned when a DC injection voltage is applied to the PM section (shown in Figure 1). An applied bias from -5.0 to 0 V to the PM section changes the index of refraction in the optical waveguide and the effective laser cavity length, causing a shift in the intermodal oscillation frequency. The phase section tuning sensitivity was measured

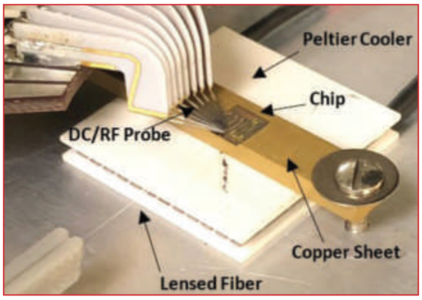


Fig. 2 DBR-based multi-mode multi-section semiconductor laser test environment.

at several PM biases; greater than 700 MHz tuning at X-Band was achieved with an average frequency tuning sensitivity of approximately 150 MHz/V. Compared to other techniques, this tuning range and sensitivity performance is among the best reported since its tuning sensitivity is significantly better than that of conventional RF voltage-controlled oscillators (VCOs).[10]

Novel forced oscillation techniques of self-injection locking[11] (SIL) and self-phase-locking loops[12] (SPLL) were used to improve the stability of the intermodal oscillation frequency. An optimized delay line using self-injection locked triple phase-lock loop (SILTPLL)[13] improves the phase noise performance without any external reference.

MML SILPLL STABILIZATION

To improve the stability of the free-running oscillation frequency, forced oscillation was employed. When a stable source is available, frequency stabilization using an external frequency reference has been reported by Daryoush et al.[14] However, self-forced oscillation techniques are useful when constructing a clean frequency source[2] as an external reference to stabilize distributed oscillators.[15]

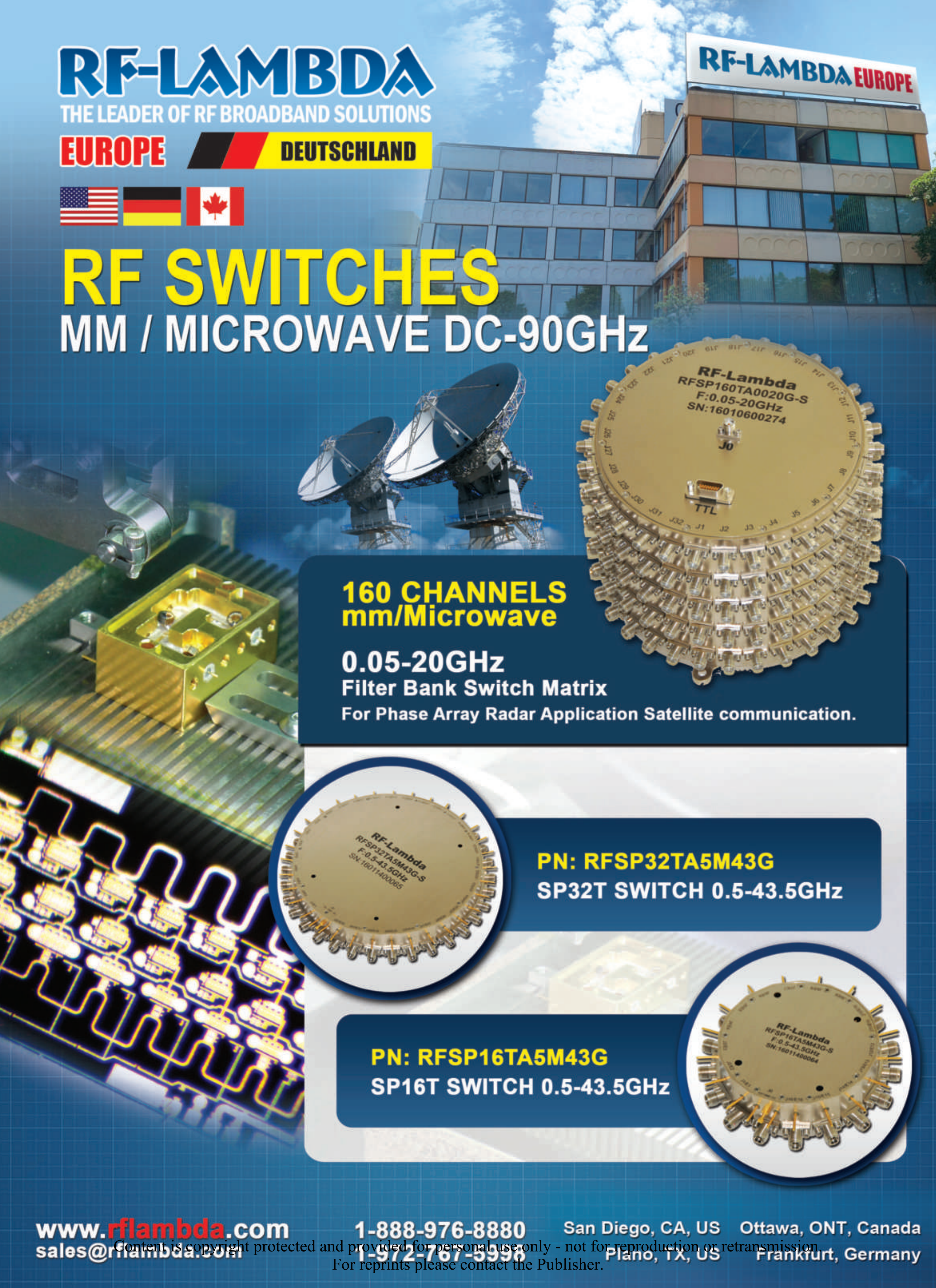
Referring to ***Figure 3***, the conceptual block diagram of a self-injection-locked phase-locked loop (SILPLL)[11] using a control theory representation is shown by the injection locking loop with the G_{IL} path. A portion of the oscillator output signal is delayed by a long delay (τ_d) and fed back to the oscillator with coupling factor ρ. The phase of the delayed signal is compared to the instantaneous phase of the current signal to generate an error signal for self-injection. The phase noise of the self-injection locking system at offset angular frequency of ω_m is expressed by equation (1):[11]

$$\left|S_{SIL}(\omega_m)\right| = \left|H_{SIL}(S)\right|^2 S_{n_i}(\omega_m) + \left|HE_{SIL}(S)\right|^2 S_{n_o}(\omega_m) \quad (1)$$

where in Laplace space of $S = j\omega_m$

$$H_{SIL}(S) = \frac{G_{IL}}{\left(1 - e^{-S\tau_d}\right)G_{IL} + 1}$$ and

$$HE_{SIL}(S) = \frac{1}{\left(1 - e^{-S\tau_d}\right)G_{IL} + 1}$$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In equation 1, S_{ni} and S_{n0} are the residual noise of the system and the phase noise of the oscillator, respectively. When the gain of the feedback system is suffice, the phase noise introduced by the free-running oscillator is to be significantly reduced.

The concept of self-phase-locking[12] is also shown in Figure 3, i.e., the loop with the G_{PLL} path. In the self-phase-lock loop (SPLL) process, a portion of the oscillator output is delayed, and the phase of the delayed signal is compared to the phase of the current signal. The comparison signal is amplified by an operational amplifier and fed back to the VCO tuning port (e.g., the voltage control of the PM portion of the MML). The feedback frequency control is initially a low frequency signal of up to 30 MHz and eventually settles at a DC signal when no frequency error is detected between the delayed and non-delayed signals.

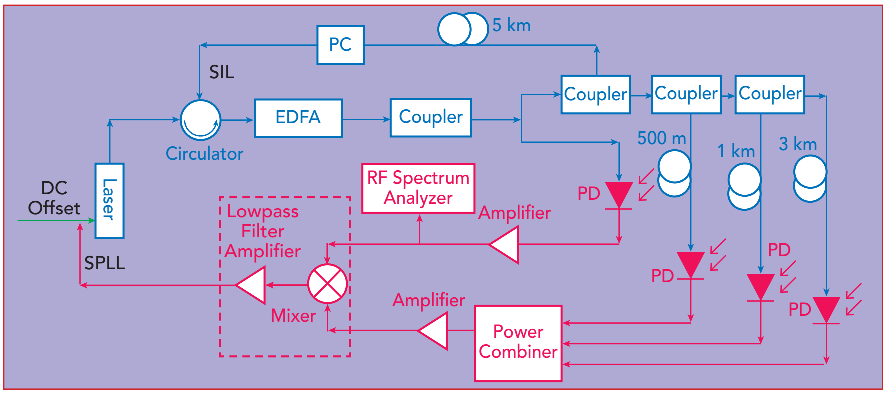

Fig. 4 Inter-modal oscillation stabilization using SIL and triple self-phase lock loop (TSPLL).

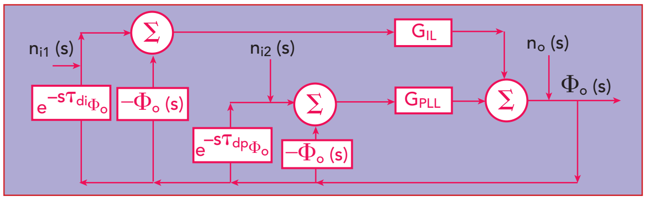

Fig. 3 Control theory representation of a SILPLL[16] composed of a SIL[11] with time delay of $τ_{di}$ and a SPLL[12] with time delay of $τ_{dp}$.

With the principal of superposition applied, the overall noise of the SPLL system is[12]

$$S_{SPLL}(\omega_m) = \left|H_{SPLL}(S)\right|^2 S_{n_i}(\omega_m) + \left|HE_{SPLL}(S)\right|^2 S_{n_o}(\omega_m)$$

where

$$H_{SPLL}(S) = \frac{G_{PLL}}{\left(1-e^{-s\tau_d}\right)G_{PLL}+1} \text{ and}$$

$$HE_{SPLL}(S) = \frac{1}{\left(1-e^{-s\tau_d}\right)G_{PLL}+1} \qquad (2)$$

Combining the SIL and SPLL leads to the SILPLL with a similar simplified expression,[16] conceptually shown in Figure 3. In this topology, the SIL and SPLL operate at the same time with separate external delay circuits. The derived expression using superposition is

$$S_{\phi_o} = \left|\frac{G_{IL}+G_{PLL}}{1+K_{IL}G_{IL}+K_{PLL}G_{PLL}}\right|^2 S_{n_i} + \left|\frac{1}{1+K_{IL}G_{IL}+K_{PLL}G_{PLL}}\right|^2 S_{n_o}$$

where

$$K_{IL} = 1-e^{-s\tau_{di}},\ K_{PLL} = 1-e^{-s\tau_{dp}} \qquad (3)$$

Equation 3 signifies that the SIL, SPLL and their combination significantly reduce the phase noise without any external reference.

The setup to test the SIL is shown in ***Figure 4***, where the instantaneous laser output is amplified using a constant gain, erbium-doped fiber amplifier (EDFA). The output is delayed by 25 μs using a 5 km fiber and fed back to the laser through an optical circulator. A tunable optical attenuator placed before the optical circulator port enables the dynamic performance to be evaluated by adjusting the optical injection power level. A

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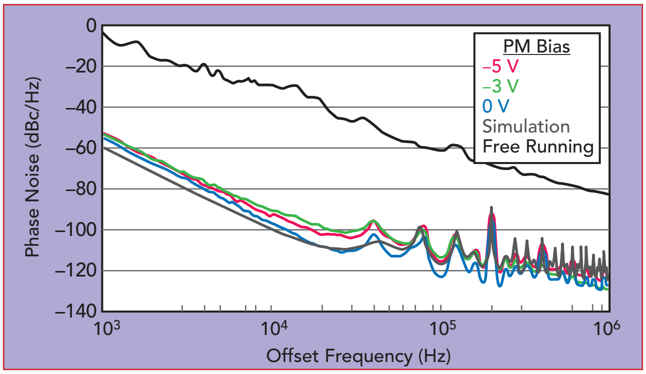

Fig. 5 Simulated vs. measured phase noise of self-forced SILPLL-stabilized inter-modal MML oscillator vs. bias. SIL: 5 km, STPLL: 500 m/1 km/ 3 km. Carrier frequency = 11.54 GHz, 3.59 dBm output. Free running oscillator shown for comparison.

polarization controller after the optical delay line provides a high efficiency optical injection signal to the optical waveguide.

The performance parameters of phase-locking range and time to pull-in to phase-locking state[17] for the SPLL is enhanced when SIL is incorporated to SPLL. The delayed and non-delayed signals are simultaneously compared in a phase detector that is realized using a mixer and lowpass filter amplifier (see Figure 4). Any instantaneous low frequency phase error pulls the frequency deviation back to the original RF oscillation phase-locking using the PM section of the MML. The PLL loop bandwidth of 50 MHz was selected to completely cover 30 MHz of frequency drift. Different offset bias conditions of the PM section were compared using optimized self-injection locking 5 km and triple, self-phase-locking 0.5, 1 and 3 km delay lines to test the phase noise (see ***Figure 5***). Triple non-harmonically related delay loops[16] suppress the peaks of the side modes from -30 to -90 dBc. In the best scenario, the timing jitter was 0.448 ps, 600× better than the free-running jitter. The accuracy of self-forced oscillation modeling results are validated and experimentally reported for phase noise of both DRO[11-14] and optoelectronic oscillators.[4]

Fig. 6 Shared DBR-based multimode semiconductor laser with symmetric multi-section multimode lasers on the left and right of a shared DBR. Chip dimensions = 4.6 mm x 1.2 mm.

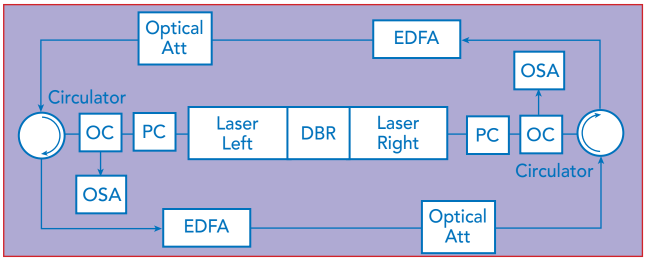

Fig. 7 SML method with two counter-propagating feedback waves of symmetric laser pairs. The current realization uses modular components off the InP chip.

