MIMO Technology Clears the Way for More Wireless Data **p33**

The Importance of Making Your RF Measurements Repeatable **p46**

Emergency Service Comms Need More than Land Mobile Radio **p66**

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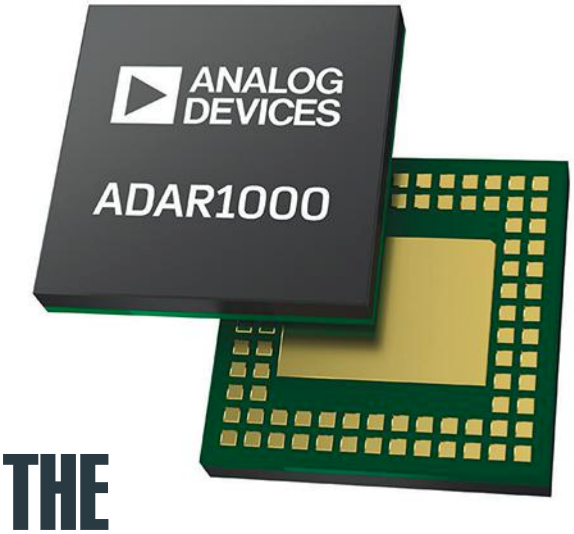

THE ANTENNA-SHRINKING BEAMFORMER

Equipped with four channels, the tiny programmable IC supports TDD and FDD **p56**

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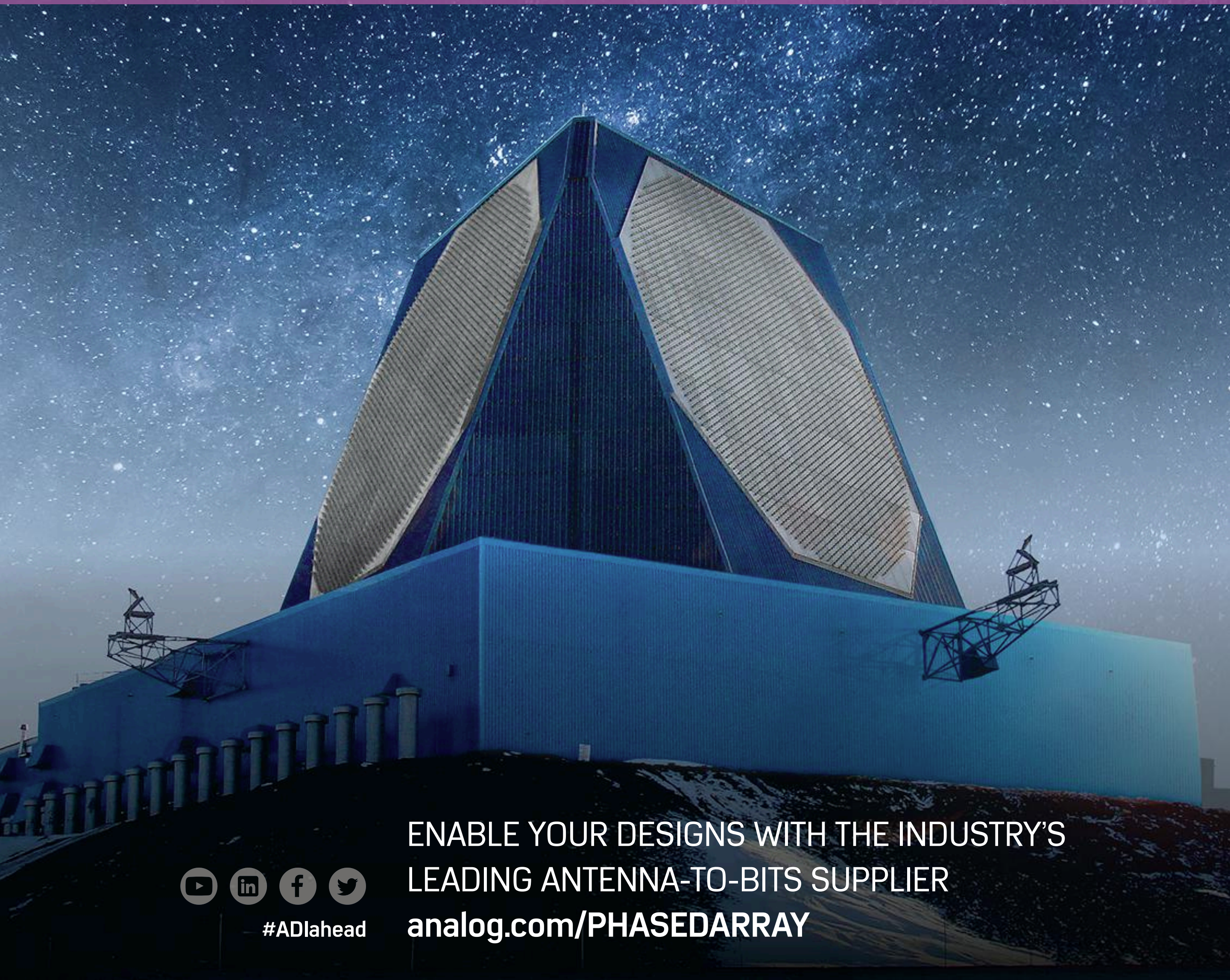
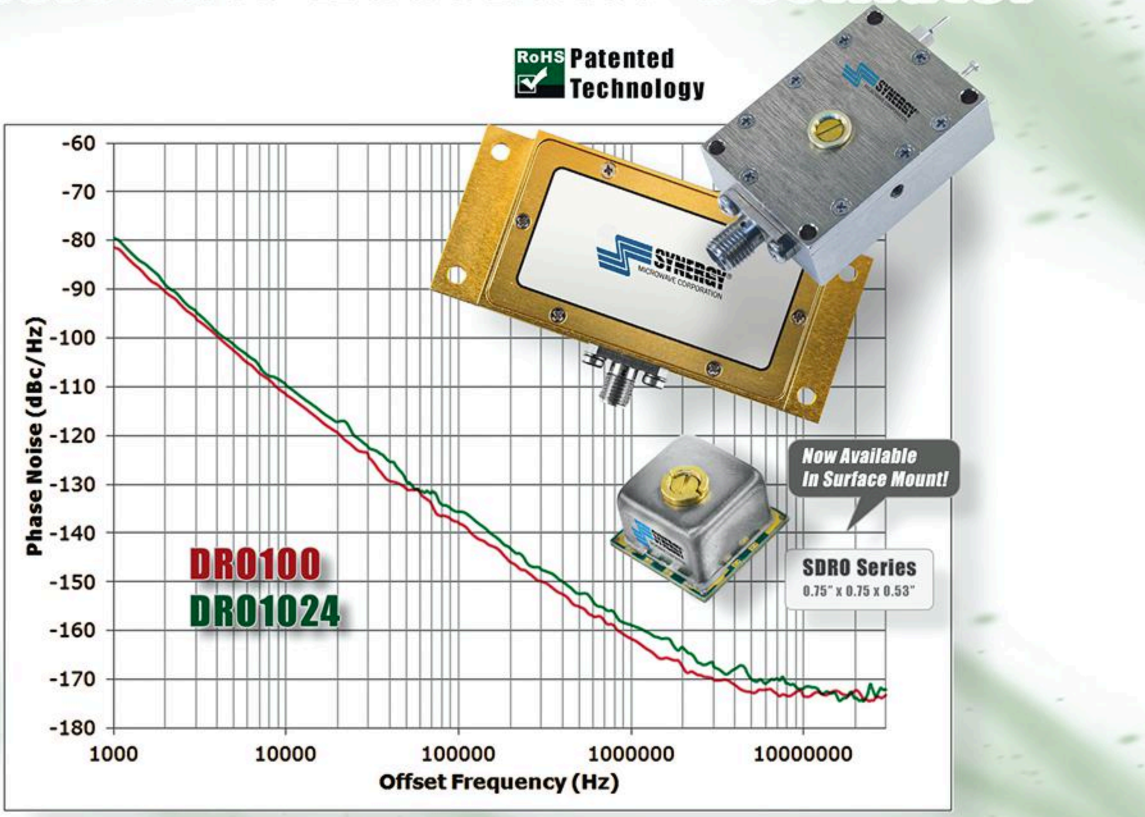


Exceptional
Phase Noise Performance
Dielectric Resonator Oscillator



Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	**-107**
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	**-111**
SDRO1250-8	12.50	1 - 15	+8 @ 25 mA	**-105**
Connectorized Models				
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DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	**-109**

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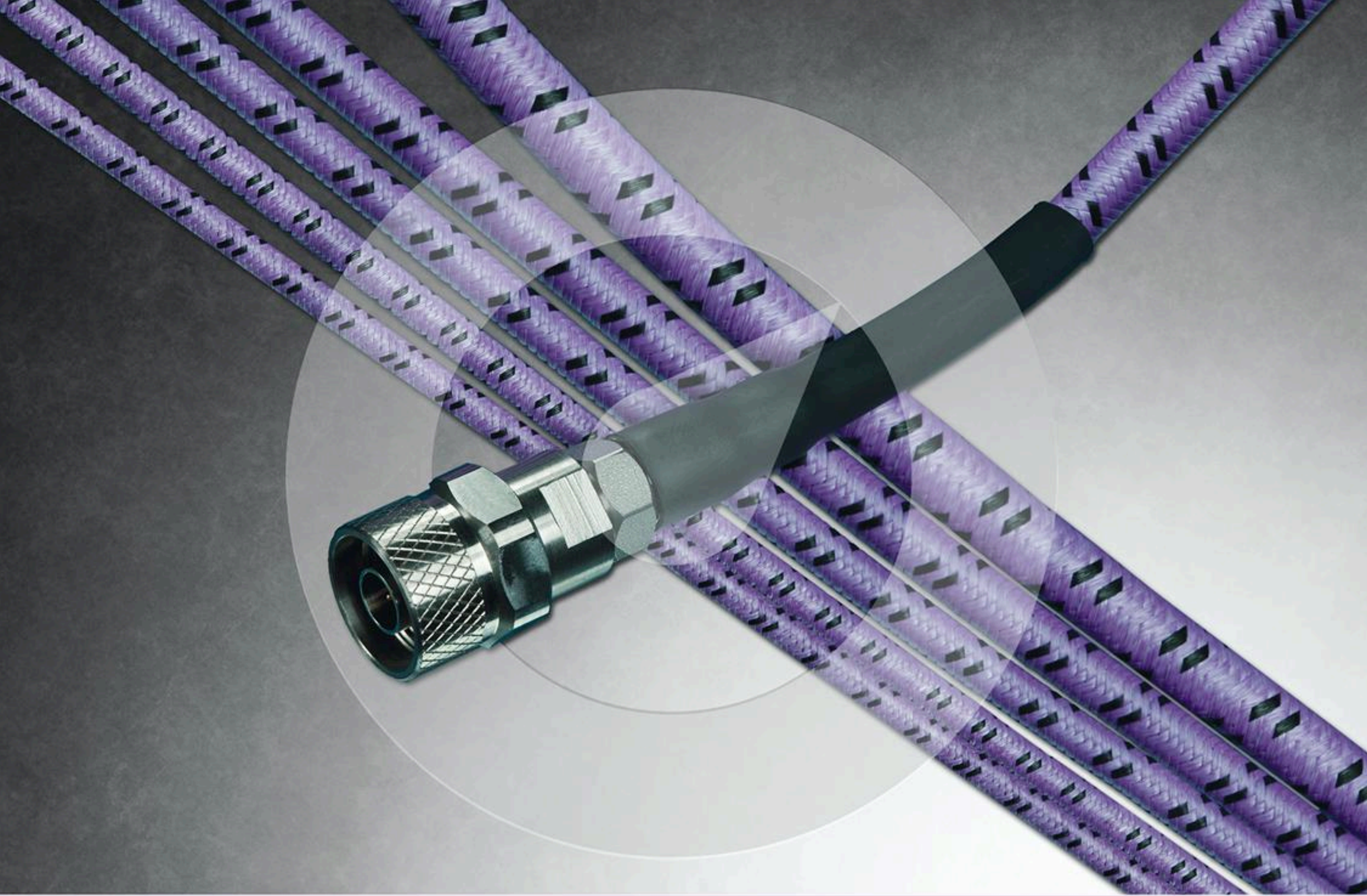

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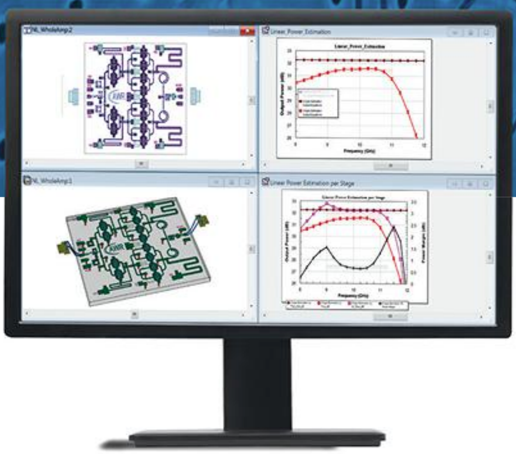

Microwave Office | Power Amplifier Design

NATIONAL INSTRUMENTS™

June 2018 VOLUME 57, ISSUE 6
Microwaves&RF

IN THIS ISSUE

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Gallium nitride is no longer limited to power-amplification applications. Now all corners of the RF/microwave industry are taking advantage of the technology's qualities.