FREQUENCY SYNTHESIS USING SML

To achieve broadband frequency synthesis, two MML pairs (see Figure 1) were configured to produce counter-propagating laser light feedback to form an RF synthesizer (see ***Figure 6***). This SML process[7] combined with frequency detuning the multimode laser sections easily provides tunable RF beat notes. ***Figure 7*** shows a block diagram of this novel SML method, which does not rely on standard active mode-locking where an external frequency reference is required. The symmetric outputs of multi-section laser pairs interact as two counter-propagating feedback waves. The larger the number of modes locked to one another, the lower the close-in phase noise, i.e., the better the RF frequency stability.[7,8]

The SML technique forces one laser output to be coherent with the other by locking the overlapped modes of the counter-propagating lasers, as bias currents of the SOA and voltages of the PM and EAM are tuned through the shared DBR and added external feedback. As shown in Figure 7, the amplified outputs from the left and right lasers are coupled back to the

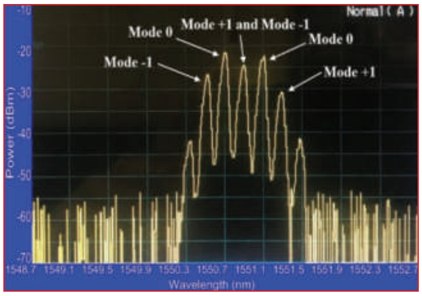

Fig. 8 Five modes shown on an optical spectral analyzer.

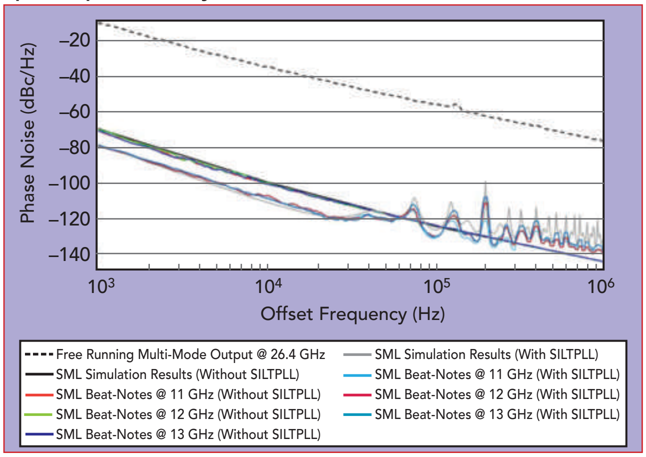

Fig. 9 Phase noise for beat-notes at 11, 12 and 13 GHz with five self-mode locked modes,[7] with and without the SILTPLL.[8] Measured and modeled results reported by Sun also shown.[18]

opposite lasers through optical circulators. The optimum level of light coupling is quantified by feedback power levels (e.g., an EDFA with optical attenuator). The measured fundamental mode of the two lasers with their intermodal gap is approximately 2.1 Ao (i.e., 26.4 GHz) for each laser. The spectra of the correlated modes is shown in ***Figure 8***. Mode +1 of the left laser overlaps with mode -1 of the right laser, which provides exactly five modes that are correlated. The best interaction of five locked modes of intermodal oscillations at 26.4 GHz achieves a measured phase noise of -92 dBc/Hz at 10 kHz offset, which is a 55 dB improvement compared to the free-running case. The estimated timing jitter is 72 fs, 1000× lower than the estimated 70 ps for the free-running case over a bandwidth of 1 kHz to 1 MHz.

To achieve RF synthesis, continuous wavelength tuning of the laser section is used after achieving mode-locked status, by tuning the SOA and PM to produce different beat notes. During this process, the laser modes remain locked. By tuning each laser section, the intermodal oscillation frequencies are tuned to 11, 12 and 13 GHz with RF power levels of 4.79, 4.80 and 4.70 dBm, respectively. The related phase noise and a comparison to analytical modeling are shown in ***Figure 9***.

COMPACT X-BAND SYNTHESIZER

The intermodal oscillation frequency of a MML can be further stabilized for a frequency synthesizer by combining self-forced-oscillation and SML. The phase noise comparison is shown in Figure 9, where the self-mode-locked modes are frequency tuned and employ a SILTPLL to reduce the phase noise by an additional 10 dB at offset frequencies below 100 kHz.

This improvement is attractive to realize highly stable synthesizers. The U.S. Defense Advanced Research Project Agency (DARPA) has recently challenged the RF synthesizer community with the following performance requirements under the GRYPHON Program:[19] stable frequency synthesis from 1 to 40 GHz packaged in under 10 cm^3, with phase noise no greater than -150 dBc/Hz at 10 kHz offset from a 10 GHz carrier with a 6 dB/octave roll-off, and the capability to operate in a harsh military environment (-40°C to +85°C temperature range and 40 g vibration). DARPA's design challenge can be met using the unique features of the MML: 1) the intermodal oscillation frequency can be modified by adjusting the common DBR section length while optimizing the multiple quantum well structure by increasing SOA gain, phase modulation sensitivity and effective cavity length; 2) the optical fiber delay elements can be replaced with cascaded, high-quality factor resonators.[20-23] Increasing the cavity length and DBR bandwidth accommodates a large number of modes for the MML. ***Figure 10*** com-

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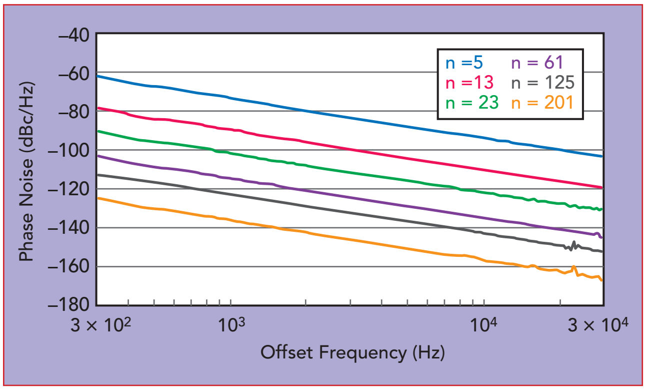
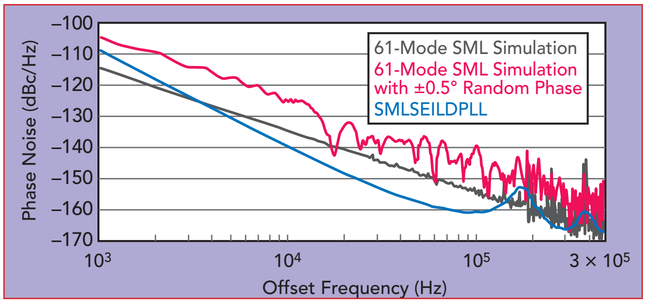


▲ Fig. 10 Phase noise vs. MML mode number. With 201 modes, the phase noise is –156 dBc/Hz at 10 kHz offset from a 10 GHz carrier.



▲ Fig. 11 Simulated performance of a 61-mode MML SML, SML with ±0.5 degree random phase error and corrected using SEILDPLL (delays of 5 ms for SEIL and 5 μs and 15 μs for SDPLL with ±0.5 degree phase error SML).

pares the close-in phase noise of the SML as the mode number increases from 5 to 201, showing a significant reduction in phase noise, which achieves the performance requirements of the GRYPHON program.

As the number of modes increases, phase-locking using SML becomes more sensitive to any internal phase degradation. Referring to **Figure 11**, note the simulated performance comparison of 61 modes of SML with no phase error and the case with ±0.5 degree of random phase error, where the phase noise degrades by 10 dB. However, when the self-electrical-injection locking and dual self-phase-locked loops (SEILDPLL) is introduced with random phase error using fiber delays of 1 and 3 km, phase noise of -140 dBc/Hz at 10 kHz offset from the carrier is achieved. Similar performance is predicted for cases of a self-forced MML with mode numbers larger than 61. These cases indicate the utility of SML and SEILDPLL to improve the stability of free-running intermodal oscillators to 40 GHz.

To meet DARPA's 10 cm^3 package size, the suggested approach incorporates a heterogeneously integrated InP MML with optical delay elements fabricated with silicon photonics (SiP). A conceptual block diagram is shown in **Figure 12**, where SiP is used for the passive optical couplers and delay elements, combined with integrated electronics using a low phase noise SiGe RF amplifier, phase detector and loop-filter amplifier as part of the SEILPLL. The green dotted line encloses the InP material heterogeneously mounted on a Si substrate. The black rectangle includes the SiP chip and the overall assembly is outlined in purple. The optical delay elements are realized using high-quality micro-disk resonators.

CONCLUSION

Optoelectronic techniques are quite viable for implementing high stability microwave frequency synthesizers. Significant improvement in frequency stability is attained using custom designed modular implementation of OEO based on the self-forced oscillation technique of SILPLL.[3] To reduce size, integrated solutions of SILPLL[24] are considered by integrating low noise RFIC using SiGe technology with SiP based optical modulators.[25] Compact design of the frequency synthesizer is demonstrated by employing InP-based MML and intermodal oscillation frequency stabilization using concept of SML[26] combined with SILPLL using high Q compact resonators.[27] A combined design following the intellectual properties described here could potentially meet the stringent requirements of the DARPA's GRY-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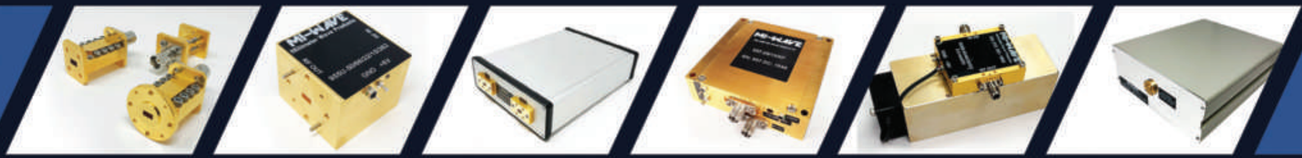

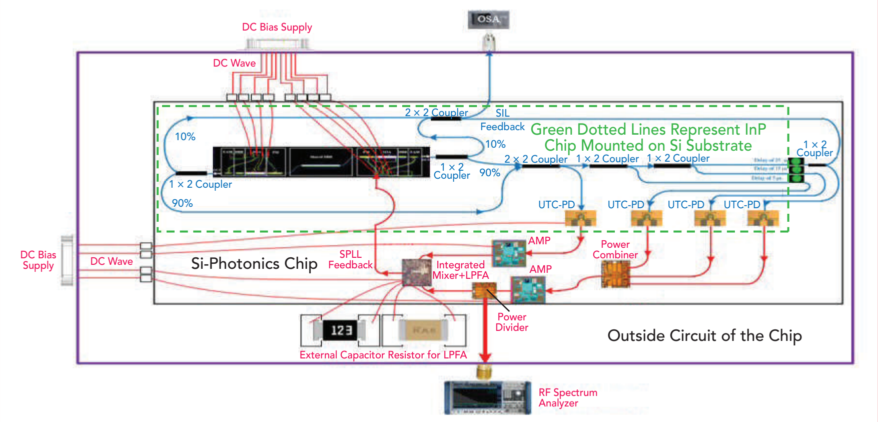

Fig. 12 Conceptual block diagram of a forced oscillation, mode-locked, multi-mode laser synthesizer on a ~10 mm x ~4.2 mm silicon chip.

PHON Program, which has challenged the technical community, a compact RF synthesizer using a heterogeneously integrated InP MML chip on SiP is proposed that will provide 1) low phase noise (-150 dBc/Hz at 10 kHz offset from a 10 GHz carrier), 2) broadband tuning (1 to 40 GHz), 3) small size (≤ 10 cm^3) and 4) operation in a rugged environment (-40°C to +85°C temperature range and 40 g vibration). A compact RF synthesizer with a very low phase noise in microwave frequency range could be envisioned by relying on the self-mode locking of a large number of modes of the presented MML with a tunable intermodal RF. Addition of a self-forced oscillation technique assures low phase noise of RF signal over the challenging environments.■

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INVITED PAPER

Fixing the Bane of Costly Component Out Of Pocket Defects

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BAE Systems, Nashua, N.H.

Darby Davis
Gel-Pak, a Division of Delphon, Hayward, Calif.

The march of technological progress continues as traditionally bulky and discrete microwave devices become integrated in increasingly smaller microelectronic modules and packages. New high performance GaN, GaAs, InP and other Class III-V and silicon semiconductor devices, along with high performance silicon variations such as SiC, are designed to push performance and enable new communications and sensing applications. As examples, active electronically scanned array radar and long-range, high throughput unmanned aerial vehicle telemetry are possible due to advances in RFICs and MMICs.

As with most advancements in technology, the steps forward come with design challenges. These challenges may be unknown and impossible to predict until the devices are shipped and integrated in new assemblies and systems. Often, enhanced features, integrated capabilities and heightened performance make the semiconductor die more expensive, and the loss of any die becomes a significant issue. This has been the case for a new generation of thin compound semiconductor die. BAE Systems, a global aerospace and defense technology company, and Gel-Pak, a division of Delphon, have investigated the loss of millions of dollars from "cost of poor quality incidents" caused by die migration in waffle pack trays, known as component out of pocket (COOP) defects. Their study revealed that while die migration occurred during customer handling of the waffle packs and chip trays, a significant amount occurred during the packaging by the supplier and subsequent transit to the customer. The wide flatness tolerances between the tray and the lid of traditional waffle packs, which far exceed the thickness of the thin semiconductor die, was the principal culprit.

This article discusses the joint study between Gel-Pak and BAE Systems and the development of a Lid-Clip Super System (LCS2™) to reduce die migration. The LCS2 protects extremely thin die, down to 2 mils (50 µm), during the jostling which occurs during handling and transport by semiconductor manufacturers, their distributors and customers around the world.

REDUCING DIE THICKNESS

Organizations from DARPA to cellular operators have invested in advanced semiconductor processes to enhance the performance of RFICs and MMICs, performance advantages such as higher power density, higher frequency coverage with wider bandwidth, improved linearity, lower noise and more integration. These developments have led to more compact ICs while integrating more signal chain components and features on the same chip, created a system-on-chip. These new processes operate through the microwave frequencies and into the mmWave spectrum, enabling new systems for communications, automotive, satellite and defense.