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Advanced antenna-array techniques make it possible to accomplish successful wireless communications links even as bandwidth is shrinking.

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Suppliers of these devices are all in, not only targeting applications like wireless communications and radar systems, but also the emerging RF energy arena.

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46 Develop Repeatable RF Measurement Methods
These practices can lead to consistent results with test equipment, including those routines that help ensure the safety of the equipment as well as those who are at the controls.

52 Pulsed vs. CW Signals: Both Loom on a Designer's Radar
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56 Beamformer IC Shrinks Size of X/Ku-Band Antennas
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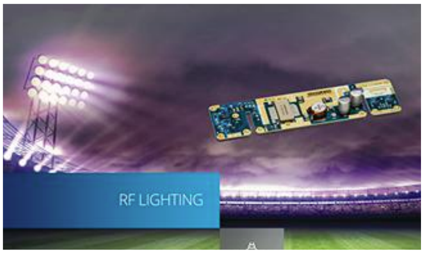
27



38

56

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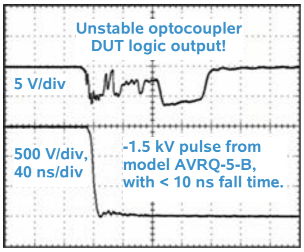
NEWS & COLUMNS

79

Transient Immunity Testers from AVTECH



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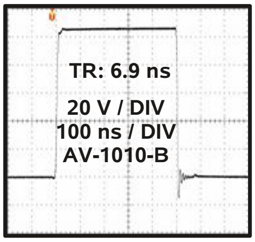

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Model AV-1010-B:	**100 Volts, 1 MHz, 25 ns to 10 ms, 10 ns rise time**
Model AV-1011B1-B:	**100 Volts, 2 ns rise time**
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Variable baseline and burst mode options and output currents to 8 Amps with accessory transformers.

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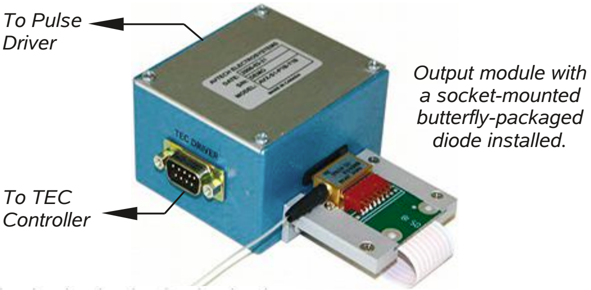
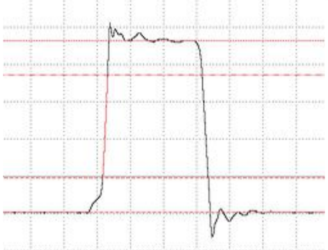
Nanosecond Laser Diode Drivers With Butterfly Diode Sockets





Model AVO-9A-B
40 mA/DIV
1 ns/DIV

Each of the 19 models in the Avtech AVO-9 series of pulsed laser diode drivers includes a replaceable output module with an ultra-high-speed socket suitable for use with sub-nanosecond rise time pulses. Models with maximum currents of 0.1A to 10A are available with pulse widths from 400 ps to 1 us. GPIB, RS-232, and Ethernet control available.

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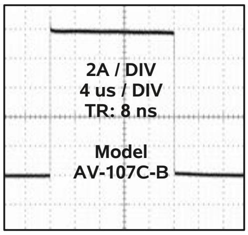

Series	I, V	PW	TR
AV-107	2 - 20 A, 60 V	0.2 - 200 us	10 - 30 ns
AV-106	5 - 100 A, 100 V	0.5 us - 1 ms	50 ns - 1 us
AV-108	12.5 - 200 A, 100V	2 us - 1 ms	5 - 15 us
AV-109	10 - 100 A, 5 V	10 us - 1 s	10 us
AV-156	2 - 30 A, 30 V	1 us -100 ms	0.2 - 50 us

Avtech has a long history of producing one-of-a-kind custom units.

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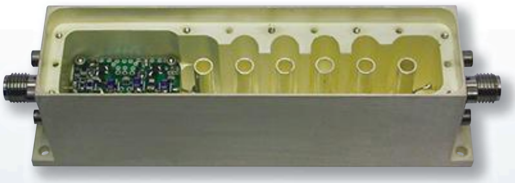
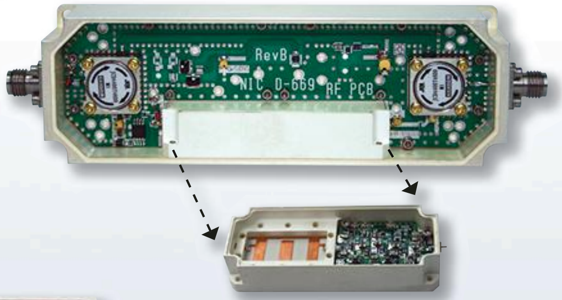
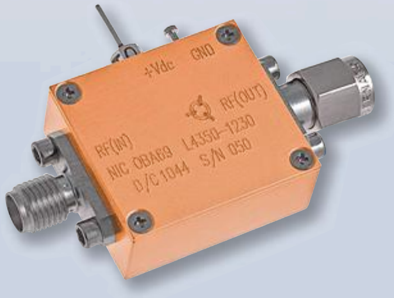
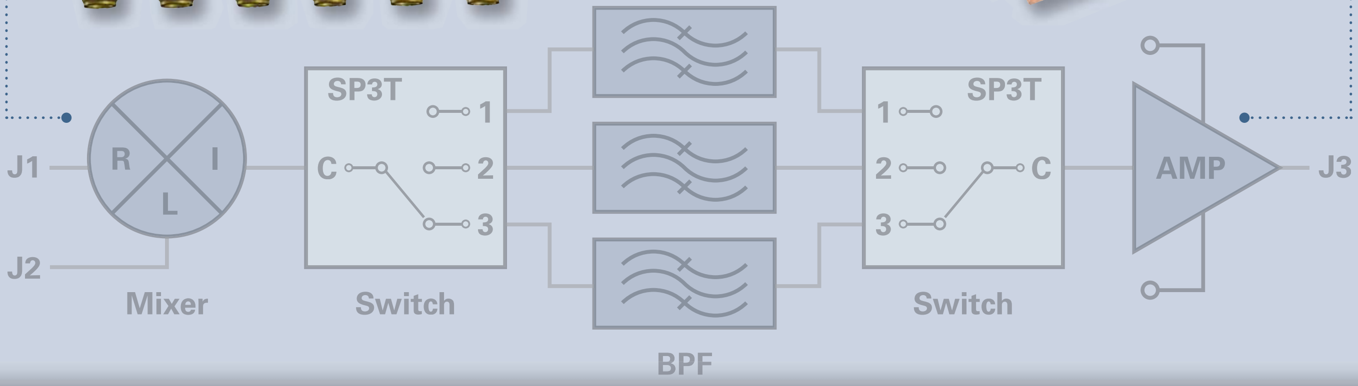



RevB
NIC D-669 RF PCB


-V GND +V
J1
E1 E2 E3
NIC 0BA69
SW110-SP6T SWITCH
www.nickc.com
J2 J3 J4 J5 J6 J7


+Vdc GND
RF(IN)
RF(OUT)
NIC 0BA69 L4350-1230
D/C 1044 S/N 050


J1
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J2
Mixer
SP3T
C
1
2
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BPF
SP3T
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2
3
C
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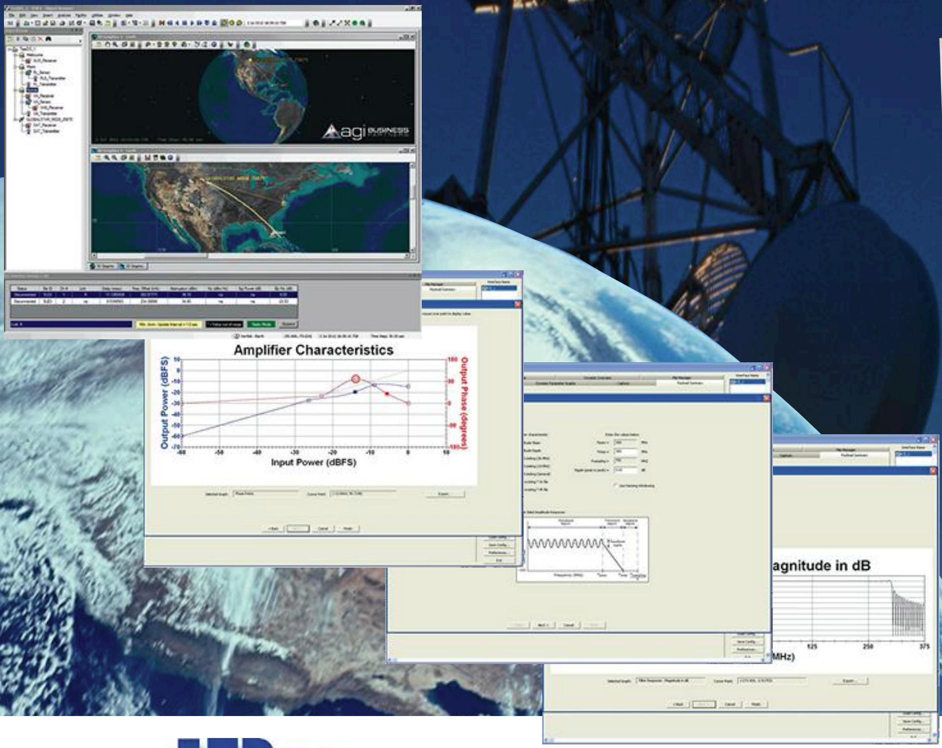

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100 W GaN

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100 W GaN

SKU 1199

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50 W GaN

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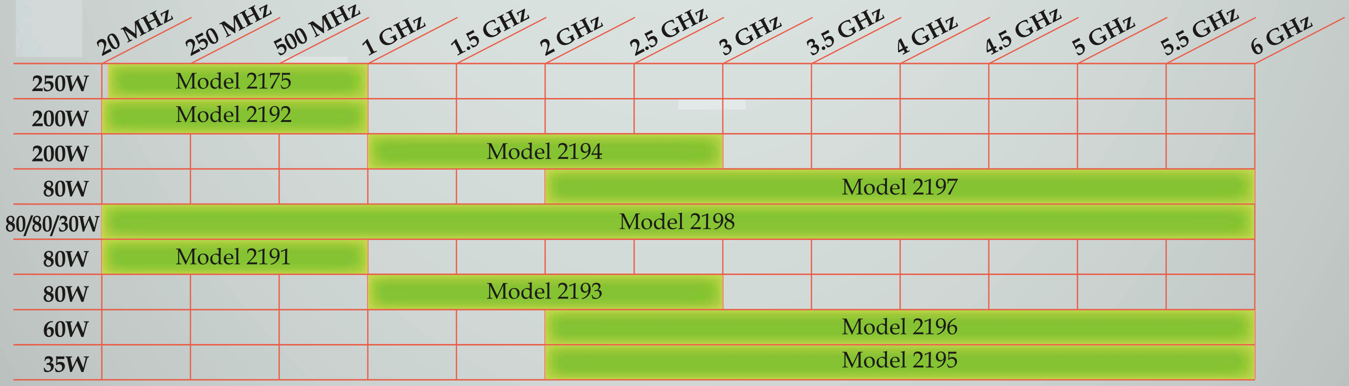

	20 MHz	250 MHz	500 MHz	1 GHz	1.5 GHz	2 GHz	2.5 GHz	3 GHz	3.5 GHz	4 GHz	4.5 GHz	5 GHz	5.5 GHz	6 GHz
250W	Model 2175													
200W	Model 2192													
200W				Model 2194										
80W						Model 2197								
80/80/30W	Model 2198													
80W	Model 2191													
80W				Model 2193										
60W						Model 2196								
35W						Model 2195								

* P_1dB Minimum

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Algorithms to Antenna: Massive-MIMO Hybrid Beamforming

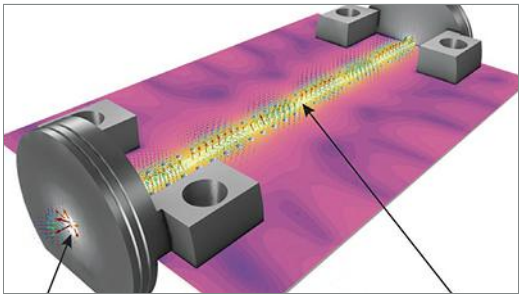
There's a practical side to hybrid beamforming when it comes to massive MIMO. MathWorks' Rick Gentile explores the technological benefits and techniques used for multi-user and single-user systems.

http://www.mwrf.com/systems/algorithms-antenna-massive-mimo-hybrid-beamforming

Millimeter-Wave Automotive Radar Testing Must be Flexible

What are the keys to effective mmWave automotive radar? Jeff Harris from Keysight takes a look at the simulation, development, and manufacturing phases required for the design and test of these systems.

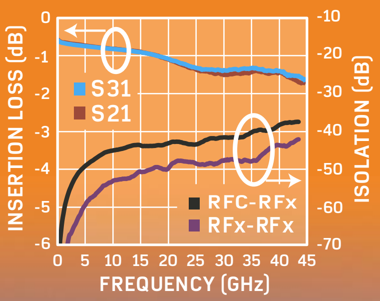
http://www.mwrf.com/test-measurement/millimeter-wave-automotive-radar-testing-must-be-flexible

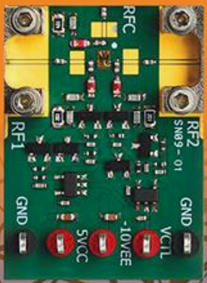


Trans-parentize Connections for 5G and WiGig Testing

The right tools are needed to develop effective connector interfaces for ever-higher-frequency applications. That means the latest in 3D software programs, including models developed by Signal Microwave.

http://www.mwrf.com/components/transparentize-connections-5g-and-wigig-testing


INSERTION LOSS (dB)
0
-1
-2
-3
-4
-5
-6
ISOLATION (dB)
-10
-20
-30
-40
-50
-60
-70
S31
S21
RFC-RFx
RFx-RFx
0 5 10 15 20 25 30 35 40 45
FREQUENCY (GHz)


RFC
RF1
RF2
SN09-01
GND
GND
5VCC
-10VEE
VCTL


RFC
RF1
RF2
ADRF5024 EVAL
VDD
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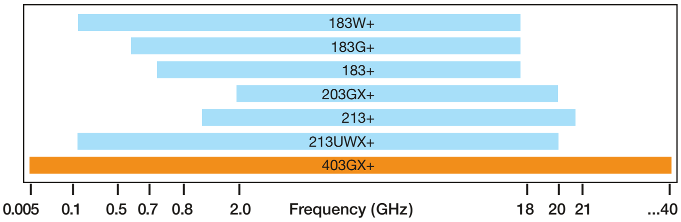
	ZVA-183WX+	0.1-18	28±2	27	35	3.0	1479.95
	ZVA-183GX+	0.5-18	27±2	27	36	3.0	1479.95
	ZVA-183X+	0.7-18	26±1	24	33	3.0	935.00
NEW!	**ZVA-203GX+**	**2.0-20**	**20±1**	**13.5**	**27.5**	**3.6**	**1295.00**
	ZVA-213X+	0.8-21	26±2	24	33	3.0	1039.95
	ZVA-213UWX+	0.1-20	15±1	15	30	3.0	1795.00
NEW!	**ZVA-403GX+**	**0.005-40**	**11±1.5**	**11**	**21**	**4.5**	**1995.00**

* Heat sink must be provided to limit base plate temperature.To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance



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JACK BROWNE | Technical Contributor
jack.browne@informa.com

Mourning a Friend and Industry Leader

Finding a way to Brooklyn, sometimes through New Jersey by way of Staten Island and the Goethals and Verrazano Bridges, brought this editor to one of this industry's more enjoyable in-plant visits. Brooklyn meant only one company when it came to RF/microwave technology, and that company is Mini-Circuits. Whether it was for a frequency mixer, which was one of the component "starting technologies" for this company, or for a demonstration of some of its more recent technologies, such as power amplifiers, a visit to Mini-Circuits meant a first look at some of the best-performance components in the RF/microwave industry.

But it also meant something that was available nowhere else: a visit with Harvey Kaylie, founder and long-time president of Mini-Circuits, and one of the truly creative and innovative people this industry has ever seen. I deeply mourned the passing of Harvey Kaylie during the recent Memorial Day weekend. Mini-Circuits has been built upon a lifetime of Harvey Kaylie's hard work and genius insight into this industry's needs—it will not go away anytime soon. I for one will miss Harvey and what he meant to this magazine and to me, personally, as a friend.

A visit to Mini-Circuits always meant a look at some of the best, most practical active and passive component technology in the industry, as well as for the best prices. Amazingly, not only are the performance levels so high for so many different types of components, from amplifiers to transformers, but some of them are less than a buck!

"How did they do that?" was always one of the questions that came to mind during a visit to Brooklyn, and Harvey Kaylie would always generously and graciously provide the details on the design efforts that went into every new product, and how the company was able to do it for such a small price tag. But perhaps more importantly, Harvey would also explain why they did it—why they pushed for a specific set of performance goals and why they tried, and always did, bring it to market at prices that were a fraction of their competitors' prices.

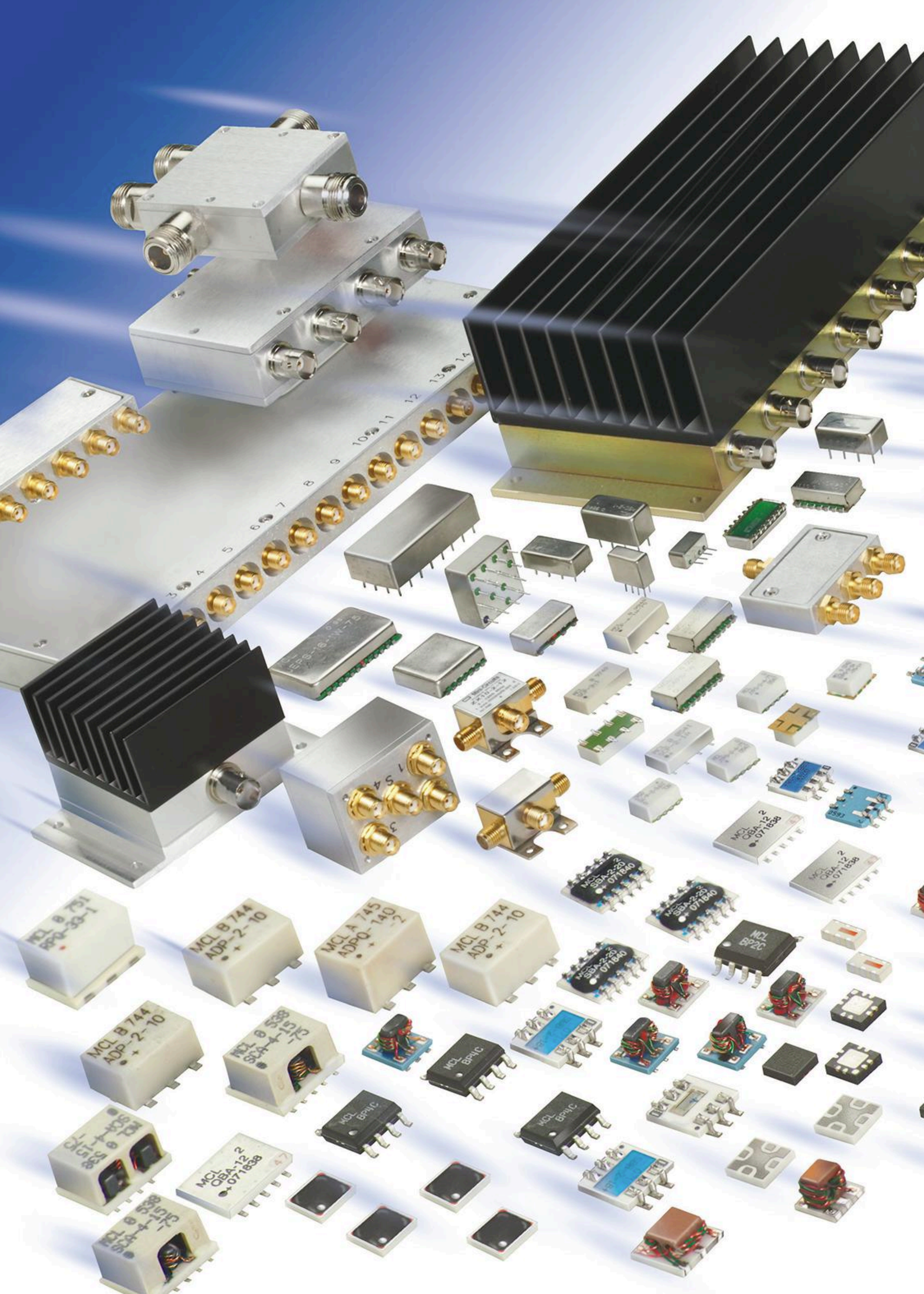
Perhaps what meant the most during those visits was a chance to get to know Harvey, to see a quite-human side of him. Here was a man with the reputation as one of the RF/microwave industry's fiercest competitors and negotiators, and he was all of that. But he was also generous enough with his time to share it well over 30 years ago with a much younger editor, on a magazine with a title of just *MicroWaves*, who had more than a few things to learn about high-frequency electronics.

Coming to Mini-Circuits during those early visits with a background in audio electronics, it was Harvey Kaylie who kindly explained that prefixes such as M and G, and not just k, could go in front of the abbreviation Hz used for signal frequencies. It was Harvey who explained what mixers did, and the importance of other components, such as local oscillators (LOs) and intermediate-frequency (IF) amplifiers and filters in a receiver.

Perhaps just as memorable during those visits to Mini-Circuits was watching Harvey's love for Brooklyn and that local Sheepshead Bay area that houses its factory. And when baseball came up in the conversation, it was watching Harvey and listening to his remembrances not of the Los Angeles Dodgers, but of the Brooklyn Dodgers. Or, more recently, his enthusiasm for the local minor-league ("single A division") baseball team, the Brooklyn Cyclones, and how the company was involved with the local team as a sponsor, and his excitement about the team getting better because of its help.