Lowering the cost, weight and size of the semiconductor devices helps to enable new systems. One aspect is reducing die thickness, which reduces the thermal resistance between the device junction and the conductive path that removes the heat. The RF performance may also benefit from thinner die, with lower parasitics that extend the upper frequency range. Thinning techniques have been developed for compound semiconductor and silicon on insulator wafers to reduce die thicknesses for RF, microwave and mmWave applications.[1–3]

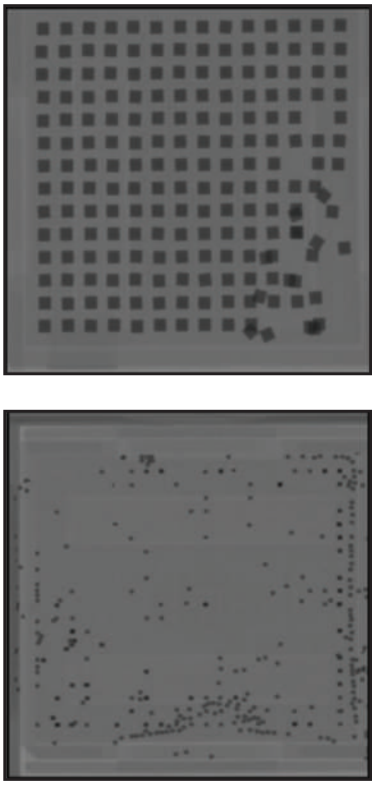

Fig. 1 X-ray images of COOP with a traditional waffle pack.

DIE MIGRATION

Despite the performance and integration benefits, reducing die size causes handling and transportation challenges. COOP refers to a die in a waffle pack escaping its pocket, possibly moving to the pocket of another die (see *Figure 1*). This migration is inconvenient and costly. Die in the same pocket may become damaged as they bounce and grind against each other. A die may flip, changing its orientation and causing placement errors with automated handling equipment. Die may become lodged between pockets, damaged by the waffle pack or migrate to another pocket when the waffle pack is opened. COOP degrades the quality of the manufacturing process, causing

- Component damage and scrap
- Additional labor to inspect and reorder components
- Manufacturing delays from yield loss and interrupted production
- Reduced pick-and-place machine utilization
- Additional quality management administration
- Over-engineering the automated assembly process.

Die migration will increase manufacturing cost. Since the cost of MMICs and RFICs is substantial, losing even a few from COOP can add thousands of dollars from damage, scrap and non-value-added labor. The worst-case scenario occurs when a defect from migrated die is not caught until after die placement in the next higher assembly, adding the cost and delay for troubleshooting and rework.

ROOT CAUSE

Historically, the cause of die migration has been attributed to handling when opening the waffle pack, although there was little investigation of the end-to-end process of handling, packaging, storing and transporting semiconductor die. When traditional waffle pack chip trays were designed, die were thicker, i.e., hundreds of micrometers. In the late 2000s, die thickness began to shrink below 250 μm and is now in the tens of micrometers. Yet the industry made little change to die packaging practices for waffle packs, which increased COOP losses. Not surprisingly, device suppliers and their customers saw each other as the cause of the increasing problem. Use of X-ray and 3D measurement systems have led to more accurate identification of root causes, and there are many:

- Lack of awareness of Entegris' literature describing warpage and the potential for migration
- Carbon loaded polypropylene lids and trays with a 0.012 in. warpage specification
- ABS and carbon loaded polycarbonate lids and trays with a 0.004 in. warpage specification
- Irregular deformation of lids and trays caused by the standard one-piece clip
- Non-woven polyethylene inserts misaligned and pinched during assembly, creating escape paths
- Components not flat in the chip tray before lidding
- Stacked components, i.e., two or more components in a single pocket due to operator error or warped lids
- Operator-dependent assembly process
- Application of label to bottom side of waffle tray by customers

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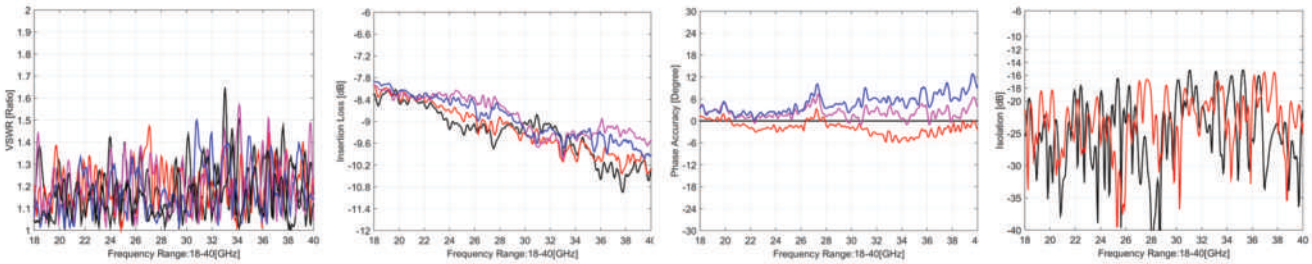
*Theoretical 6dB Included

— Typical Test Curve** —



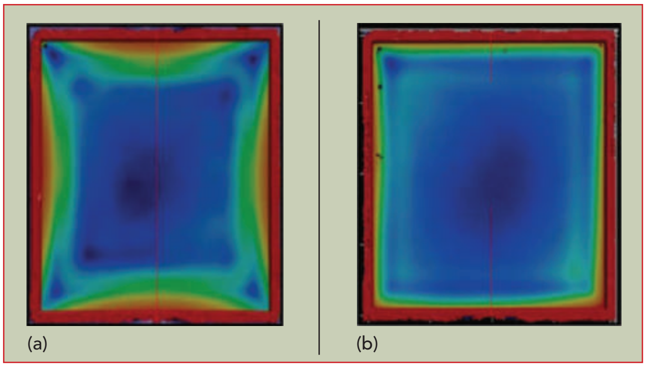
**Corresponding Channels: A1B1、A1B2、A1B3、A1B4

More Information-
Scan the

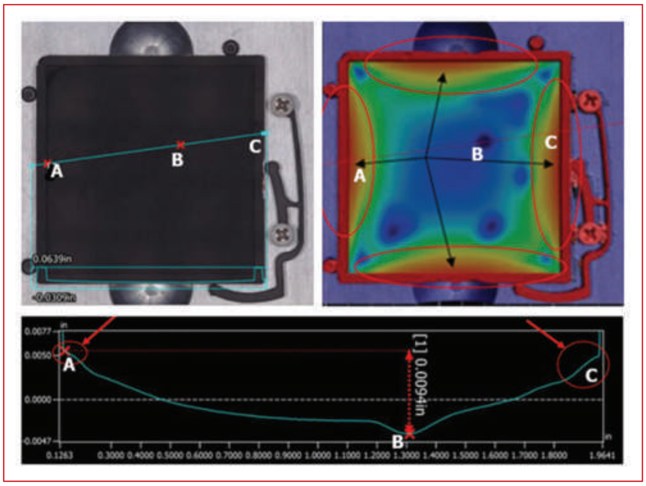
Fujian MIcable Electronic Technology Group Co.,Ltd requires removal of the clip

- Worn or broken one-piece clip
- Bump lid failure from improper use and warpage.

To improve the knowledge of COOP with the goal of reducing it, VJ Electronix developed an X-ray counter system (XQuik II) for BAE Systems in 2017. The XQuik II can view and count the components within a sealed waffle pack during receiving inspection and identify COOP before the waffle pack is opened. Data from the XQuik II system showed substantial levels of COOP when waffle packs were received by BAE Systems, prior to opening the waffle packs. This showed that COOP occurs at the supplier and during transit, not only during customer processing. COOP was found with 23 different suppliers, leading to the conclusion that semiconductor suppliers are unaware they are shipping waffle packs with COOP, as few suppliers use X-ray systems to inspect outgoing waffle packs.



▲ Fig. 2 Measured internal surface flatness of carbon loaded polypropylene (a) and carbon loaded polycarbonate (b) lids.



▲ Fig. 3 Measured internal lid surface flatness of the traditional waffle pack lid-clip system, showing 9.4 mil deflection between points A and B.

A Keyence VR-3200 3D measurement system was used to analyze waffle packs with COOP, measuring the flatness of the tray and lid materials. ***Figure 2*** shows example surface flatness measurements of carbon loaded polypropylene and carbon loaded polycarbonate lids. The carbon loaded polypropylene lid has a flatness specification of 0.012 in., and the average of the samples measured was 0.0079 in. The carbon loaded polycarbonate lid has a tighter flatness specification of 0.004 in., and the average of the samples measured was 0.0024 in. The carbon loaded polypropylene tray and lid combination have flatness tolerances wide enough for 0.004 in. thick die to escape their pockets. Combining the 0.012 in. tray flatness and the 0.012 in. lid flatness specifications yields a worst-case tolerance of 0.024 in., twice the amount for die to migrate.

Additional analysis showed that the traditional waffle pack lid-clip system had an internal lid contour measurement of 0.0094 in., which is more than 2x the height of typical GaAs and GaN die (see ***Figure 3***). These lid-clip combinations were tested with loose inserts to see if loose or misaligned inserts can increase COOP; the data shows the misalignment of loose inserts often results in die pinching and COOP (see ***Figure 4***). The investigation showed that manipulation of a loaded waffle pack by the customer risks COOP, as expected. During clip attachment and removal, uneven pressure applied by an operator can cause the waffle pack to warp, enlarging the gaps between the pock-

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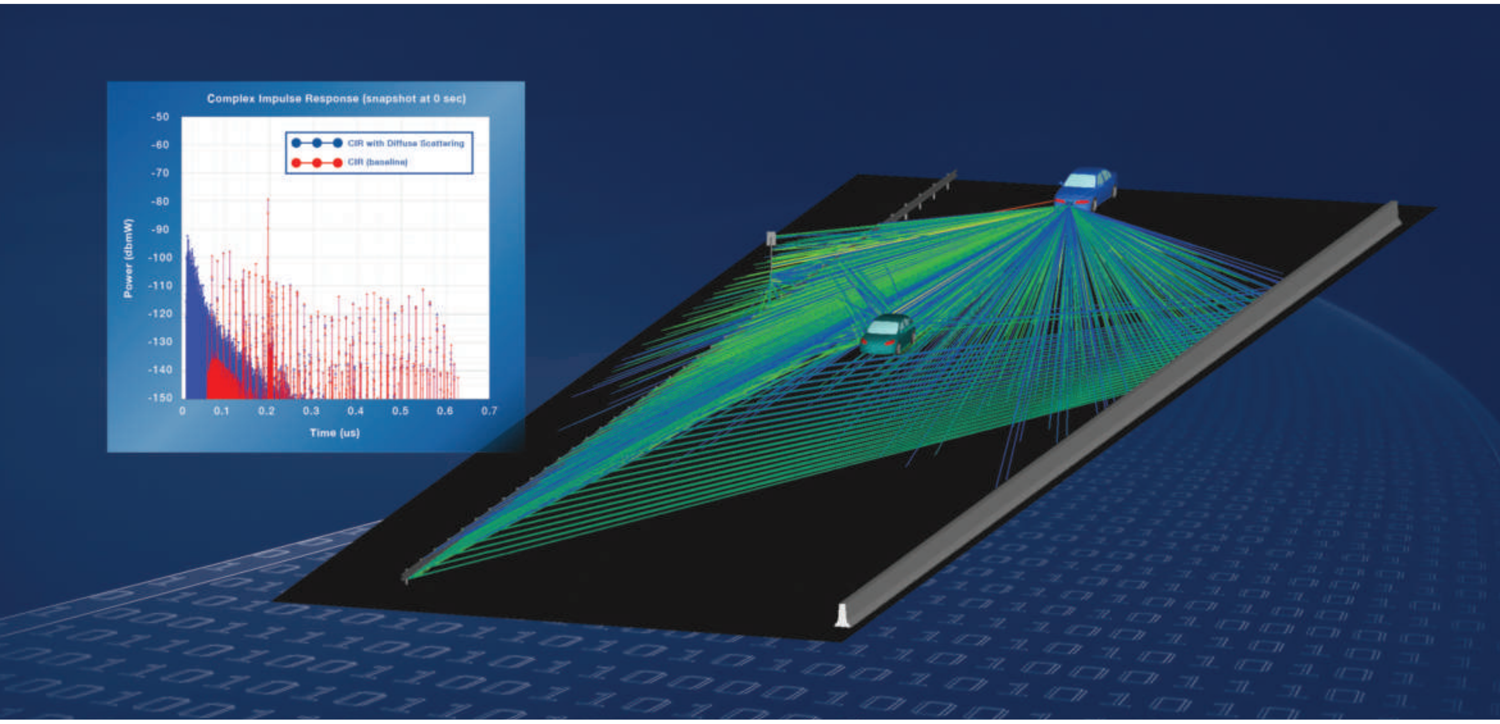

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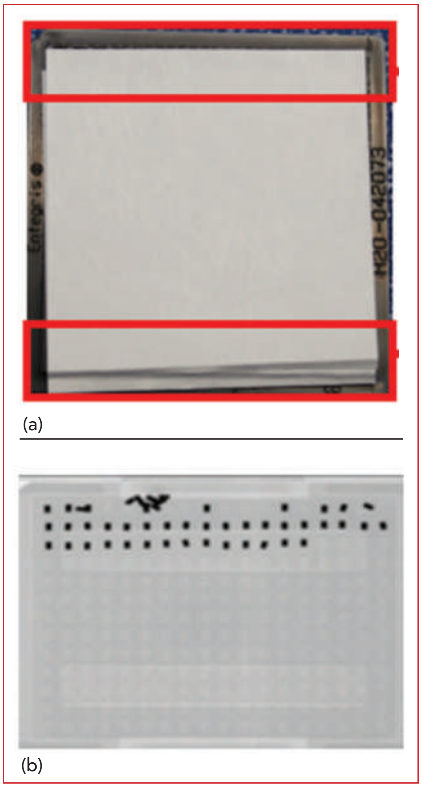

Fig. 4 **Misaligned, pinched polyethylene inserts in a waffle pack (a) create openings for COOP (b).**

The study revealed whether packing at the supplier or unpacking by the customer, the risk of thin die migrating is high.