Harvey Kaylie

That enthusiasm for Mini-Circuits, and for life in general, was such a part of Harvey Kaylie that it made everyone at the company want to get better and want the company to improve. It did get better year after year because of Harvey and what he inspired in everyone, even technical editors such as this writer who marveled at the engineering achievements of Mini-Circuits in so many different areas year after year. It was Harvey who taught me the value of life, of giving it your best shot every day, and to look out for your colleagues because you and they are part of a team like the Brooklyn Dodgers—and by working together, you can both get better. I, and certainly this industry, will miss Harvey Kaylie. But I am hoping that his values and his spirit live on within me and many others who recognize what he meant to this industry! mw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MCL A 745 ADPQ-140 -2
MCL B 744 ADP-2-10
MCL B 744 ADP-2-10
MCL B 538 SCA-4-15 -75
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Microwaves&RF **JUNE 2018**

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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

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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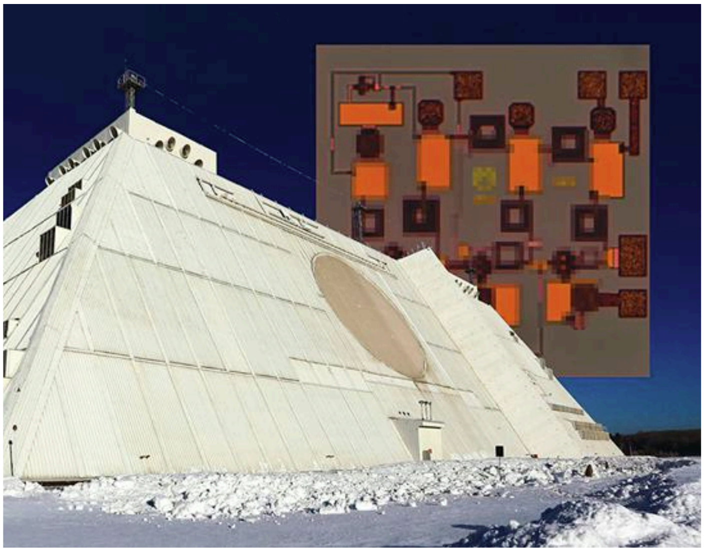
News

Positive Bias GaAs MMICs

Making Effective Phased Arrays

Custom MMIC has learned a lot over the past decade about phased-array antennas at the semiconductor level. Specifically, by switching from a depletion-mode to an enhancement-mode GaAs process for an X-band low-noise amplifier (LNA), for example, Custom MMIC's designers were able to eliminate the negative voltages and voltage sequencers that are a part of a depletion-mode amplifier. Performance benefits were also significant. The enhancement-mode GaAs LNA achieves 1-dB lower noise figure, 8-dB more gain, an eight-fold reduction in DC power, and one-half the unit cost of the earlier depletion-mode LNA design.



The use of an enhancement-mode GaAs PA process provided more power and gain with less power consumption than an existing high-frequency GaAs PA process with a depletion-mode approach. *(Graphic courtesy of Custom MMIC)*

In addition, the company leveraged the enhancement-mode amplifier circuit design into a one-chip pair of matched LNAs for boosting the different polarizations of a return signal in a phased-array system. Custom MMIC also worked with their packaging vendor to develop a low-cost QFN plastic package to match the die size of the dual amplifier. The end result was a "standard" product with minimal size, weight, power, and cost (SWaP-C). By taking this "different" approach to the processing of GaAs MMICs, the firm is creating novel MMIC solutions for phased-array radars as well as compact circuits for emerging EW and commercial 5G wireless communications systems utilizing both GaN and GaAs approaches.

"We're learning more everyday about phased array radar and antenna system design challenges," said Custom MMIC Chief Scientific Officer Charles Trantanella. "Our product design approach has always been to listen and react, and we're very pleased to have been able to not only deliver the high-frequency performance specifications phased array system designers were looking for, but also the added-value of things like positive bias and positive gain slope characteristics that are proving invaluable in their quest to meet SWaP-C objectives."

Although depletion-mode pHEMT processes are typically used for ICs, in which a negative voltage is applied to the active device gate and a sequencing procedure is used to prevent device damage by ensuring that the gate voltage is applied before the drain voltage, the need for negative voltage unnecessarily adds to the cost and complexity of a circuit design. Especially in a phased-array system, with potentially thousands of antenna elements and active devices, the opportunity to employ enhancement-mode MMIC devices represented a chance for a large reduction in SWaP-C.

By using an SBIR grant from the U.S. Army, Custom MMIC developed an enhancement-mode power amplifier (PA) circuit in place of an existing depletion-mode PA. It has more gain (5 dB), more power (1 dB), and better linearity than the existing PA, but with 25% less DC power consumption, providing an excellent argument for the use of an enhancement-mode biasing approach. The solution has since been built upon, as seen in its suite of standardized positive bias MMIC amplifiers. ■

NEW TEST CHAMBER OPENS DOORS to 5G mmWave Devices

NO DOUBT, NEXT-GENERATION 5G millimeter-wave (mmWave) devices will require sophisticated test solutions. With that in mind, Ethertronics *(www.ethertronics.com)* recently announced its 5G mmWave test services and chamber to evaluate 5G antenna performance *(see figure)*. The company showcased its new technology at the 2018 Mobile World Congress.

"Our 5G chamber shows how we can not only design and manufacture, but also test mmWave antennas," said Laurent Desclos, vice president and general manager, Ethertronics/AVX antenna division. "There is lots of discussion about how 5G is right around the corner. For mmWave antenna solutions, the challenges are not only designing them, but also manufacturing them to have the precision and the accuracy that is needed and then being able to verify and test. For us to be a one-stop shop and provide all these services to our customers, we went down the avenue of developing our own anechoic chamber so that we can design and test our antennas for the upcoming 5G market."

In terms of frequencies, Ethertronics' test chamber is intended for testing from 28 to 60 GHz. Desclos noted the feedback received from one of its partners, "We have one partner we've been working with; we've been developing and testing antennas for them. They are now interested in acquiring one of our chambers just because of its capabilities and performance."

The mmWave 5G test chamber is able to characterize a wide range of parameters, including gain, directivity, beamwidth, 3D radiation pattern, and antenna efficiency. The test chamber has also been designed to support forthcoming 5G mmWave regulatory and emissions testing standards.

In addition, sub-1-degree accuracy in both elevation and azimuth angles can be achieved due to fine-stepped in-chamber device-under-test (DUT) rotation. On top of that, users can take advantage of the user-interface (UI) software tools for measurement and post-processing tasks. ■

The mmWave 5G test chamber developed by Ethertronics can handle frequencies from 28 to 60 GHz.

ARMY LOOKS TO BAE for Advanced Missile Warning

BAE SYSTEMS HAS been awarded a contract worth as much as $97.9 million by the U.S. Army for a next-generation missile warning system that will protect pilots and crews from new and emerging threats. The contract covers the development of Quick Reaction Capability (QRC) as part of a Limited Interim Missile Warning System (LIMW) that will build on BAE's 2-Color Advanced Warning System (2C-AWS) technology.

The next-generation missile warning capability is meant to provide U.S. Army aircraft with missile warning and hostile fire protection for improved survivability and chance of success in spite of advancing threats. "Army aviators are facing an evolving threat environment that requires advanced detection capabilities," said Paul Markwardt, VP and GM of Survivability, Targeting, and Sensing Solutions at BAE Systems. "Our system will provide the Army fleet with unmatched protection capability that helps warfighters execute their missions."

BAE Systems has developed the 2C-AWS system by working with Leonardo DRS, which will provide the two-color infrared (IR) sensor to the sensitive detection that enables the system's unparalleled effectiveness in identifying emerging threats. The 2C-AWS system is designed to be upgradeable to keep pace with future threats and customer requirements; it also works well with existing Army aircraft survivability equipment, including aircraft interfaces and electronic countermeasures (ECM) systems. ■

The 2C-AWS threat warning system, with IR detection capability developed by Leonardo DRS, is the basis for a new U.S. Army missile warning system contract. *(Image courtesy of BAE Systems)*

The MPU5 radio and smaller version, the Embedded Module, have both received FIPS 140-2 security validation from NIST. *(Courtesy of Persistent Systems)*

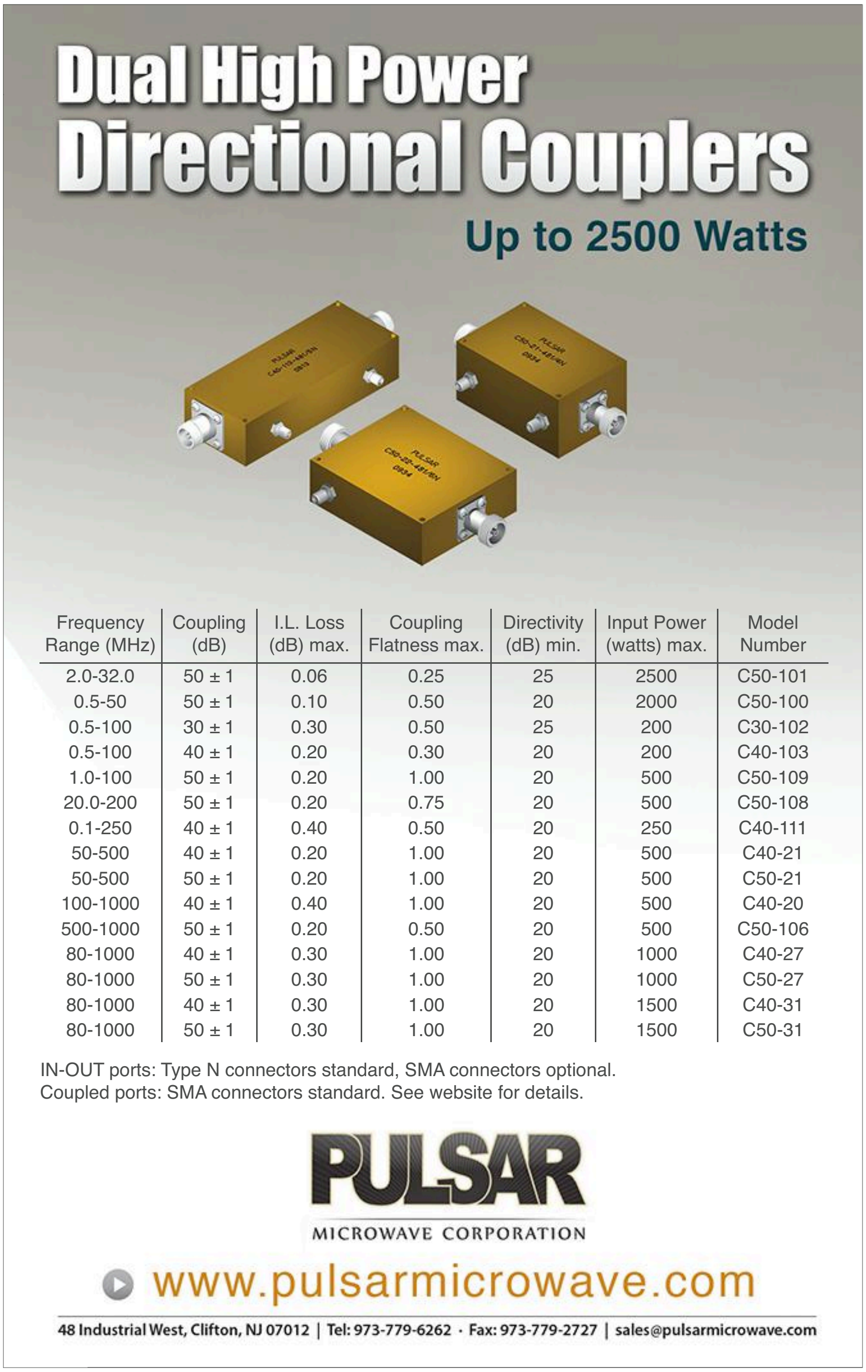
NETWORKING RADIO EARNS NIST Security Validation

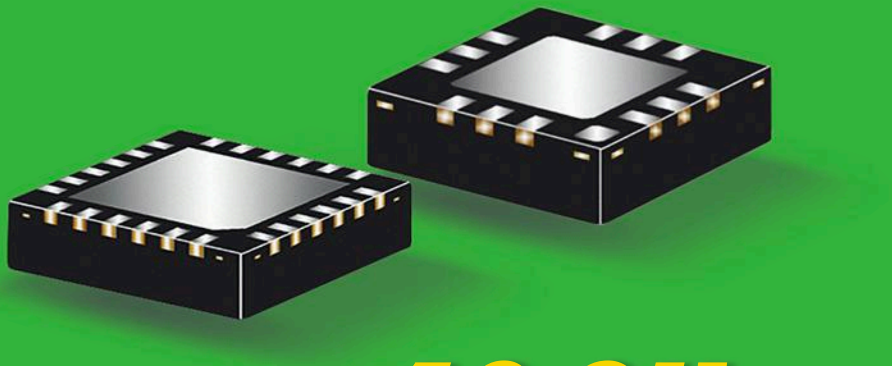
PERSISTENT SYSTEMS HAS received a high-level security validation from the National Institute of Standards and Technology (NIST) for its MPU5 networking radio and Embedded Module products. Specifically, it is Federal Information Processing Standards (FIPS) 140-2 security validation, and it allows the MPU5 and other communications products from Persistent Systems to be used by U.S. government agencies requiring a high level of security in their communications.