NEW PACKAGING SYSTEM

To prevent COOP, a bare die packaging system needs to encapsulate the die from when the supplier packs the waffle pack, through shipping and unpacking by the customer. As the traditional waffle pack system was designed in a previous era, when devices were much thicker, a simple fix or insert is unlikely to solve the tolerance, quality and structural deficiencies for the current die. To protect the increasingly expensive die they contain, a new packing system is necessary, one compatible with automated manufacturing. The key requirements of a reimagined lid-clip system are

- Captivate the die fully during packing, shipping and unpacking
- Compensate for waffle pack tray and lid flatness variation within their specified limits
- Use an integrated industry interleaf with no additional modifications, materials or steps
- Provide enhanced electrostatic discharge (ESD) protection, using low outgassing and static dissipative silicone-free materials meeting all relevant industry standards
- Compress the lid uniformly around the full perimeter of the package.

These goals led to the development of the LCS2, engineered to pair with standard, pocketed trays, to resolve the mechanical issues caused by traditional waffle packs. Gel-Pak developed the LCS2 to captivate each die in a pocket and prevent migration (see ***Figure 6***). The LCS2 is fabricated using low outgassing, static dissipative and low density polyurethane

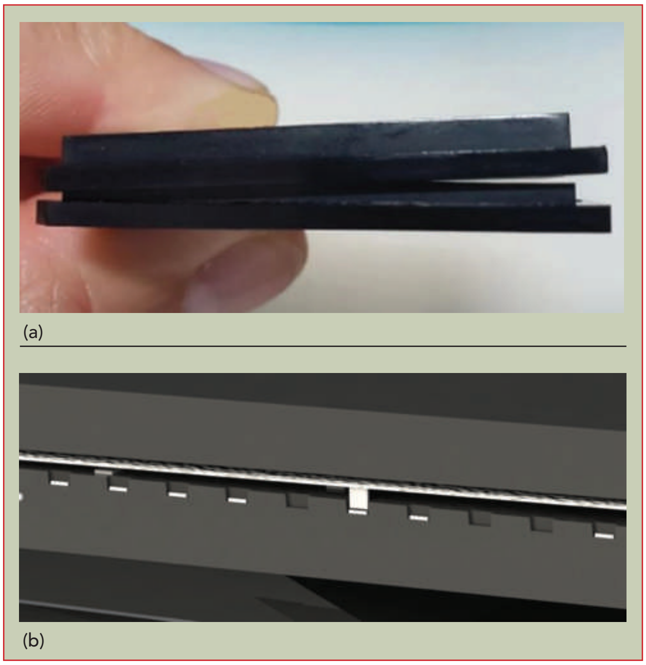

Fig. 5 **Waffle pack lid separating from the tray during normal handling (a), leading to COOP (b).**

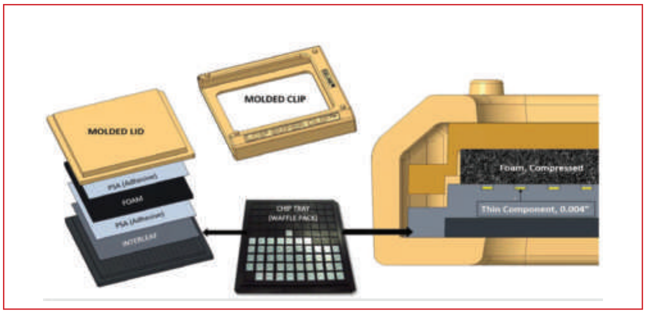

Fig. 6 Structure of the Gel-Pak LCS2 with gasketed tray pockets.

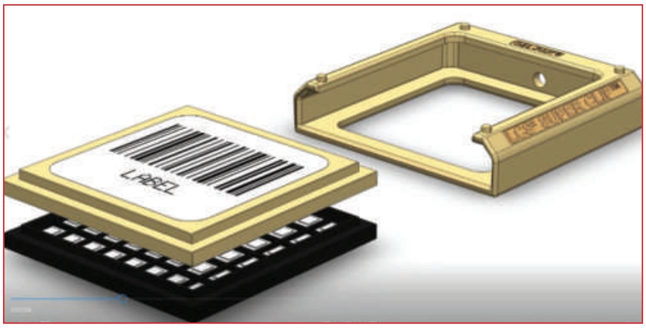

Fig. 7 LCS2 components.

foam, integrated with an industry-approved interleaf material and assembled into a static dissipative injection molded lid with a silicone-free, pressure sensitive adhesive. A new clip design provides uniform compression around the entire lid perimeter, ensuring a tight interface between the entire interleaf and a warped waffle tray surface (see ***Figures 7*** and ***8***). The static dissipative materials were selected and tested to ANSI/ESD S11.11 and deliver ESD Class 000 protection, which is suited to high value devices with the lowest voltage susceptibility.

TESTING THE LCS2

Testing the LCS2 has demonstrated its efficacy to protect thin semiconductor die. Drop test experiments using several lid-clip combinations and 0.002 in. thick GaN die were conducted, using a 34 in. height to represent catastrophic handling. X-rays verified the security of the die and whether COOP occurred. 100 drop tests were performed on 10 of the lid/clip products. The results showed no COOP (see ***Figure 9a***). When the same test was performed using the historic industry clip instead of the new clip, COOP was observed (see ***Figure 9b***). This test establishes the effectiveness of the new clip design.

Gel-Pak's LCS2 Super System has demonstrated the capability to virtually eliminate COOP for all sized components, especially ultra-thin die less than 10 mils. The LCS2 reduces non-value-added supplier corrective action requests and return material authorizations. Though the new packaging system must be field tested, the evidence points to LCS2 eliminating millions of dollars in yield loss and improving supply-chain quality and efficiency.■

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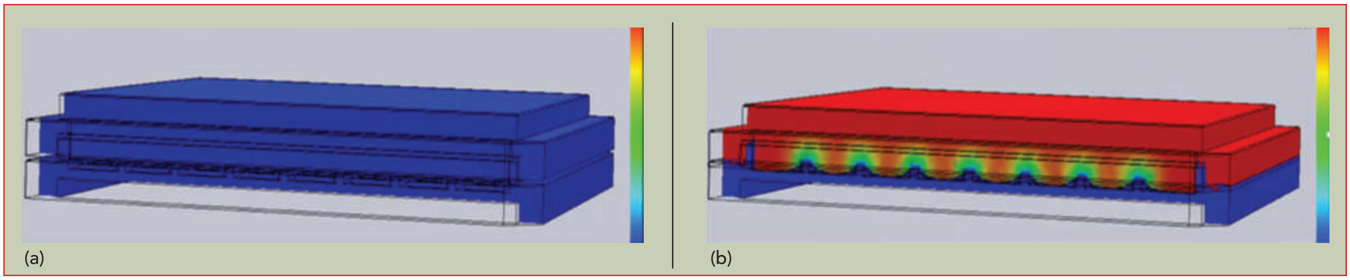

Fig. 8 LCS2 lid on the waffle pack tray without the new clip compressing the foam gasket (a) and with the clip compressing the foam (b). Simulation courtesy of Forgione Engineering.

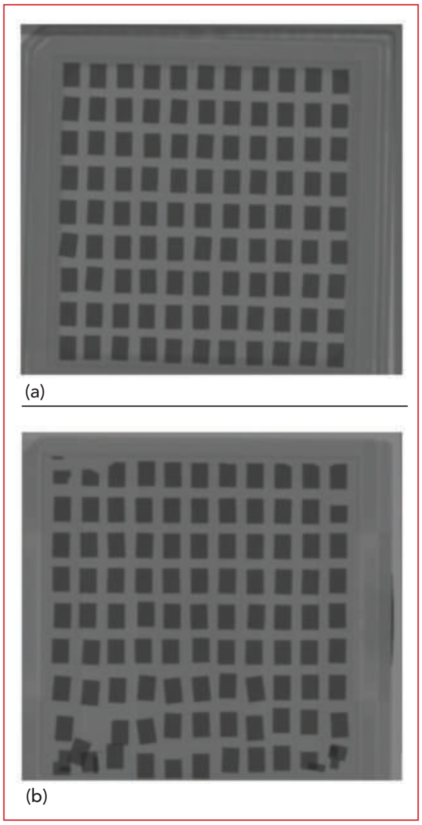

Fig. 9 X-ray images following 10 drops from 34 in. height: LCS2 (a) and new lid with the old industry standard clip (b), the latter leading to COOP and damaged die.

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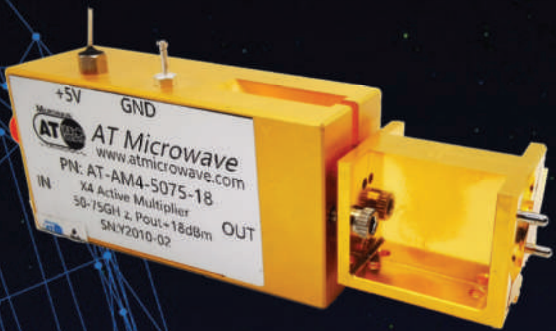

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Single Antenna Full Duplex Communications Using Variable Impedance Network

Gavin T. Watkins
Toshiba Research Europe Limited

Full duplex (FD) has the potential to double wireless communications capacity by simultaneously allowing transmission and reception (STAR) on the same frequency channel. In this article, a single antenna architecture with a hybrid coupler to isolate transmit and receive paths is evaluated. The fourth port of the hybrid coupler is terminated with a variable impedance (Z_V), which is tuned for maximum self-interference cancellation (SIC) between the paths. Z_V consists of a Wilkinson power splitter with its two splitting ports connected via a variable attenuator and variable phase shifter. This allows an incident signal applied at its summation port to be reflected back into the hybrid with an arbitrary gain and phase relative to the incident signal. Using a commercially available sleeve dipole antenna, up to 53 dB SIC is achieved over a 20 MHz bandwidth in the 2.45 GHz industrial, scientific and medical (ISM) band.

The pursuit for ever greater wireless connectivity has led to a rapid evolution of Wi-Fi standards over the last decade, each offering greater capacity in an already crowded spectrum. One proposed technique which can theoretically double data capacity is FD by allowing STAR on the same frequency.[1-4] STAR, however, is limited by self-interference, where the transmitted signal interferes with the received signal. Transmit power can often be 100 dB greater than the power of the received signal. Not only does this degrade the signal-to-noise ratio of the received signal; it can also damage sensitive receiver circuitry.

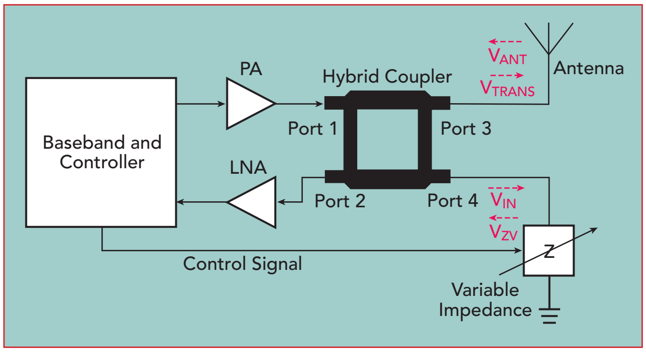

Fig. 1 **Single antenna, hybrid coupler full duplex system.**

Some FD architectures use separate antennas decoupled by polarization[2] and/or isolated by physical separation.[3] However, the complex antenna design or extra space needed to accommodate two separate antennas often makes these approaches unfeasible. Single antenna solutions where the transmit and receive paths are coupled to the same antenna with a passive RF network are more practical. Most single antenna FD development has been based on circulators.[4] Unfortunately, circulators are often too large and expensive for consumer electronics. Transmission line networks like the rat-race combiner,[5] hybrid coupler[1,6] and directional coupler[7] are more practical. They also offer the possibility for greater integration, if the transmission lines are replaced with lumped elements.[8]

This work is based on a hybrid coupler, where the fourth port is terminated with a variable impedance, Z_V. Z_V is tuned to reflect part of the transmitted signal back into the coupler so it destructively interferes. When aligned in amplitude and phase, a high level of SIC is possible. Although the focus of this work is Wi-Fi communications in the ISM band, it can be applied to other ap-

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	100 kHz	-177...-178 dBc/Hz

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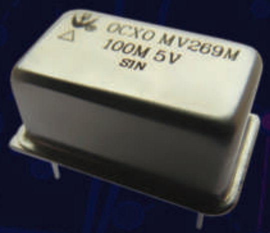

21x13x9.5 mm

SIN or HCMOS

Phase noise:	10 Hz	-102 dBc/Hz
(for SIN)	100 Hz	-135 dBc/Hz
	1 kHz	-163 dBc/Hz
	10 kHz	-175 dBc/Hz
	100 kHz	-178 dBc/Hz

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plications, such as radio frequency identification,[6] frequency-division duplex communications systems,[9,10] radar,[5] test and measurement[11] and backhaul.[12]

SINGLE ANTENNA FD CIRCUIT

A simplified schematic of a single antenna, hybrid coupler FD system is shown in ***Figure 1***. The baseband circuit generates an RF signal which is amplified by a power amplifier (PA) for transmission and applied to port 1 of a hybrid coupler with an equal (3 dB) power split. Port 2 of the hybrid is connected to a low noise amplifier in the receive path. In an ideal 50 Ω system, isolation between ports 1 and 2 exists due to the 180-degree phase difference between the two paths from port 1 to port 2. Half of the PA output signal is passed to the antenna at port 3 (V_{TRANS}) and the other to the variable impedance Z_V at port 4 (VIN). Part of V_{TRANS} is reflected by the antenna due to mismatch, denoted as the vector V_{ANT}. The gain and phase of V_{ANT} relative to V_{TRANS} is a factor of the antenna impedance and the length of cable connecting it to the hybrid coupler. Similarly, part of V_{IN} is reflected by Z_V and denoted as vector V_{ZV}. Z_V is controlled by the baseband circuit, so that V_{ZV} and V_{ANT} cancel at port 2.

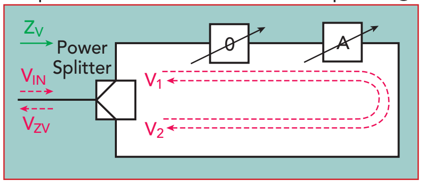

Fig. 2 **Two-dimensional variable impedance, Z_V.**

To provide a high degree of SIC, V_Z must have the same magnitude as V_{ANT} and opposite phase. To do this, it must meet the following requirements:

(1) Sufficient range to cover the required band

(2) Sufficient resolution such that $V_Z = -V_{ANT}$

(3) V_Z must match V_{ANT} over the whole signal bandwidth.

The simplest published implementation of Z_V consists of a single variable capacitor, which is tuned in only one dimension and, therefore, cannot simultaneously meet (1) and (2).[1] Two-dimensional designs such as those based on vector modulators,[13] can meet (1) and (2) but are often narrowband.[14] Three dimensional multi-tap delay lines can meet all three requirements but are complex, making them unsuitable for consumer electronics.[3,9]

This article describes a new two-dimensional Z_V consisting of a Wilkinson power splitter with its two output ports connected through a variable attenuator, A, and variable phase shifter, θ (see ***Figure 2***). V_{IN} enters the splitter and leaves it as two equal signals, V_1 and V_2. After passing around the loop through

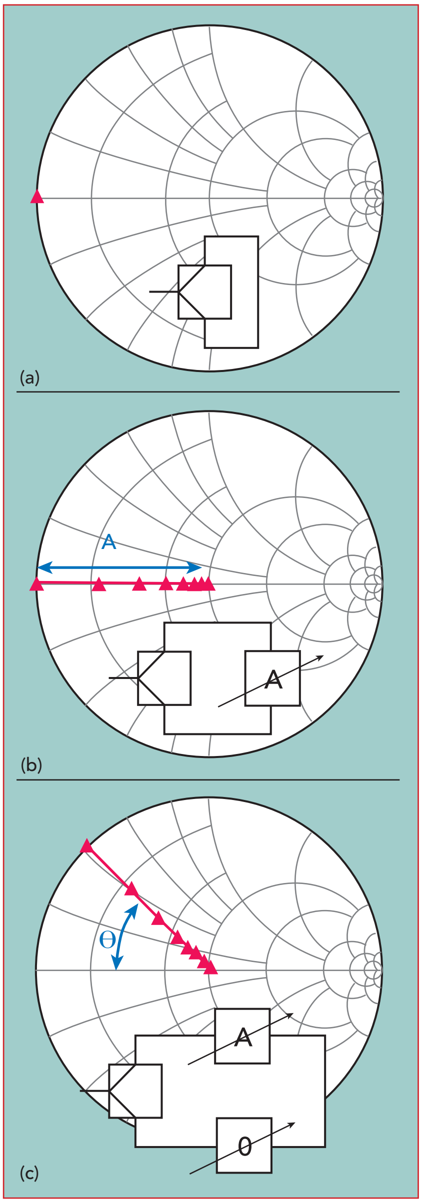

Fig. 3 **Z_V operation: splitter with ports connected directly together (a), adding an attenuator to control the magnitude of V_{ZV} (b) and adding a phase shifter to control the phase of V_{ZV} (c).**

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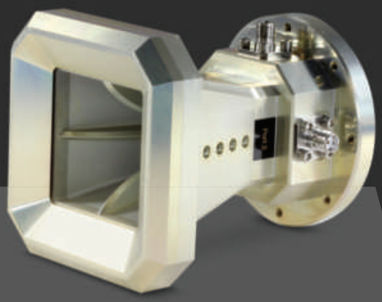

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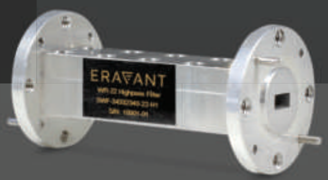

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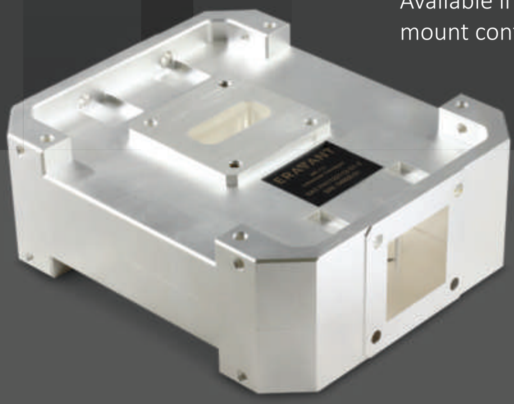

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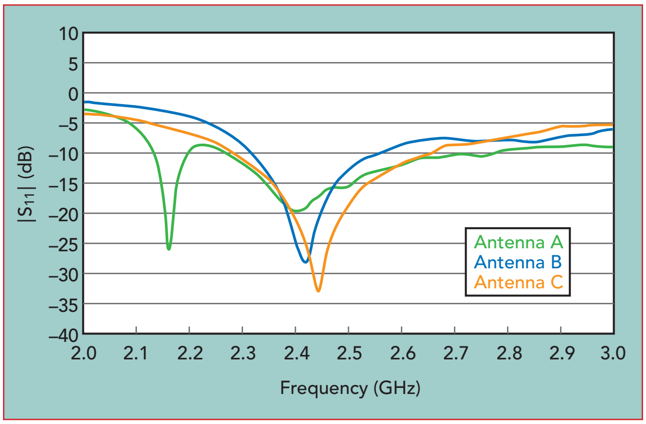


Fig. 4 $|S_{11}|$ measurements on three dipole antennas.

variable phase shifter θ and attenuator A, the signals are injected back into the hybrid coupler as V_{ZV}. A and θ control the gain and phase of V_{ZV} relative to V_{IN}. Due to the reciprocal nature of the network, the signal travels in both directions around the loop, overcoming the inherent insertion loss of the split.

The operation of the injection loop Z_V is explained further in ***Figure 3***. In Figure 3a, the two output ports of the splitter are connected directly together with a zero-length transmission line. Assuming a standard Wilkinson power splitter composed of two λ/4 sections, there is a 180-degree phase shift through this path. Looking directly at the input node, Z_V appears as a short circuit. Adding A (see Figure 3b) allows the magnitude of V_{ZV} to be controlled, so that Z_V can appear as a short circuit, 50 Ω at maximum A or any impedance between the two. Incorporating θ in the network allows the angle of V_{ZV} to be rotated around the Smith Chart (see Figure 3c).

The insertion loss of A and θ restricts the magnitude of the mismatch that can be synthesized, since V_{ZV} will always be smaller than V_{IN}. Mismatches from the individual components, which interact with V_{ZV}, reduce the tuning range, as well. The most critical source of mismatch is from the input of the splitter, which tends to shift Z_V away from the center of the Smith Chart, effectively introducing an impedance offset.[14]

SIMULATED SIC

To understand what level of performance—therefore SIC—can be achieved, the antenna mismatch must be characterized. Three commercially available sleeve dipole antennas, designated A, B and C, were measured (see ***Figure 4***). They were measured in isolation, i.e., with no large metal structures nearby, but not in an anechoic chamber, so the data includes some environmental reflections. While all three have better than 10 dB return loss over the 2.4 to 2.5 GHz ISM band, antenna C performed the best. A return loss of 33 dB at 2.45 GHz indicates that V_{ANT} will have a magnitude 33 dB smaller than V_{TRANS}. This means the antenna by itself provides 33 dB SIC if everything else is ideal. The role of Z_V is, therefore, to provide greater SIC than the inherent 33 dB provided by antenna C.

The FD system in Figure 1 with injection loop Z_V was simulated in Cadence AWR's Microwave Office, importing the S-parameters of antennas A through C as sub-circuits.

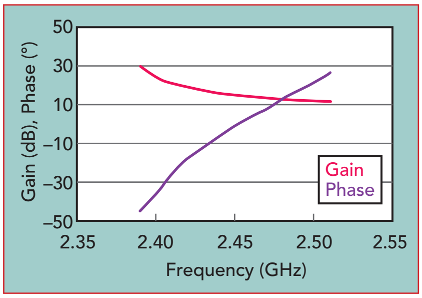


Fig. 5 Simulated gain and phase settings for 60 dB SIC.

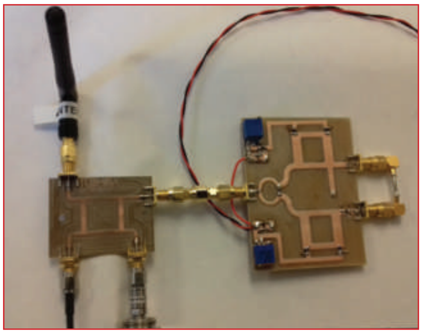
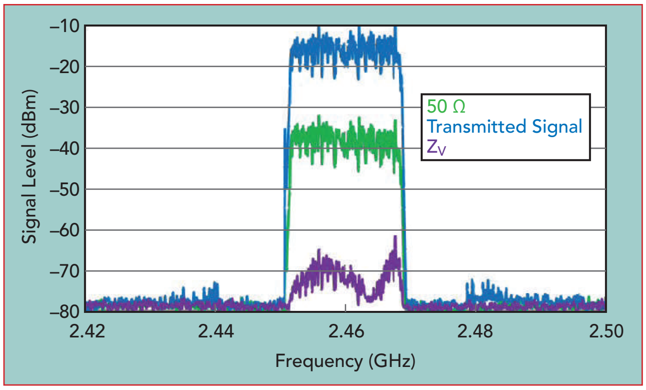
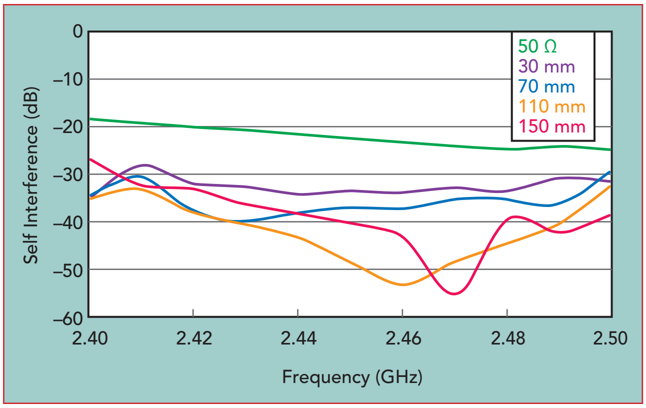


Fig. 6 Prototype system, with the hybrid coupler and antenna (left) and Z_V (right).



▲ Fig. 7 Measured performance with a 20 MHz, 2.46 GHz Wi-Fi signal, showing the transmitted signal, maximum SIC (Z_V) and interference with a 50 Ω load replacing Z_V.



▲ Fig. 8 Measured SIC across the 20 MHz ISM band showing effect of phasing unwrapping.

In the simulation, better than 60 dB narrowband SIC was achieved over all regions in the ISM band by tuning A and θ. The values of A and θ are shown in ***Figure 5*** for antenna C; the tuning range was 18 dB for A and 72 degrees for θ.

IMPLEMENTATION

To verify the operation, a prototype on an FR4 substrate was constructed for use in the 2.45 GHz ISM band (see ***Figure 6***). The hybrid coupler is on the left, with antenna C above it, and Z_V is on the right.

Previous work[14] used discrete gain- and phase-switched elements for Z_V. Although this allowed easy interfacing to a digital baseband controller, it lacked resolution, so analog elements were used in this version. Other work used MEMs tunable elements to tune the variable impedance but had limited tuning range.[15]

Here, A was implemented using the hybrid coupler with two of its ports terminated in PIN diodes, and θ was implemented using a hybrid coupler with varactor diodes at two of its ports[16]—both tuned with multi-turn trimmer resistors. These could easily be replaced with digital-to-analog converters for interfacing to a digital baseband controller. A coaxial cable linked A and θ so they could be tested independently. SMA adapters were used between the hybrid coupler and Z_V, so the electrical length could be adjusted.

The FD system was evaluated with a Keysight N5172B EXG signal generator, which produces a 20 MHz bandwidth signal for the transmit path, and a Keysight N9010A EXA signal analyzer as the receiver. With antenna C connected, A and θ were tuned for maximum SIC over the entire 20 MHz signal bandwidth. ***Figure 7*** shows the result for a 20 MHz bandwidth Wi-Fi signal at 2.46 GHz; it also shows the transmitted signal and the interference level when Z_V was replaced by a 50 Ω load. 53 dB SIC was achieved, which is 30 dB better than with the 50 Ω load. This is important, as it justifies using an actively controlled Z_V. For this result, the electrical length between the hybrid and Z_V was 110 mm.

Self-interference was also measured across the full ISM band with a 20 MHz bandwidth signal. ***Figure 8*** shows the performance, where the four traces represent different degrees of phasing unwrapping. Phase unwrapping is accomplished by increasing the electrical length between the hybrid coupler and Z_V in one wavelength steps with SMA adapters. This ensures $\angle V_{ANT} = -\angle V_Z$ over the entire 20 MHz signal bandwidth. The result of this can be seen in Figure 7, where the best

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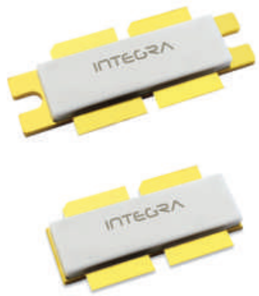

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match between V_{ANT} and V_Z occurs at 2.46 GHz.

A comparison of FD systems is presented in ***Table 1***. This design performs favorably, achieving the second largest SIC compared to other single antenna architectures. Only the work of Bharadia et al.[3] performs better; however, this system is significantly more complex, using a multiple tapped delay line, making it impractical for consumer electronics.

TABLE 1 COMPARISON OF SINGLE ANTENNA FD SYSTEMS

Reference	Frequency (GHz)	Bandwidth (MHz)	SIC (dB)	Architecture
1	1.9	20	40	Mechanical Tuner
2	2.5–4.7	NA	31	Antenna
3	2.35	50	50	Two Antennas + Canceller
4	2.45	20	60	Tapped Delay Line
9	0.8975	35	11	Tapped Delay Line
14	2.44	20	45	Variable Impedance
15	0.8/1.9	20	49	Variable Impedance
This Work	2.4–2.5	20	32–53	Variable Impedance

CONCLUSION

An RF FD front-end achieved a high degree of SIC over a 20 MHz bandwidth. While the target application is Wi-Fi in the 2.45 GHz ISM band, the approach is suitable for many other applications. A new Z_v architecture was introduced using a tuneable loop to control the magnitude and phase of reflection. A practical system tested with a 20 MHz Wi-Fi signal achieved up to 53 dB SIC at 2.46 GHz, with a similar level of performance possible over the entire ISM band with this simple architecture.■

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As the auto industry prepares for a self-driving future, automakers must choose from a range of innovative technologies to develop safe and affordable autonomous vehicles (AV).