As an example, with this validation, government users can use the MPU5 radio *(see figure)* to connect to the Federal Enterprise Network with the assurance that communications are immune to eavesdroppers. The MPU5 radio system operates with the Wave Relay mobile ad-hoc networking (MANET) routing protocol, allowing users to transmit and relay voice, video, text, and data in a peer-to-peer fashion. The Embedded Module delivers secure communications capabilities similar to those of the MPU5 radio, but in a smaller configuration for use as sensors and for integration into unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs).

“We offer a self-forming, self-healing, scalable MANET that is robust and dynamic and can operate in austere and challenging environments that would normally disrupt other communication systems,” said Eric Stern, director of engineering at Persistent Systems. “This makes the MPU5 and Embedded Module very attractive for government users.”

The MPU5 radio has been used by a number of U.S. government groups, including the Departments of Justice and Homeland Security, but many agencies require a FIPS 140-2 validation. To receive that validation, the MPU5 and the Embedded Module were put through the Cryptographic Module Validation Program (CMVP). The CMVP is a joint initiative between the National Institute of Standards and Technology in the United States and the Communications Security Establishment (CSE) in Canada. ■





The xFold Cinema drone is well-equipped for use with cinema cameras for video streaming. *(Courtesy of PrecisionHawk)*

PRECISIONHAWK TEAMS with North Carolina on BVLOS Drones

INNOVATIVE DRONE DEVELOPER PrecisionHawk *(www.precisionhawk.com)* has been named a partner to the North Carolina Department of Transportation's (NCDOT) Division of Aviation in its project to accelerate the testing of currently restricted unmanned aerial systems (UAS) operations. This includes beyond visual line of sight (BVLOS) flights, which is a technology that may possible be applied for the use of UAS drones for package delivery and other commercial applications. Drones from PrecisionHawk (Raleigh, N.C.) are used in a number of industries, including agriculture, energy, insurance, government, and construction *(see figure)*.

"We commend the White House for recognizing the significant business potential that drones bring to agriculture, commerce, emergency management, human transportation, and other sectors," said Diana Cooper, senior vice president of policy and strategy at PrecisionHawk. "These partnerships present a unique opportunity to advance UAS technologies in local industries, and we thank the Administration for its investment in American aviation and for sharing our vision of a regulatory roadmap that encourages innovation while ensuring airspace safety."

PrecisionHawk will join the NCDOT as part of the Unmanned Aircraft Systems Integration Pilot Program (UAS IPP). For the next three years, the program will work to bring unmanned medical supply delivery and develop unmanned traffic management systems to track drones. PrecisionHawk recently reported to the FAA on BVLOS studies in its Pathfinder Report. The report offers a comprehensive safety example and various possible standards for BVLOS drone flights.

"Drones have proven to be a transformative force for business intelligence and operations, and today's decision by the FAA amplifies this opportunity by bringing together the public and private sectors to embrace innovation while balancing the safety and security of our nation's airspace," said Michael Chasen, CEO of PrecisionHawk. "Our work with these exemplary agencies will open up the skies for drone flight over long distances—an imperative for commercial drone applications—and unlock the next generation of American aerial intelligence and innovation." ■

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ANTENNAS MAKE CONNECTIONS While They Harvest Energy

Antenna arrays can provide controlled, focused signals for communications systems over wide ranges of frequencies. However, researchers at Notre Dame University-Louaize (Zouk Mosbeh, Lenanon), the American University of Beirut (Beirut, Lebanon), and the University of New Mexico (Albuquerque, N.M.) report that such arrays can also provide the dual functionality of energy harvesting when they are integrated vertically on top of a solar panel.

The dual-function design is actually two antenna arrays operating at 1.8 to 2.4 GHz. The elements of the two antenna arrays consist of copper-based and transparent inverted-F antennas. The transparent array, which has the same dimensions as the copper array, is used to verify that the integration of the copper-based antenna array does not degrade the conversion efficiency of the solar panel.

The antenna arrays cover a bandwidth with a large number of commercial wireless signals for energy harvesting. The integrated solar panel enhances the radiation characteristics of the arrays by acting as an extended ground plane.

As part of the design, an RF rectifying circuit rectifies the captured RF signals from the antenna arrays into dc power that can be combined with the output power from the solar panels and supplement the solar energy during times of low sunlight. As the ground plane increases, the antenna gain increases until achieving maximum gain of 4.6 dB for a width of 5 cm. When the width is greater than 5 cm, the gain no longer increases, but the antenna back lobe is noticeably reduced.

The RF rectifying circuit achieves high efficiency at measured frequencies of 1.5, 2.0, and 2.4 GHz; efficiency decreases with increasing frequency. The efficiency of the copper-based array is about 15% higher than that of the transparent array, likely due to the lower conductivity of the polymer used inside of the transparent material compared to the copper-based antenna elements.

During measurements of harvested voltage for the copper-based array versus the transparent array, very little difference was found between the two, even when measured every 15 minutes during a sunny day. In addition, it was found that placement of the copper antenna elements in an orthogonal fashion at both edges of the solar panel had minimal effect on the solar-energy efficiency.

The experiments showed the practical benefits of creating an additional energy source from a structure that would also be required for wireless communications. The high efficiency of the rectifying circuit is an important contribution to the overall achievement. Furthermore, by using an impedance-matching network, the same rectifying circuit can be employed for both the copper-based and the transparent antenna arrays.

See "A Communicating Antenna Array with a Dual-Energy Harvesting Functionality," *IEEE Antennas & Propagation Magazine*, Vol. 60, No. 2, April 2018, p. 132.

AIMING FOR REPEATABLE THz S-Parameter Measurements

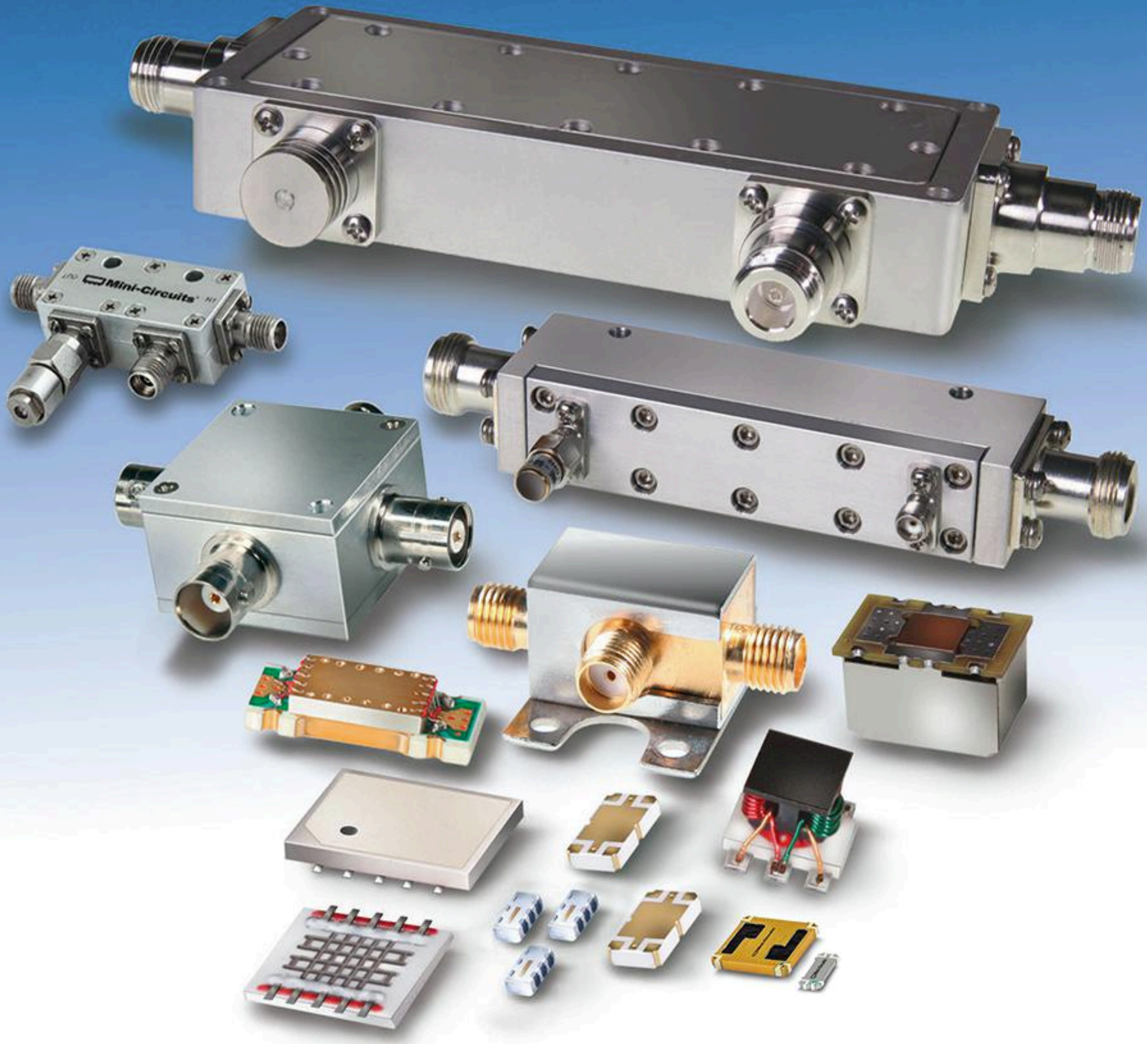
WIRELESS-COMMUNICATIONS APPLICATIONS are steadily moving higher in frequency, with fifth-generation (5G) wireless networks promising the regular use of millimeter-wave frequencies. For truly short-range communications links and other applications, such as medical diagnostics, signal frequencies in the terahertz (THz) range are not within reason, although such applications will require the support of commercial measurement solutions, such as vector network analyzers (VNAs) for S-parameter measurements.

The accuracy of such high-frequency measurements will depend on the quality of calibration standards and how calibrations are performed, since even improperly torqued waveguide flanges can result in measurement errors at those high frequencies. When VNAs are used with frequency extension modules to reach THz frequencies, any flexures in cables connecting a local-oscillator (LO) source to the frequency extension module can also destroy the repeatability of THz measurements.

Masahiro Horibe of the National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan) has seen the rising interest in higher-frequency signals, noting that by 2020, high-speed data transfers will be taking place at 340 GHz at the Tokyo Summer Olympic Games. He experimented with different waveguide flange interfaces, using precision claws with minimum tolerance to achieve rotational angular alignment necessary for minimal measurement errors at experimental frequencies as high as 1.1 THz. To explore the repeatability of different mounting arrangements, S11 measurements were made with 10 different connection and disconnection cycles, with magnitude and phase measurements made across a frequency range of 750 to 1050 GHz.

Horibe's study investigated the effects of different waveguide flange designs on VNA measurement uncertainty at THz frequencies. The research revealed that IEC 60154-2 type-F waveguide flanges provide precise connection and good connection repeatability compared to other flange designs. Even such factors as the surface roughness of interconnections must be inspected and monitored to maintain good repeatability at VNA measurement frequencies as high as 1.1 THz.