In the early phases of development, companies pursuing "full-stack," level 4 and 5 autonomy favored a hardware-centric approach to solve the challenges of perception. Servers filled car trunks, requiring specialized cooling; unsightly LIDAR sensors costing hundreds of thousands of dollars were mounted to the tops of vehicles; and multi-chip radar arrays used digital processing on expensive FPGAs. While these high-end approaches helped demonstrate that complex perception challenges could be solved, the use of costly hardware made the implementation prohibitively expensive for commercial and consumer markets. The hardware sensors and associated computing often cost several times the cost of the vehicle.

Oculii's Virtual Aperture Imaging (VAI) technology platform offers a software alternative to solve the hardware problem and make autonomous technology more accessible for commercial and consumer applications. Oculii uses artificial intelligence (AI) software to enhance commercial, market-proven, mass-manufactured radars, achieving the sensor perception required for autonomous operation at price points orders of magnitude cheaper than competing approaches. To demonstrate the capabilities of the VAI platform to improve performance by 100x, Oculii has released two full-stack radar products running on standard silicon radar platforms: EAGLE and FALCON.

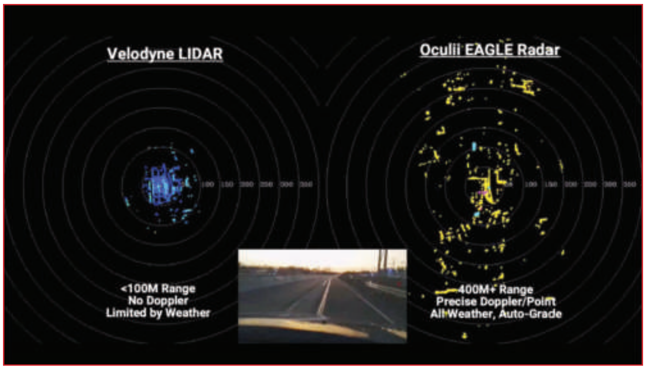

Fig. 1 **Comparing the Velodyne LIDAR (left) and Oculii EAGLE radar (right) imaging.**

HIGHEST RESOLUTION 4D RADAR

EAGLE is the highest resolution commercial 4D imaging radar, with joint 0.5-degree horizontal and 1-degree vertical spatial resolution across a 120-degree horizontal and 30-degree vertical instantaneous field of view. Operating with radar sensors in the 76 to 81 GHz automotive band, EAGLE generates images with tens of thousands of pixels per frame and tracks targets to more than

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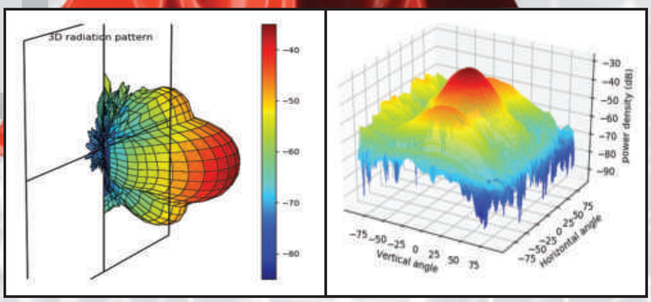


Milliwave Silicon Solutions
millibox@milliwavess.com
+1 408 892 9595
millibox.org

Fig. 2 **EAGLE radar attached to the front car bumper.**

350 m range, enabling vehicles to safely operate at high speeds and in all weather conditions. Its target sensitivity enables detecting and tracking low radar cross section targets like pedestrians and motorcyclists, making EAGLE well suited for use in congested urban environments. As required for automotive applications, the sensor operates across an extended temperature range from -40°C to 105°C.

Used on a low-power, two chip hardware platform with six transmit and eight receive channels, EAGLE provides the spatial resolution of an eight IC cascaded radar, i.e., with 24 transmit and 32 receive channels. It cost-effectively improves radar performance by more than 50x with just software (see ***Figure 1***). Using DSPs for processing, which are lower cost and consume less power than FPGAs, EAGLE consumes less than 5 W biased at 12 V. It is smaller than an index card, enabling integration that preserve the aesthetics of the car (see ***Figure 2***).

HIGH RESOLUTION FROM A SINGLE IC

Smaller than a business card, Oculii's FALCON is the most compact 4D imaging radar, with three transmit and four receive channels on a single IC. Also operating in the 76 to 81 GHz automotive radar band, it has a range of 200 m with 2-degree horizontal and 5-degree vertical resolution across a 120-degree horizontal and 30-degree vertical field of view.

Like EAGLE, FALCON provides long range coverage with high resolution across a wide field of view and operates from -40°C to 105°C. However, its power consumption is only 2.5 W. This, combined with small size, makes it well suited as a corner radar for advanced driver assistance systems (ADAS) or for autonomous robots, where low energy use is critical. Multiple FALCON sensors can be fused to cover all directions and work in all environmental conditions.

LEARNING OVER TIME

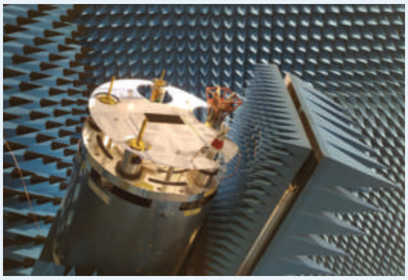
Until now, the only way to increase radar resolution has been to add more antennas, significantly increasing cost, size and power consumption. Oculii's platform provides an alternative by using AI software, specifically an adaptive phase-modulated waveform that changes in real time with the environment. No additional antennas are needed. This dramatically improves radar resolution, increases range and widens the field of view without changing the bill of material or adding hardware cost.

Oculii's AI software improves over time, learning from the environment as the radar sensors are exposed to more scenarios. The software adaptively embeds information from the environment, making the system "smarter" and improving resolution, range and sensitivity.

What makes Oculii's software unique for AVs: it does not require new hardware. The sensors use the existing radar to improve sensor perception at a price point that makes autonomy more affordable. By solving the long-standing hardware limitations, Oculii can accelerate the arrival of AVs to the mass market.

Oculii's products are also suited to the current automotive radar market. The pandemic has strained car production, adding financial and operational challenges to already costly and complex ADAS technologies. With radar sensors in millions of vehicles, Oculii's AI-powered radar can use these same platforms to improve resolution over a wider field of view and extend detection range without changing hardware or requiring a structural redesign of the car.

Oculii
Beavercreek, Ohio
www.oculii.com



1–220 GHz Automated Antenna Feed Carousel for OTA Testing

For 5G over-the-air (OTA) testing, EMITE has released a fully automated feed antenna carousel using a 1.8 m quiet zone compact antenna test range (CATR) in the EMITE F200 anechoic chamber. The system meets 3GPP's gNodeB standard for OTA testing, measuring all the key performance indicators defined in chapters 6 and 7 of 3GPP TS.38.521-1/2/3. EMITE's system is being used by two companies that are leading manufacturers of gNodeBs.

EMITE's novel carousel provides fully automated measurements from 1 to 220 GHz in both vertical and horizontal polarizations, saving days of manual changes normally required to make a complete set of measurements. gNodeB OTA testing is accomplished with just the push of a button, operating overnight without supervision.

The system uses an automated vector signal generator, vector signal analyzer and test algorithms, with the measurements controlled by the system's software and graphical interface. The carousel rotates several antennas to the CATR focal point and uses an embedded mmWave down conversion hardware module developed by EMITE that integrates mmWave oscillators, switches, amplifiers, multipliers, mixers and combiners to create several RF paths with various signal levels to measure OTA to 220 GHz. The separate RF paths protect the test instruments from excessive input power and maintain the link budget for spurious emissions testing (worst case).

The antenna carousel can be combined with a "barbeque" positioner for the base station being tested, which enables automated loading and unloading of heavy equipment at the chamber entrance.

EMITE Ingeniería SL
Fuente Álamo de Murcia, Spain
www.emite-ing.com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2.4mm Connector
DC to 50GHz, VSWR≤1.2
2.92mm Connector
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DC to 34GHz, VSWR≤1.15
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Test Cables up to 110GHz
Frontlynk Technologies Inc.
www.frontlynk.com

High Performance Hybrid Couplers for Wideband Applications to 40 GHz

To support wideband applications, Pasternack has expanded its line of RF hybrid couplers, adding 21 models and extending frequency coverage to 40 GHz. These coaxial designs, with SMA or 2.92 mm connectors, provide an even split with 90- or 180-degree phase shift and flat phase and amplitude balance across the frequency range. They have low insertion loss, good return loss and high isolation between ports, with power handling capability up to 100 W CW.

As one example of the extended family, the PE2CP1150 is a 3 dB coupler covering 2 to 40 GHz and providing 90 degree phase shift between the two output ports, with 10 dB minimum isolation between ports. The typical phase balance is ±8 degrees, ±10 degrees maximum, and the amplitude balance is ±0.8 dB typical, ±1.2 dB maximum. Typical insertion loss is 1.3 dB, 2.5 dB maximum. Input power handling is 20 W CW and 200 W peak. For best performance at the upper end of the frequency range, the coupler has 2.92 mm female connectors on all ports. The operating temperature range is –45°C to +85°C.

The family includes couplers for narrower bandwidth applications, such as the PE2CP1161, a 3 dB coupler with a 180-degree split, covering 26.5 to 40 GHz with 15 dB minimum isolation and 2.5 dB maximum insertion loss. Maximum phase and amplitude balance are ±6 degrees and ±1 dB, respectively. Input power handling is 20 W CW and 300 W peak, and the coupler has 2.92 mm female connectors on all four ports.

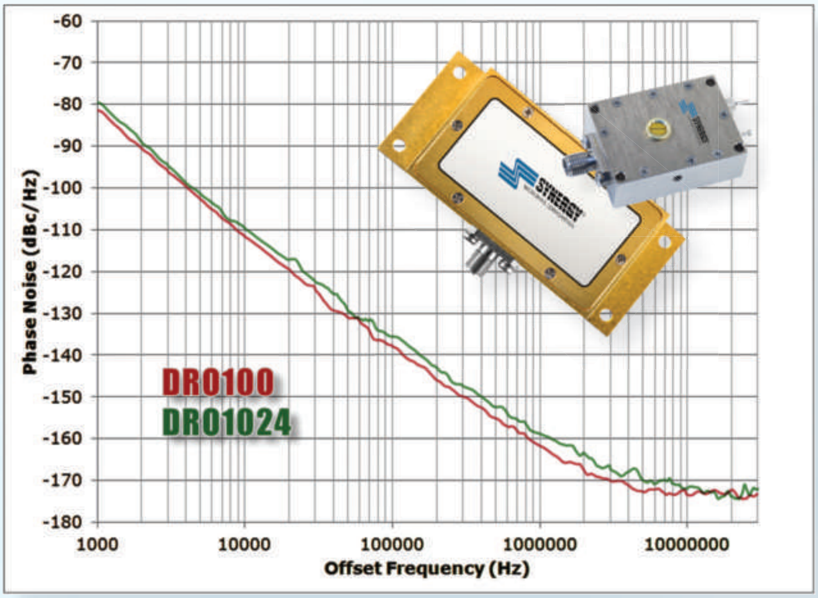
As with Pasternack's broad line of RF, microwave and mmWave components, these hybrid couplers are in stock and available for immediate shipping. No minimum order quantity is required.

VENDORVIEW

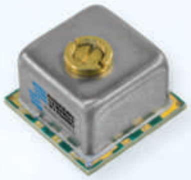
Pasternack
Irvine, Calif.
www.pasternack.com

Exceptional Phase Noise

Dielectric Resonator Oscillator



Available In Surface Mount.



SDRO Series
0.75" x 0.75 x 0.53"

Call Us!

For extended temperature range (-40º to 85º C)

RoHS **Patented Technology**

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO800-8	8.000	1 - 10	+8.0 @ 25 mA	-110
SDRO900-8	9.000	1 - 10	+8.0 @ 25 mA	-112
SDRO1000-8	10.000	1 - 15	+8.0 @ 25 mA	-107
SDRO1024-8	10.240	1 - 15	+8.0 @ 25 mA	-105
SDRO1118-7	11.180	1 - 12	+5.5 - +7.5 @ 25 mA	-104
SDRO1121-7	11.217	1 - 12	+5.5 - +7.5 @ 25 mA	-106
SDRO1130-7	11.303	1 - 12	+5.5 - +7.5 @ 25 mA	-106
SDRO1134-7	11.340	1 - 12	+5.5 - +7.5 @ 25 mA	-107
SDRO1250-8	12.500	1 - 15	+8.0 @ 25 mA	-104
SDRO1300-8	13.000	1 - 12	+8.0 @ 25 mA	-104
SDRO1400-8	14.000	1 - 12	+8.0 @ 25 mA	-102
SDRO1500-8	15.000	1 - 12	+8.0 @ 25 mA	-100
Connectorized Models				
DRO80	8.000	1 - 15	+7.0 - +10 @ 70 mA	-114
DRO8R95	8.950	1 - 10	+7.0 - +10 @ 38 mA	-109
DRO100	10.000	1 - 15	+7.0 - +10 @ 70 mA	-111
DRO1024	10.240	1 - 15	+7.0 - +10 @ 70 mA	-109
DRO1024H	10.240	1 - 15	+7.0 - +10 @ 70 mA	-115
KDRO145-15-411M	14.500	*	+7.5 @ 60 mA	-100

New Models!

* Mechanical tuning only ±4 MHz

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Mail: 201 McLean Boulevard, Paterson, NJ 07504

MAKING WAVES

Update on Altum RF, a Growing New Company

Greg Baker from Altum RF gives *Microwave Journal* Editor Gary Lerude an update on the company's market focus and new products at IMS2021.

Altum RF

https://bit.ly/3d9XDao

Datasheet Library

This tool categorizes products and makes it easy to find specs for dB Control's TWT amplifiers, MPMs, power supplies, RF sources and receivers.

dB Control

www.dbcontrol.com/datasheet-library/

New Radar Test Benches for Over-the-Air Testing

How can you perform realistic testing of radar-based vehicle functions? Watch this video podcast to learn about performing OTA testing on a test bench.

dSPACE

www.dspace.com/en/inc/home/medien/videos/podcast-videos/video_lb_darts.cfm

Website Update for SENCITY®OMNI-S Antenna

The HUBER+SUHNER website has been updated to include a new landing page for their configurator variation, the OMNI-S, which provides an easy way to custom-design your individual omni-directional SENCITY® OMNI-S antenna.

HUBER+SUHNER

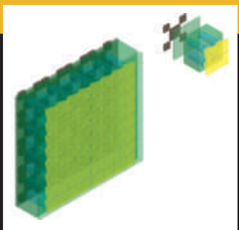
https://bit.ly/3pCNvfj

Knowles White Paper

Check out the recent white paper by Knowles, "Reduce SWaP, Increase Performance of Phased Arrays with an Innovative Filtering Approach."

Knowles Precision Devices

https://bit.ly/362WxsS

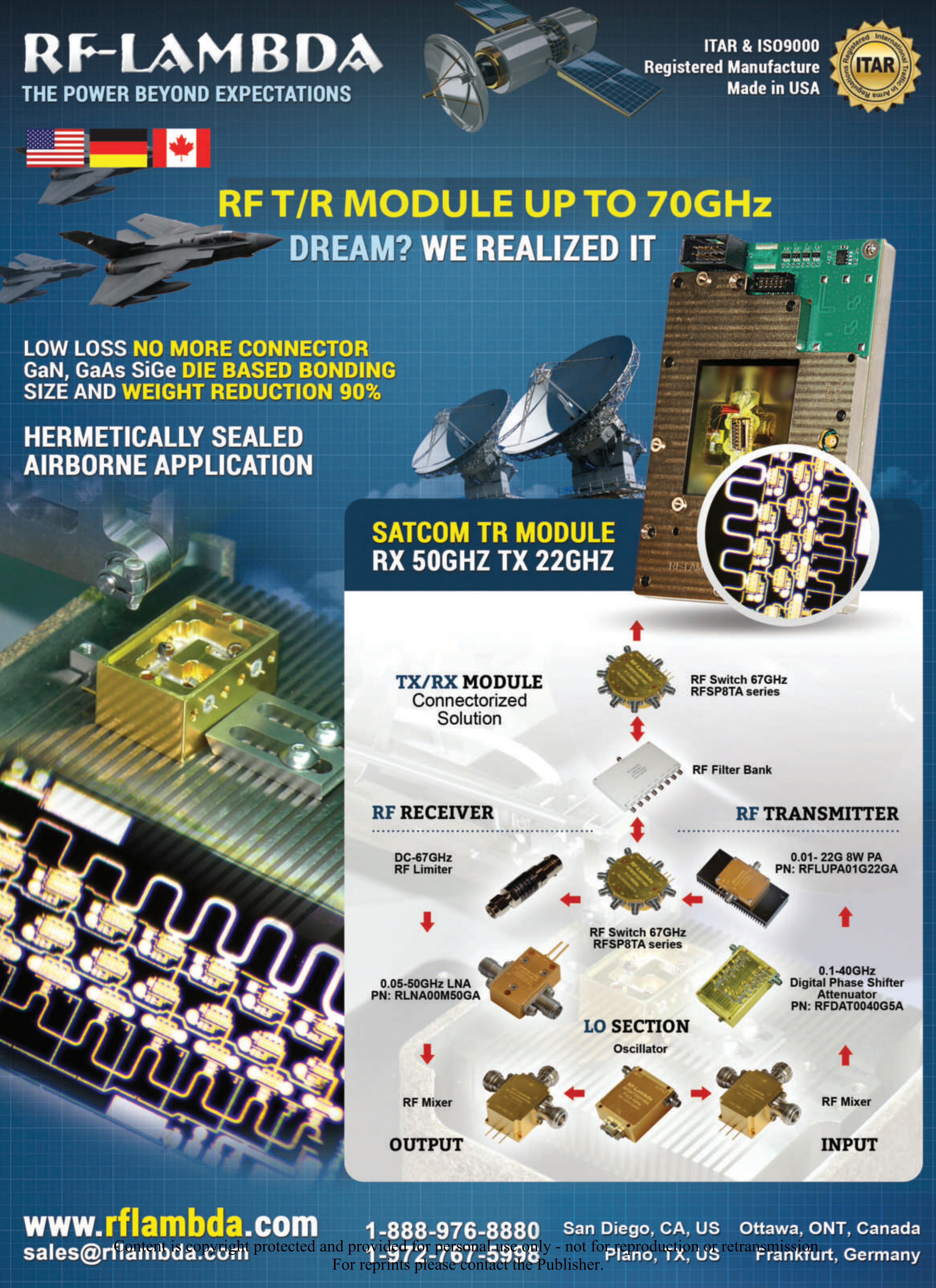


LadyBug Tech Moves

In order to serve our customers better, we have moved to a new larger facility. Same people, same quality, same service—new larger building.

LadyBug Tech

www.ladybug-tech.com.



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RFSP8TA series
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RF RECEIVER
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DC-67GHz
RF Limiter
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PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
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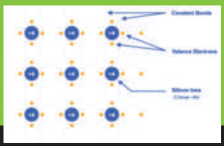
A Primer on RF Semiconductors (MMICs)

This blog post by Mini-Circuits explores the fundamentals of RF semiconductors to provide a foundational understanding of how they function, starting from atoms.



Mini-Circuits
https://blog.minicircuits.com/a-primer-on-rf-semiconductors-mmics/

The Center of Your 5G Design

To meet the demand for 5G RF front-end components, RFMW is offering a broad portfolio of complementary components from the industry's leading RF device manufacturers.

RFMW
https://rfmwblog.com/2021/06/17/rfmw-the-center-of-your-5g-design/

Rohde & Schwarz Signals Subpage

Rohde & Schwarz's new Signals subpage delivers curated content from the world of mobile connectivity: the evolution of 5G, private networks, automotive connectivity and future technologies, alongside the T&M solutions that make them reality.

Rohde & Schwarz
www.rohde-schwarz.com/signals

BLOG UPDATE: New Tech Coming from Signal Hound

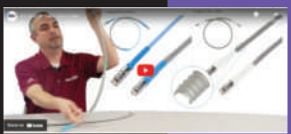
Learn about the 43.5 GHz SM435B and the 6 GHz BB60D Spectrum Analyzers coming soon. BB60D will deliver 10 dB more dynamic range than its predecessor!

Signal Hound
https://signalhound.com/new-2021

New Video: 10 Facts About Spectrum

Why is SPECTRUM INSTRUMENTATION a successful manufacturer of high performance digitizers, generators and digital I/O products? Learn more about the secrets of their success in the new two-minute video, right on the starting page.

SPECTRUM INSTRUMENTATION
www.spectrum-instrumentation.com



The Benefits of Armored RF Cable Assemblies

SV's armored RF cable assemblies provide exceptional corrosion and crush resistance and are ideal in harsh environments. Watch our new video to learn more.

SV Microwave
https://bit.ly/3d8SFe1

NEW PRODUCTS

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

COMPONENTS

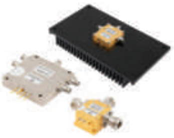
Ultra-Broadband Capacitors

AVX Corp., a manufacturer and supplier of advanced electronic components and interconnect, sensor, control and antenna solutions, has released new UBC 550 Series ultra-broadband capacitors designed to deliver reliable, repeatable performance from 16 KHz to 70+ GHz in ultra-broadband microwave and mmWave RF applications with stringent operating requirements. The new UBC 550Z, 550U and 550L Series ultra-broadband capacitors have a rugged and compact single-piece, surface-mount, multilayer ceramic construction made of the highest quality, RoHS-compliant materials and exhibit ultra-low insertion loss, excellent return loss, flat frequency response and high unit-to-unit repeatability.

AVX Corp.
www.avx.com

High-Power PIN Diode Switches

VENDORVIEW



Fairview Microwave Inc. has debuted a new series of high-power broadband RF and microwave PIN diode coaxial packaged switches that are ideal for aerospace and defense, microwave radio, military and commercial communications, VSAT, SATCOM, test and measurement, wireless infrastructure and fiber optics applications. Fairview Microwave's new high-power RF and microwave PIN diode switches utilize GaN semiconductor technology. In the manufacturing process, GaN and chip & wire technology ensures state-of-the-art power performance with excellent power-to-volume ratio, making these ideal for broadband high power applications.

Fairview Microwave Inc.
www.fairviewmicrowave.com

High-Power Capacitors

Passive Plus Inc. (PPI) offers a series of 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. Please contact PPI directly, for information and availability of these capacitors in magnetic or non-magnetic termination, or microstrip, axial and radial ribbon, axial and radial wire leads and custom assemblies.

Passive Plus Inc.
www.passiveplus.com

RF Loads

VENDORVIEW

Pasternack has expanded its line of RF loads to address myriad applications involving test, R&D, production, commercial and military RF communications systems. Pasternack's new RF loads can be used to terminate coax cables, multicoupling devices and test equipment across a variety of applications. Features include maximum power of 1 W, 1.85 mm, 2.4 mm, 3.5 mm, SMP and SMPM connector options, 18 GHz, 27 GHz, 34.5 GHz, 40 GHz, 50 GHz and 67 GHz frequency options and excellent VSWR performance.

Pasternack
www.pasternack.com

Bi-Phase Modulator

VENDORVIEW

PMI Model No. BPM-1840-180-292FF is a bi-phase modulator that operates over the 18 to 40 GHz frequency range. Typical insertion loss of 8 dB; maximum VSWR of 3.0:1; switching speed 100 ns maximum; phase variation ±40° typical; amplitude balance ±4.0 dB typical; and power handling 20 dBm operational. This compact housing measures 1.0" × 1.0" × 0.5" and is outfitted with 2.92 mm female connectors.

Planar Monolithics Industries
www.pmi-rf.com

Dielectric Varactor

Made with a unique tunable dielectric, ideal for phase shifters, VCO's, tunable filters and tunable matching networks with high linearity requirements. The dielectric maintains a low ESR, even up at mmWave frequencies. These varactors maintain micro-second level switching speed and are SMT compatible. Tecdia offers a range of capacitance values and form factors that are available for samples upon request.

Tecdia
www.tecdia.com

CABLES & CONNECTORS

Coaxial Contacts

MIcable D38999 high performance coaxial contacts are used for MIL-DTL-38999 circular connectors, there are 2 sizes and 4 types of contacts available at present that are BMA type (size 8), RMMP type (size 8), SMMP type (size 12) and SSMP type (size 12). The working frequency range of size 8 contacts is DC-18 GHz, and size 12 is DC-40 GHz normally and the VSWR of the contacts are 1.25@18 GHz and 1.35@40 GHz typically.

Fujian MIcable Electronic Technology Group Co., Ltd.
www.micable.cn

SMP Self-Lock Connector

The space flight-ready, high performance SMP-SL (Sub-Miniature Push-On-Self-Lock) connector from HUBER+SUHNER is small and lightweight, yet robust enough to withstand the harsh environment of space. Its innovative design utilizes a secure interlock mechanism which simplifies installation and eliminates unintentional disconnection. The connector also comes equipped with a visual aid that verifies if the connector is fully mated, thus streamlining quality inspection during system integration. To learn more about connectivity solutions for space flight applications, visit the website.

HUBER+SUHNER AG
www.hubersuhner.com

IMS

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19–24 JUNE
COLORADO CONVENTION CENTER
Denver, Colorado

IEEE
MTT-S
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Be a part of the premier Microwave and RF Event!

Consider submitting a proposal for workshops, technical lectures, focus and special sessions, and panel and rump sessions.

IMS2022 is the centerpiece of Microwave Week 2022, which includes the RFIC Symposium (www.rfic-ieee.org) and the ARFTG Microwave Measurement Conference (www.arftg.org).

The Peaks of Microwaves

Join us as we explore the new Peaks of Microwaves including:

- Radar, Phased Arrays, OTA test: the triumvirate of modern microwave systems
- Microwaves for Tiny AI and IoT
- Hardware for Intelligent Mobility, Automotive, and IIoT applications
- Microwaves and satellites for Space 2.0
- 5G/6G Hardware: from components to system-on-chip and RF to THz
- Quantum RF Engineering
- Evolving RF/EM design strategies

Microwave Week provides a wide variety of technical and social activities for attendees and exhibitors.

New This Year: IMS2022 Systems Forum

- "The Connected Systems Summit," presenting current thinking on next generation wireless technologies at mmWave and THz frequencies, will include presentations, panels and a pavilion on the exhibition floor
- Focused sessions investigating the synergy between radar, phased arrays, and OTA test and applications
- Space 2.0 event highlighting advances in aerospace, the Internet-of-Space and the MTT CubeSat competition

Something for Everyone

- Competitions for best Advanced Practices Paper and Student Paper
- RF Bootcamp intended for students, engineers, and managers new to microwave engineering disciplines
- Workshops and application seminars from our exhibitors, explaining the technology behind their products
- Networking events for Amateur Radio (HAM) enthusiasts, Women in Microwaves (WiM), and Young Professionals
- Guest hospitality suite

Important Dates

17 September 2021 (Friday)
PROPOSAL SUBMISSION DEADLINE For workshops, technical lectures, focus and special sessions, panel and rump sessions.

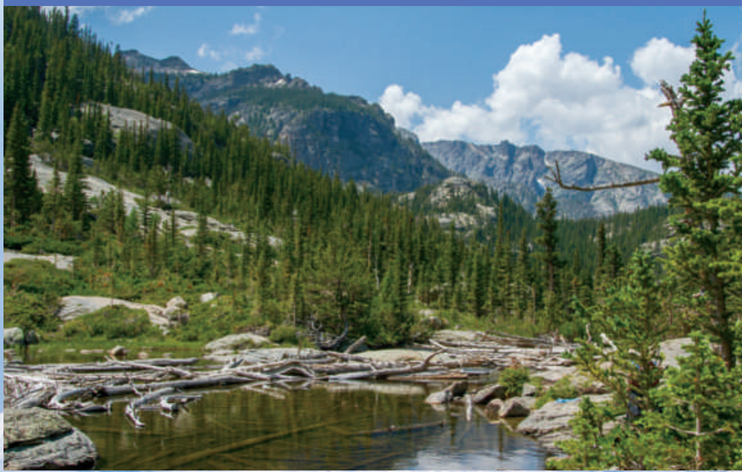
7 December 2021 (Tuesday)
PAPER SUBMISSION DEADLINE All submissions must be made electronically.

2 February 2022 (Wednesday)
PAPER DISPOSITION Authors will be notified by email.

9 March 2022 (Wednesday)
FINAL MANUSCRIPT SUBMISSION DEADLINE
Manuscript and copyright of accepted papers.

6 April 2022 (Wednesday)
SLIDE PRESENTATIONS DEADLINE FOR ALL AUTHORS AND PRESENTERS

19-24 June 2022
MICROWAVE WEEK IMS2022, RFIC 2022, ARFTG, and Exhibition



Visit ims-ieee.org/ims2022 to review the Calls for Proposals and to submit your proposals today!