See "Measurement Uncertainty in Terahertz VNAs," *IEEE Microwave Magazine*, Vol. 19, No. 2, March/April 2018, p. 24.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Catch GaN if You Can

Gallium nitride is no longer limited to power-amplification applications. Now all corners of the RF/microwave industry are taking advantage of the technology's qualities.

Gallium-nitride (GaN) technology's impact on the RF/microwave industry cannot be overstated, as it's enabling applications from space and military radar to cellular communications. And while GaN is generally associated with power amplifiers (PAs), it has other use cases as well. GaN's journey since its introduction has been fascinating, and it's likely to be even more so as we enter the era of 5G.

GaN'S ROLE IN THE RADAR AND SPACE REALMS

Two variants of GaN technology are GaN-on-silicon (GaN-on-Si) and GaN-on-silicon-carbide (GaN-on-SiC). GaN-on-SiC contributes heavily to space and military radar applications, according to Damian McCann, director of engineering, RF/microwave discrete products group at Microsemi *(www.microsemi.com)*. "Today, RF engineers are finding new applications and solutions to take advantage of the ever-enhanced power and efficiency performance levels achieved by GaN-on-SiC devices, notably in space and military radar applications.

"With GaN being a wide-bandgap semiconductor material that provides high levels of hardness, mechanical stability, heat capacity, very low sensitivity to ionizing radiation, and thermal conductivity, clever designs result in even greater size, weight, and power (SWaP) advantages. We have also seen GaN-on-SiC technology outstrip once competitive technologies—even at lower frequencies."

System designers stand to benefit from GaN-on-SiC technology. McCann explains, "Thermally enabled and highly integrated laminate technology, when coupled with GaN-on-SiC, is allowing the system designer to now look to even greater levels of integration, notably extending primary radars to cover multiple bands in the same physical area and adding increased secondary radar functionality. Applications within the space market have also recently seen an increase in GaN-on-SiC feasibility work, notably in applications in which the efficiency of GaN is complemented by the ability to operate at ever-higher frequencies."

1. The film-deposition control provided by Veeco's Propel GaN MOCVD system helps improve buffer quality.

He adds, "The power density of millimeter-wave (mmWave) GaN brings a new set of design techniques looking for even greater levels of back-off. Solutions must extend beyond power and linearity in power back-off, but also to when power control is needed or when operating into variable levels of VSWR."

McCann also notes that GaN-on-SiC technology makes it possible to replace older klystron technology. He says, "The general application of active electronically scanned arrays (AESAs) and phased-array elements in military and commercial space applications is also looking to take further advantage of GaN-on-SiC monolithic-microwave-integrated-circuit (MMIC) integration to reach new levels of power—even replacing aging klystron technology in some cases.

GaN technology isn’t limited to space and radar applications. It’s driving innovation in the arena of cellular communications. And what about the 5G networks of the future? What role will GaN have there?

“The most notable absence from the market, though, is the number of qualified 0.15-µm GaN-on-SiC foundries. This is something the whole industry is only too readily aware of as roadmap developments take shape addressing these exciting new applications.”

GaN AND 5G COMMUNICATIONS

GaN technology isn’t limited to space and radar applications, though. It’s driving innovation in the arena of cellular communications. And what about the 5G networks of the future? What role will GaN have there?

Somit Joshi is senior director of metal-organic chemical vapor deposition (MOCVD) product marketing at Veeco Instruments *(www.veeco.com)*. He says, “The ambitious scope of 5G promises to transform cellular communications, creating new opportunities for carriers and service providers. 5G is currently being planned with a vision of greater than 10 Gbps transmission speeds for mobile broadband (phones/tablets/laptops) and ultra-fast low latency for Internet of Things (IoT) applications.”

Joshi adds, “Today, GaN is slowly replacing silicon (Si) in specific applications (i.e., RF amplifier front ends of 4G/LTE base stations). Next-generation 5G deployment will involve additional use of GaN technology. Pre-5G, there was increasing use of GaN-on-SiC in the macro cell. 5G will bring in GaN-on-Si to rival GaN-on-SiC designs with inroads into the small cell space (micro/metro cells) before potentially overlapping into femtocells/home routers and even into handsets.”

GaN technology will be critical in terms of the higher frequencies expected to be used by 5G networks, according to Joshi. He explains, “5G will deploy gradually over time and in multiple frequencies. Two primary frequency ranges will be sub-6-GHz for wide-area coverage and frequencies greater than 20 GHz (mmWave bands) for high-density areas like stadiums, airports, etc. For 5G technology to meet stringent expectations (faster data rates, low latency, massive broadband), new GaN innovations will be needed to enable higher targeted frequencies (i.e., 28- and 39-GHz bands).”

Furthermore, GaN technology will be well suited for 5G handsets. Joshi adds, “From a technology standpoint, 5G suffers from attenuation issues, requiring multiple antennas to improve signal quality using spatial multiplexing techniques. Each antenna requires dedicated RF front-end chipsets. Compared to gallium arsenide (GaAs) and Si, GaN has less antenna requirements for the same power levels. The resultant form factor advantages make GaN ideally suited for 5G handsets.

“Moreover, higher power efficiency and lower transmission losses result in significant power savings. Integrating multiple GaN transistors monolithically opens up new functionality and capability. GaN has some limitations when operating at lower voltages (less than 5 V)—issues being worked on by process experts, integrated device manufacturers (IDMs), and research institutes.”

Lastly, Joshi explains what Veeco brings to the table. “We are at the forefront of GaN-on-Si development in collaboration with leading device companies and research institutes. Leveraging the single-wafer TurboDisc technology that provides dopant control and compositional uniformity while reducing the cost-per-wafer, we are helping customers solve tough challenges of RF loss, transistor performance, harmonic distortion, and device reliability. This is achieved by leveraging the Propel MOCVD system’s superior film-deposition control for buffer quality improvement and its capability to incorporate hard-to-deposit materials like InAlN, etc. *(Fig. 1)*.

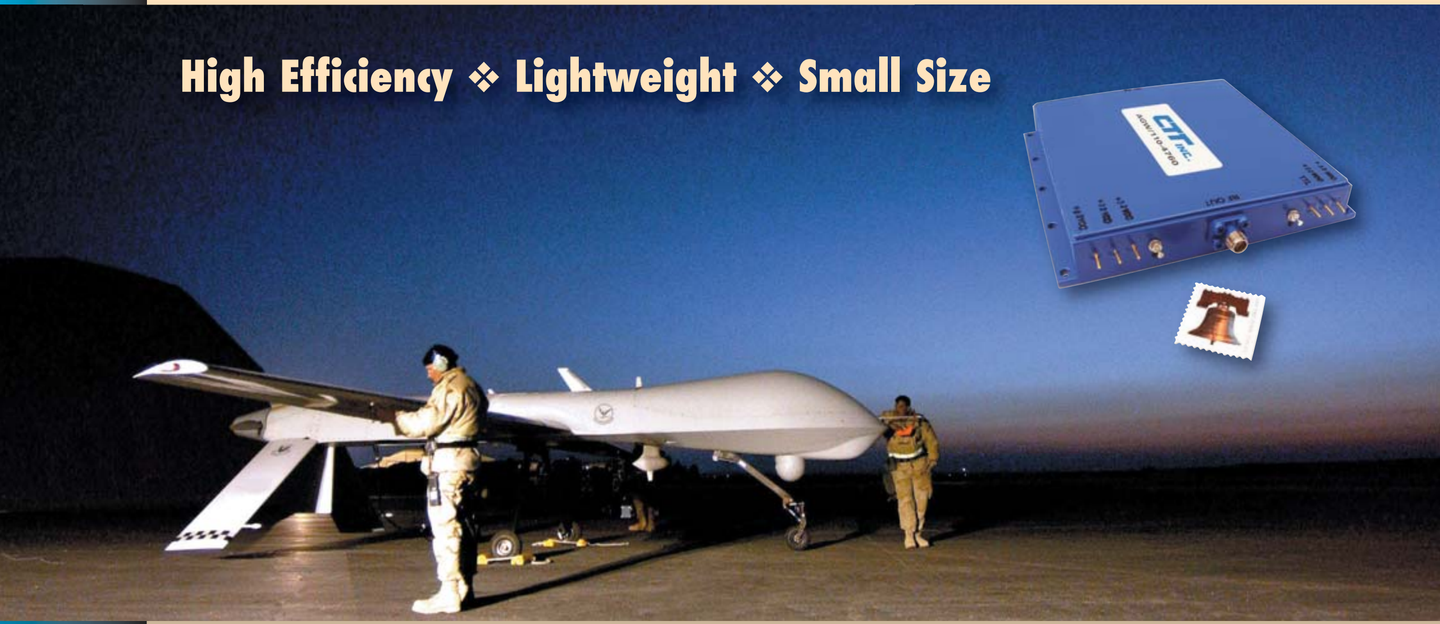
“The market for GaN-on-Si and GaN-on-SiC is small and challenges persist as tools and processes still need to mature to increase yield and throughput,” continues Joshi. “However, we see significant potential as use cases continue to proliferate with process and technology improvements for 5G applications.”

BEYOND POWER AMPLIFIERS: GaN-BASED LOW-NOISE AMPLIFIERS

In the RF/microwave industry, GaN technology is typically associated with power amplifiers. But one company, Custom MMIC *(www.custommmic.com)*, is demonstrating that GaN does indeed have other use cases by developing low-noise amplifiers (LNAs) based on GaN technology.

“We are often asked why we developed a line of GaN high-electron-mobility-transistor (HEMT) LNAs at microwave frequencies when GaAs pseudomorphic-high-electron-mobility-transistor (pHEMT) LNAs are much more common,” says Chris Gregoire, senior applications engineer at Custom MMIC. “The reason is simple: GaN offers more than just low noise.

“For one, GaN has much higher input power survivability, which can greatly reduce or eliminate the front-end limiter often associated with GaAs pHEMT LNAs. By eliminating the limiter, GaN can also reclaim the loss of such a circuit, thereby lowering the noise figure even further. Second, GaN LNAs have much higher output third-order intercept point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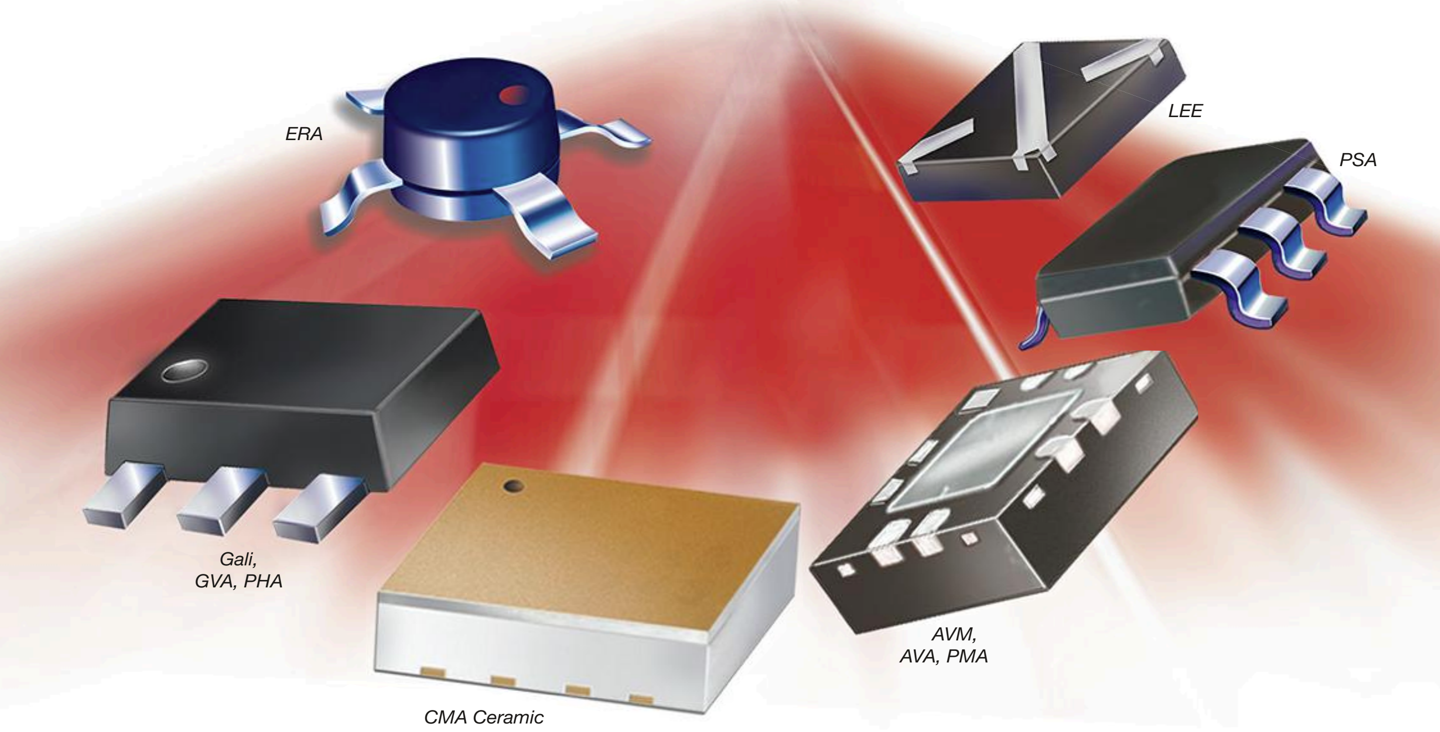

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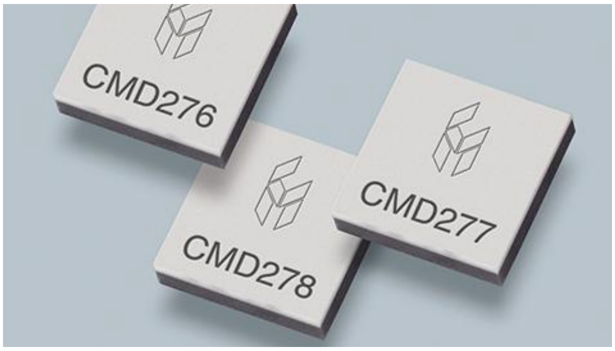


2. These three low-noise amplifiers were developed using GaN technology.

(IP3) than their GaAs pHEMT counterparts, which improves receiver linearity and allows for greater sensitivity."

Gregoire continues, "One main reason GaN offers such advantages is its inherently high breakdown voltage as compared to GaAs processes. When an LNA is overdriven, the gate-drain breakdown can induce failure. GaAs pHEMT devices have typical breakdown voltages of 5 to 15 V, which severely limits the maximum RF input power these LNAs can withstand. GaN processes, on the other hand, feature voltage breakdowns in the 50- to 100-V range, thereby allowing for much higher input power levels without damage. Additionally, the higher breakdown voltage allows GaN devices to be biased at higher operating voltages, which directly translates into higher linearity.

"We have learned to maximize the advantages of GaN and create state-of-the-art LNAs that have the lowest possible noise figure along with high linearity and high survivability. As a result, GaN is the preferred LNA technology for any high-performance receiver system, especially when immunity to jamming signals is a vital requirement."

Custom MMIC recently announced three new GaN-based LNAs *(Fig. 2)*. "We invite you to examine our three newest GaN LNAs," says Gregoire. "The CMD276C4, which operates from 2.6 to 4 GHz, features 14.5 dB of gain, a noise figure (NF) of 1.2 dB, and an output IP3 of +32 dBm. The CMD277C4, which operates from 5 to 7 GHz, features 20 dB of gain, a NF of 1.2 dB, and an output IP3 of +33.5 dBm. The CMD278C4, which operates from 8 to 12 GHz, features 15 dB of gain, a NF of 1.8 dB, and an output IP3 of +33 dBm. Additionally, all three components can withstand a maximum continuous input signal of up to 5 W—with or without bias voltage applied."

Simply put, GaN technology has become a major force in the RF/microwave industry. In the future, its role is likely to expand further due to 5G communications and more. And while GaN and PAs go hand in hand, one shouldn't overlook the fact that LNAs are also being developed with the technology. To sum it all up, it might be time to catch onto GaN if you haven't already, because its future looks bright. mw

JACK BROWNE | Technical Contributor

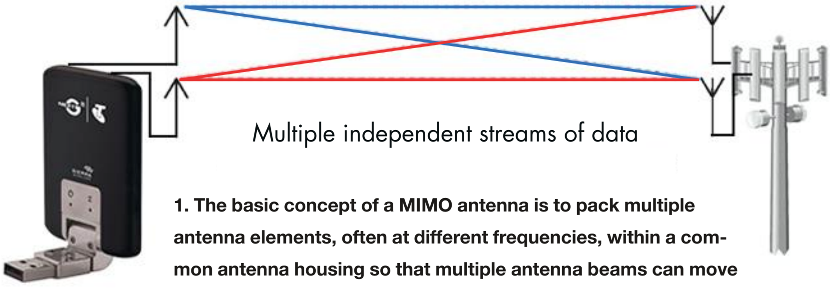
MIMO Clears Channels for More Wireless Data

Advanced antenna-array techniques make it possible to accomplish successful wireless communications links even as bandwidth is shrinking.

Antenna arrays may not always receive the attention they deserve, but in many wireless-communications applications, they are the "silent enablers" that make the connection from one point to another. Each generation of wireless communications seems to be attempting a new, higher data rate along with its wireless voice and video capabilities, exacerbating the need for novel technologies such as multiple-input, multiple-output (MIMO) antenna techniques. In many ways, MIMO is a variation on the phased-array techniques that have long been successful in military electronic systems, including radars.

In its simplest form, MIMO technology amounts to cramming more than one compatible antenna into a package that's meant for just a single antenna, increasing the information per bandwidth that can be sent across a wireless link. MIMO techniques make use of the natural multipath tendencies of radio waves when propagating from a transmitter to a receiver, so that the multipath effects are used to advantage, to strengthen signals, gain propagation distance, and increase communications system data rates.

As MIMO antenna designs are refined and their beam patterns optimized, more wireless users can benefit from a given amount of bandwidth. This is especially important as systems such as fifth-generation (5G) wireless reach to millimeter-wave frequencies in search of available bandwidth.



1. The basic concept of a MIMO antenna is to pack multiple antenna elements, often at different frequencies, within a common antenna housing so that multiple antenna beams can move back and forth. *(Courtesy of TELCO Antennas)*

One key difference exists between traditional phased-array antenna systems typically associated with military applications and MIMO antennas: the phase shifts used to create the antenna patterns in phased arrays are performed by analog components, such as phase shifters, while beamforming with MIMO antennas is most often achieved with digital-signal-processing (DSP) techniques. Such use of DSP methods and the Eigen beamforming techniques of MIMO antennas can compensate for non-line-of-sight (NLOS) beam shifts and overcome the effects of multiple reflections in reconstructing an antenna's beam pattern with a given number of antenna elements.

WHY GO MIMO?

MIMO antennas were developed due to the large number of users expected in IEEE 802.11n wireless local-area networks (WLANs). Using multiple antennas in a single housing, or multiple-element MIMO antennas in a configuration that appears to be a single antenna, increases the data throughput and communications range of a WLAN compared to a network with a single antenna and the same radio transmit power. The use of a greater number of antenna elements or MIMO antennas also helps to minimize the effects of signal fading due to reflections and absorbed signals, compared to systems operating with a single antenna. The wireless-communications capacity of a WLAN can be increased by transmitting multiple data streams at the same time over MIMO antennas *(Fig. 1)*.

The basic idea of using spatial multiplexing with multiple transmitters and receivers and MIMO antennas involves the transmission of different streams of information with different antennas or antenna elements. A receiver with at least as many antennas or antenna elements as the transmitter can decipher that many streams of received data from the transmitter. This, in turn, increases the data flow through a system with a limited amount of bandwidth compared to a system with a single antenna. A 2 × 2 MIMO antenna can support two transmitters and two receivers, while a 4 × 4

MIMO system is able to transfer twice as much data, using four independent data streams, or four transmitters and four receivers.

Constant expansion of cellular communications and the advance of each cellular generation has also encouraged the use of MIMO antennas. Traditionally, cellular communications systems involved a single antenna on a telephone tower and base station and smaller antennas used within each user's handset. As more internet services became handled by cellular, portable telephones, more capacity was needed by 3G and then 4G Long Term Evolution (LTE) cellular systems.

Increased capacity is a function of various parameters, including bandwidth, which is limited, but it's achievable with more antennas or antenna elements, as in MIMO antennas. In appearance, whether at a base station or in a portable handset, a MIMO antenna appears much like a conventional antenna, whether it's directional or omnidirectional in nature. However, it will provide multiple input/output ports in the form of connectors for its numerous internal antenna elements.

Base-station MIMO antennas are commonly used in 4G LTE wireless networks, IEEE 802.11n WLANs, and other wireless devices, with two or more antenna elements per housing. For a directional antenna configuration, such as a Yagi antenna in a 4G LTE system, at least two separate antennas must be within the housing to benefit from MIMO operation. In this case, the first antenna in an LTE installation is rotated to a 45-deg. angle while the second antenna is set at a 135-deg. angle, to gain the most benefits of the two separate antennas' directional characteristics. Also, remember that LTE uses what's known as polarization diversity to distinguish between the data streams passing between the two separate antenna elements.

The multiple antennas or antenna elements in a MIMO system enable several spatial degrees of freedom which are not possible in traditional single-input, single-output (SISO) antenna systems. Spatial degrees of freedom with the multiple antenna elements can be used for multiplexing or receiver diversity techniques, or a combination of the two, to help increase communications system capacity when the channel bandwidth is limited.

SELECTING SPEED

More antennas or antenna elements in a MIMO design usually translate into higher transmission/reception speeds for a WLAN modem. However, an IEEE 802.11n modem with the multiple antennas of a MIMO design must

support all features of IEEE 802.11n for the highest speed possible. Commercial MIMO antennas are available with different numbers of antenna elements, allowing users to select different levels of MIMO benefits.

MIMO techniques enable antennas to combine multiple communications data streams from different signal paths and at different times. This use of spatial diversity takes advantage of any extra antennas in a system by means of receiver diversity techniques to increase the range of the communications system. Anytime the number of antennas in a system is more than the number of spatial streams, the system is a candidate for applying receiver spatial diversity.