AMPLIFIERS

Amplifier

VENDORVIEW

Exodus AMP2053A-1 is a rugged SSPA replacing aging TWT technology. Broadband, class A/AB design for all industry standards. 6 to 10 GHz, 100 W minimum, > 120 W typical & 50 dB gain. Excellent power/gain flatness as compared to TWTs. Forward/Reflected power monitoring, VSWR, voltage/current and temperature sensing for superb reliability and ruggedness. The nominal weight is 45 lbs in a compact 4U chassis, 7"H × 19"W × 22"D.

Exodus Advanced Communications
www.exoduscomm.com

Broadband GaN Power Amplifier

VENDORVIEW

Inspower Model INS3037 is a high-power, class AB, GaN amplifier that operates from 700 to 2700 MHz. It provides a saturated output power of 100 W minimum with a power gain of 50 dB minimum. This PA operates from an input DC voltage of 26 to 30 VDC. Module size is 230 × 120 × 25 mm and is available in a module only or integrated with a heat sink. This is an Inspower standard amplifier, usually in stock and can be shipped with short lead times.

Inspower
www.inspower.co.kr

Low-Noise Amplifier

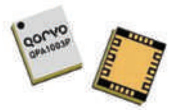
VENDORVIEW

Mini-Circuits' model ZVA-18403GX+ low-noise, wideband amplifier features a low noise figure of typically 3.8 dB and high gain of typically 43 dB from 18 to 40 GHz. It is available with or without a heat sink and operates from a single supply of +9 to +15 V DC. It draws 175 mA maximum current at +9 V DC. The RoHS-compliant, 50 Ω amplifier delivers typical output power at 1 dB compression of +21 dBm from 18 to 24 GHz and +23 dBm from 24 to 40 GHz.

Mini-Circuits
www.minicircuits.com

MMIC Amplifier

VENDORVIEW

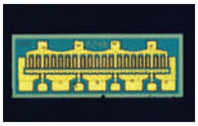


RFMW announced design and sales support for a wideband, high-power, MMIC amplifier from Qorvo. The QPA1003P operates from 1 to 8 GHz and typically provides 10 W saturated output power with power-added efficiency of 30% and large-signal gain of 25 dB. This combination of wideband performance provides the flexibility designers are looking for to improve system performance while reducing size and cost. The QPA1003P is matched to 50 Ω with integrated DC blocking capacitors on both RF I/O ports, simplifying system integration.

RFMW
www.rfmw.com

SEMICONDUCTORS

GaAs MESFET Chips



The BeRex Inc. BCF-series family of GaAs MESFET chips addresses the need for low phase noise with high gain and power in applications such as single and multi-stage amplifiers, oscillators, synthesizers, etc. ranging in frequency from DC to 26.5 GHz. This BCF-series family consists of seven devices, each with a 0.25 μm gate length and having gate widths from 200 μm to 2400 μm (up to 1 W for the largest 2400 um device).

BeRex Inc.
www.berex.com

NewProducts

650 V SiC MOSFETs

Richardson RFPD, Inc. announced the availability and full design support capabilities for three new 120 m Ω, 650 V SiC MOSFETs from Wolfspeed, a Cree Company. Wolfspeed's 650 V SiC MOSFET portfolio is based on the latest third-generation C3M™ SiC MOSFET technology, offering the widest range of on-resistances, the industry's lowest on-state resistances in a discrete package, as well as low switching losses—enabling high efficiency and power density. The new 120 m Ω, 650 V SiC MOSFETs are available in both through-hole (TO-247-3, TO-247-4) and surface mount (TO-263-7) packages.

Richardson RFPD
www.richardsonrfpd.com

SOURCES

Solid-State Microwave Generator

RFHIC's RIF58800-20SG is an 800 W, GaN solid-state microwave generator operable from 5725 to 5875 MHz. The shelf-type generator is ideally designed for microwave heating, composite welding and various industrial applications. Unlike any other product on the market, the RIF58800-20SG provides frequency sweeping, power controlling and signal source switching capabilities. The RIF58800-20SG comes fully equipped with a power supply unit and control unit, simplifying system integration, and lowering OPEX costs. The RIF58800-20SG can withstand a reflected power up to 6:1 at maximum output power.

RFHIC
www.rfhic.com

SOFTWARE

COMPLETE Library v21.3

VENDORVIEW

Modelithics announced the release of version 21.3 of the Modelithics COMPLETE Library for use with the Cadence® AWR Design Environment® Platform. This release includes 31 new models representing nearly 1,850 additional microwave/mmWave components. Version 21.3 of the Modelithics COMPLETE Library now contains over 775 highly scalable Microwave Global Models™ representing more than 22,000 passive and active components. This collection of models for discrete die, surface mount and packaged devices are integral for developing PCB-based RF & microwave circuits.

Modelithics Inc.
www.modelithics.com

ANTENNAS

LTE Antennas

Novocomms announced the global launch of the FPCB LTE 4G antenna. The FPCB LTE 4G is the latest addition to the British technology company's family of patented multi-channel antenna for use within the Internet of Things (IoT) sector. Novocomms has invested heavily to provide customized engineering support to their customers – unique within the industry. The company's highly qualified team of engineers have many years of industry experience in providing solutions within the IoT supply chain.

Novocomms
www.novocomms.com

NewProducts

TEST & MEASUREMENT

Nano5G Impedance Tuner

Maury Microwave announces the release of its Nano5G impedance tuner, optimized for 5G FR2 load pull. The Nano5G has been miniaturized to less than 2.5" allowing it to be directly connected to a wafer probe. The direct impact on load-pull measurements at 28 GHz include an improved typical VSWR at the probe tip reference plane Γ 0.87 and typical phase skew reduction to < 30 degrees when considering a 100 MHz signal and two adjacent side channels.

Maury Microwave
www.maurymw.com

ZNA Vector Network Analyzers

VENDORVIEW

Rohde & Schwarz launched the R&S ZNA originally two years ago. The newly introduced models cover frequency ranges of up to 50 GHz and 67 GHz. The R&S ZNA features excellent RF performance, including wide dynamic range and extremely low trace noise, and comes with a user-friendly, purely touch based GUI. Its unique hardware platform offers up to four internal, phase coherent sources plus a fifth source which can be used as a second internal local oscillator or as an additional source for measurements on mixers.

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

Spectrum Analyzer

The new SM435B flagship unit, a high-performance spectrum analyzer and monitoring receiver, will expand your reach into millimeter wave spectrum analysis at an affordable price point. Tuning from 100 kHz to 43.5 GHz, the SM435B analyzer has 160 MHz of instantaneous bandwidth (IBW), 110 dB of dynamic range, 1 THz/sec sweep speed at 30 kHz RBW (using Nuttall windowing), and ultra-low phase noise for $22,000USD. Pre-order now for the mid-October 2021 release.

Signal Hound
www.signalhound.com

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TOP REASONS TO ATTEND

CLAYTON R. PAUL GLOBAL UNIVERSITY
The Clayton R. Paul Global University will host 10 interactive lectures and 20 hours of in-depth EMC classes in the 1st week of the symposium from 27 - 29 July.

WORKSHOPS & TUTORIALS
A program of nearly 40 workshops and tutorials covering EMC, Signal Integrity, and Power Integrity will run in the 2nd week of the symposium (USA Eastern Daylight Time) through the entire week on Monday, Tuesday, Wednesday, Thursday, and Friday from 2-6 August with an opportunity to ask the speakers questions.

250+ TECHNICAL PAPERS
A program of over 250 peer-reviewed technical papers will be presented in the 3rd week of the symposium, 9 -13 August. All paper sessions run through the entire week on Monday, Tuesday, Wednesday, Thursday, and Friday, with an opportunity to ask the speakers questions.

OPPORTUNITIES TO JOIN TECHNICAL COMMUNITY ACTIVITIES
Our technical meetings (including our 14 Technical and Special Committees and an extensive program of Standards Working and Continuity Groups) will take place Mondays thru Fridays of 26-30 July as well as in the third and fourth weeks of the symposium, 9-20 August. These meetings are open to all to attend with a no charge "guest pass" registration.

CONTENT AVAILABLE ON DEMAND
Content will be available on-demand after the conference so you can watch (or re-watch) any or all of the presentations, wherever you are in the world.

SCHEDULE ACCOMMODATES YOUR BUSY WORK OBLIGATIONS
The extended schedule helps our virtual attendees manage their work, home, and symposium schedules while also providing the opportunity to attend more sessions and technical meetings than would be possible at an in-person conference. Recordings will be available on-demand through 30 September 2021.

VIRTUAL EXHIBIT HALL
The technical exhibition is an integral ingredient in our symposium and gives exhibitors the opportunity to interact with attendees. We are looking to our sponsors to provide the materials and education we all gain so much from when visiting their booths. Special exhibitor technical demonstrations will be given each day Monday thru Friday, in the 2nd week of the symposium 2-6 August.

REDUCED REGISTRATION FEES
To reflect the challenges presented by COVID-19, registration fees for technical program access will be heavily discounted. Free "guest" passes will be available for those interested only in attending technical meetings (e.g. Technical Committees, Standards Working Groups) and accessing sponsor materials. A group discount is available for ten registrations from one organization.

ADVANCE PROGRAM AVAILABLE ONLINE

www.emc2021.org

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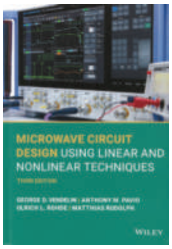

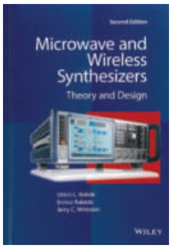

New Editions of Two RF/Microwave Classics

New editions of two foundational books on RF/microwave design have been published: the third edition of "Microwave Circuit Design: Using Linear and Nonlinear Techniques," by George Vendelin, Anthony Pavio, Ulrich Rohde and Matthias Rudolph; and the second edition of "Microwave and Wireless Synthesizers," by Ulrich Rohde, Enrico Rubiola and Jerry Whitaker.

The goal of the first edition of "Microwave Circuit Design" was to provide engineers with a thorough analysis of microwave circuit design, from basic circuit concepts to active devices and the common functional blocks used in RF/microwave systems. The third edition retains this goal and the relevant material from the prior edition, while adding more than 200 pages on CMOS, GaN and SiC semiconductors, plus a discussion of feedback power amplifiers for mmWave frequencies.

Similarly, "Microwave and Wireless Synthesizers" has been updated to include the current generation of semiconductor devices and ICs used in frequency synthesizers. The book still addresses the theory and practical architectures of frequency synthesizers, including loop fundamentals, special loops, loop components, multi-loop synthesizers and synthesizer noise and spurious responses. Examples illustrate design approaches and measurement techniques.

The authors of both volumes are long-time contributors to the industry and well-versed in the subjects of their respective books.

To order these books, contact:

Microwave Circuit Design Using Linear and Nonlinear Techniques, 3rd Edition
April 2021, 1200 pages
e-book and print editions
Published by Wiley
ISBN: 978-1-119-74170-1

Microwave and Wireless Synthesizers: Theory and Design, 2nd Edition
April 2021, 816 pages
e-book, print and online editions
Published by Wiley
ISBN: 978-1-119-66611-0

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Qorvo's SHIP Assembly and Test Center: A Trusted Source for Heterogeneous RF Packaging

The pandemic proved the warning the U.S. Department of Defense (DoD) has voiced for decades: supply chains spread around the globe can be unexpectedly interrupted. Add the growing regional tensions and it becomes obvious the U.S. needs its critical technologies and industries within the country. Yet the U.S. share of global semiconductor wafer capacity has declined—to 12.5 percent in 2019—and virtually all high volume semiconductor packaging is done in Asia.

Unlike the silicon used for processing, memory and other digital functions, the U.S. has maintained leadership in the high performance RF semiconductor technologies so critical for defense systems, primarily GaAs and GaN. The gap is in multi-chip module packaging, the ability to integrate digital and RF semiconductor circuits with passive components and interconnects to create a system in a package (SiP)—what Gordon Moore envisioned as the logical extension of the single IC, now called heterogeneous integration.

To address these supply chain and technology challenges, last fall the DoD awarded Qorvo a contract to develop an RF production and prototype center where customers use Qorvo's processes to design a SiP using RF, mixed-signal and digital ICs. The 4-year initiative, worth up to $75 million, is called SHIP (State-of-the-art Heterogeneous Integrated Packaging) for RF or SHIP-RF. The DoD awarded a similar program for advancing digital packaging to Intel.

The focus of SHIP-RF will be adding new process capabilities and manufacturing capacity to Qorvo's Advanced Microwave Module Assembly (AMMA) facility in Richardson, Texas, in conjunction with end-to-end "quantifiable assurance." *Microwave Journal* profiled the first generation of AMMA in a December 2015 Fabs and Labs. The SHIP-RF effort comprises three tasks: 1) onshore some of Qorvo's critical commercial assembly processes used for smartphone front-end modules, 2) develop new capabilities for heterogeneous packaging of silicon and RF die and 3) increase automation and capacity to support SHIP-RF.

To enable customers to use the capabilities of SHIP-RF, Qorvo will also form a design center with simulation, layout and verification tools, including a library of proven design blocks. These process and assembly design kits will reduce development time and risk and provide confidence that a new design will be producible with high yields.

To validate the SHIP-RF capabilities, Qorvo will build three demonstration products, which are being defined by defense partners, Qorvo and the DoD. These demonstrators will help Qorvo define the needed packaging and process technologies and ensure they support both defense and commercial needs once the project completes in 2024. At that time, Qorvo will offer packaging and test services for defense and commercial customers, just as it offers GaAs and GaN foundry services.

Qorvo's GaAs and GaN MMICs are at the heart of many of the latest generation U.S. radar and electronic warfare sensors. Qorvo is also a DoD trusted supplier for the foundry and AMMA packaging processes located in its Richardson facility. This trusted certification will be extended to the SHIP-RF Assembly and Test Center, offering defense primes more options for improving system capabilities while reducing size, weight, power and cost. A trusted, turnkey supplier within the U.S., one able to cost-effectively manufacture highly integrated, high performance RF SiPs and offer quantifiable assurance will reduce a critical risk within the defense industrial base and help the U.S. maintain technology leadership.

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