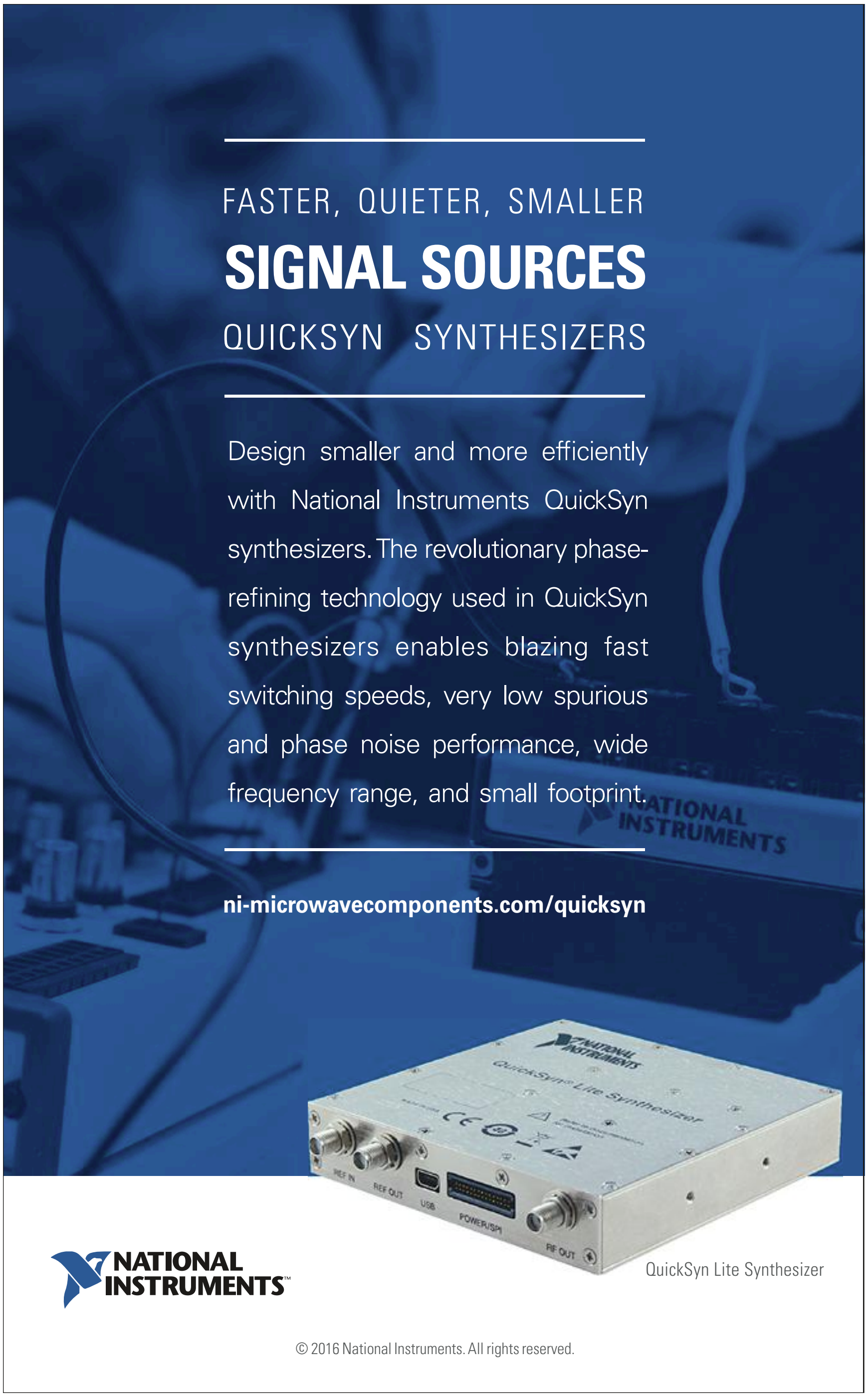
For example, L-Com has developed a number of different MIMO antenna designs for use at 2.4 GHz and 4.9 to 5.8 GHz, with multiple dual-polarized antenna elements in each unit. The HyperLink HG2414DP-3NF is a three-element, flat-panel antenna that combines antenna elements with vertical and horizontal polarization and high gain for MIMO point-to-point and point-to-multipoint applications at 2.4 GHz. The antenna's diversity radio capabilities allow for the interoperability of two radios on transmit and receive paths.

When more frequency coverage is required, more MIMO antenna elements can be combined as in L-Com's four-element, dual-polarized HyperLink HG2458-13HDP-4NF MIMO antenna. It blends together two vertically polarized and two horizontally polarized dual-band antennas for use at 2.4 GHz and from 4.9 to 5.8 GHz in support of WLANs.

MODELING MIMO

As MIMO is applied to advanced communications systems, including emerging 5G wireless networks, modeling software provides a critical "first look" at how multiple antenna elements interact across many different frequencies, from RF through millimeter-wave frequencies. The Genesys and Momentum simulation software from Keysight Technologies, for example, are used for different aspects of MIMO antenna modeling, including for predicting the antenna patterns possible from multiple antenna elements.

The MIMO modeling capability contained within Remcom's Wireless InSite simulation software can predict the path data between each transmitting and receiving element in a MIMO design and help study key channel characteristics for multiple-element antenna designs. Wireless InSite provides the means to simulate even large arrays in massive-MIMO systems. **mw**



CHRIS DeMARTINO | Technical Engineering Editor

High-Power Devices Have Become a High-Stakes Market

Suppliers of these devices are all in, not only targeting applications like wireless communications and radar systems, but also the emerging RF energy arena.

Any communications system that transmits high-frequency signals into the air must do so at power levels high enough to meet the needs of the given application. For example, cell phones and base stations both must transmit signals at sufficient levels of power to enable cellular communications. And for radar and satellite-communication (satcom) systems, as well as many others, the transmission of RF/microwave signals at acceptable power levels is critical.

High-power RF/microwave technology stretches beyond data-transmission applications, though. A relatively new area of interest involves utilizing solid-state RF technology for applications such as cooking, automotive ignition, industrial heating, and more. With that in mind, suppliers of RF/microwave power devices are staying busy to meet the needs of both traditional and non-traditional applications.

1. This 200-W PA module from Ampleon is intended for applications like plasma lighting, industrial heating, and cooking and defrosting.

WIRELESS EVERYWHERE

Today, wireless communication permeates through every part of the globe. And wireless traffic can rise dramatically at certain times in one environment, particularly during major events like the Super Bowl. To put this into context, NXP Semiconductors *(www.nxp.com)* recently published an interesting blog post, “Wireless Providers at Super Bowl LII Can’t Afford a Fumble.” The author, Jim Norling, vice president, RF cellular infrastructure at NXP, described how wireless carriers prepared for the massive amounts of voice, data, and video traffic that were expected at this year’s Super Bowl in Minneapolis.

According to the post, technicians from the major cellular carriers reinforced the Minneapolis metro area’s infrastructure, adding more small cells and strengthening both fronthaul and backhaul paths with more fiber. Verizon increased the number of remote units in its distributed antenna system (DAS) at the stadium by 50%. The carrier also added cell sites and small cells at both the Mall of America and Minneapolis-St. Paul International Airport.

T-Mobile boosted LTE capacity by 35% and added carrier aggregation. AT&T utilized LTE-Advanced, increased antennas in the stadium to 800, and deployed a DAS at 16 places in the area. Not to be outdone, Sprint built its own 800-remote DAS in the stadium, used LTE-Advanced and carrier aggregation, and mounted 200 small cells throughout Minneapolis.

What was a key ingredient in all of this activity? According to the post, RF power transistors make it all possible, as they allow the thousands of DAS remote units, small cells, and base stations to transmit signals indoors and outdoors—in any kind of weather. Without these RF power transistors, the wireless activity at an event like the Super Bowl wouldn’t be possible.

Norling explained, “According to *www.mobilesportsreport.com*, mobile data record usage keeps climbing, enabled by smart stadium network DASs. We supply RF power transistors—key components for the DAS networks—keeping sports fans connected with essential coverage to call, text, and stream video anywhere within the stadiums and other venues.”

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THE NEW REALM OF RF COOKING

Solid-state RF technology is now making inroads into RF energy applications, with cooking being one specific area of interest. For instance, NXP is also developing technology to cook and defrost food.

Earlier this year, the company announced its smart defrost solution. “Our smart defrost solution uses solid-state RF energy to rapidly and automatically thaw a wide range of frozen foods to an even temperature and with minimal moisture loss,” said Pierre Piel, senior director and general manager for multi-market RF power at NXP.” The smart defrost solution is based on NXP’s laterally diffused metal oxide semiconductor (LDMOS) technology.

Piel added, “Once your food is defrosted, you can cook it using solid-state RF energy from NXP, too. Closed-loop RF heating systems are influencing the latest automated and connected smart-appliance market, using RF energy for even heating, consistency, and adaptability. NXP is enabling original equipment manufacturers (OEMs) to differentiate smart kitchen appliances with unique and high-quality cooking and defrost solutions.”

Another company heavily invested in solid-state RF cooking is MACOM *(www.macom.com)*, with the company touting its gallium-nitride-on-silicon (GaN-on-Si) technology for such applications. MACOM recently published the blot post, “RF Energy in Daily Life Part 5: GaN for Baking.” The post stated, “Consumers will benefit from solid-state RF energy in significant ways centric to system reliability, food processing speed, and throughput. The evolution of the solid-state microwave oven is expected to result in a device that is capable of cost-effective baking with unprecedented efficiency, ensuring a cake rises and bakes evenly, and cupcakes on the outer rim of the pan bake as evenly as those in the center.”

MORE RF ENERGY APPLICATIONS

Cooking isn’t the only application for RF energy. As mentioned earlier, automotive ignition and industrial heating are among the other application possibilities. At the forefront of it all is the RF Energy Alliance (RFEA; *www.rfenergy.org*), which is a non-profit technical association comprised of companies “dedicated to realizing the potential of solid-state RF energy as a clean, highly efficient, and controllable heat and power source.” Member companies include both NXP and MACOM.

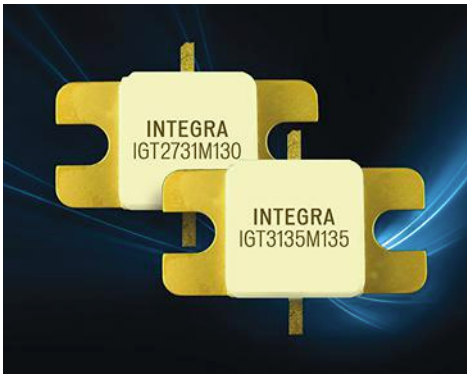
Another RFEA member company to take note of is Ampleon *(www.ampleon.com)*. The firm recently introduced the BLF0910H9LS600, which is a 600-W LDMOS power transistor for RF energy applications. The device operates in the 915-MHz band.

Another new device developed by Ampleon is the BPC-10M6X2S200—a 200-W LDMOS power-amplifier (PA) module *(Fig. 1)*. Operating at 423 to 443 MHz, the amplifier is suitable for applications like plasma lighting, industrial heating, and cooking and defrosting.

POWERING RADAR APPLICATIONS

A discussion of high-power RF devices wouldn't seem complete without mentioning radar applications. How have the requirements for high-power radar applications changed in recent years?

"There are two changes that I see," explains John Walker, senior engineer at Integra Technologies *(www.integratech.com)*. "Firstly, with the advent of GaN, it is now feasible to generate much higher power than was previously possible using solid-state at S-band and above. Consequently, there is much interest in developing solid-state alternatives to traveling-wave tubes (TWTs) at S-band and above. The second trend is the move toward much longer pulse length and higher duty cycle solid-state amplifiers in radar systems for longer range detection."



2. Shown are two GaN-on-SiC transistors developed by Integra for S-band radar applications.

Integra recently announced several new products, such as the IGT2731M130 and IGT3135M135 GaN-on-silicon-carbide (GaN-on-SiC) transistors for S-band radar applications *(Fig. 2)*. The IGT2731M130, which covers a frequency range of 2.7 to 3.1 GHz, delivers a minimum of 130 W of peak output power. The IGT3135M135 covers a frequency range of 3.1 to 3.5 GHz while delivering as much as 135 W of peak output power.

The landscape for RF power devices is clearly vast, as wireless communications, radar systems, new RF energy applications, and more are prompting suppliers to raise the bar to meet these tougher requirements. It will be interesting to see how RF energy applications—which are still in the early stages—unfold over time as suppliers develop the products to make these applications mainstream. **mw**

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Extending the Bandwidth of An Elliptical Monopole Antenna

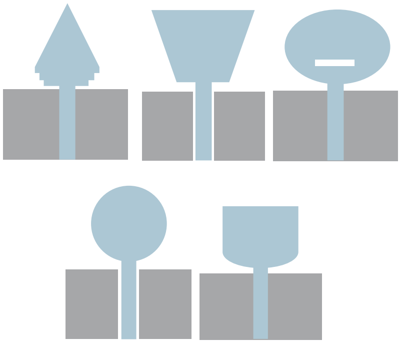
By optimizing design parameters through EM simulation, an initial antenna design can be extended from dc to 25 GHz to a much wider bandwidth of 10 to 110 GHz.

Wide-bandwidth antennas represent a more compact alternative to the use of multiple antennas to cover the same bandwidth. Numerous design approaches are available for achieving wide antenna bandwidth, including an elliptical monopole antenna developed by the authors. It consists of an elliptical patch fed by coplanar-waveguide (CPW) transmission line and matched to 50 Ω for wideband operation. The antenna was developed through comprehensive parametric studies and the design aid of the three-dimensional (3D) electromagnetic (EM) simulation software CST Microwave Studio from Computer Simulation Technology *(www.cst.com)*.

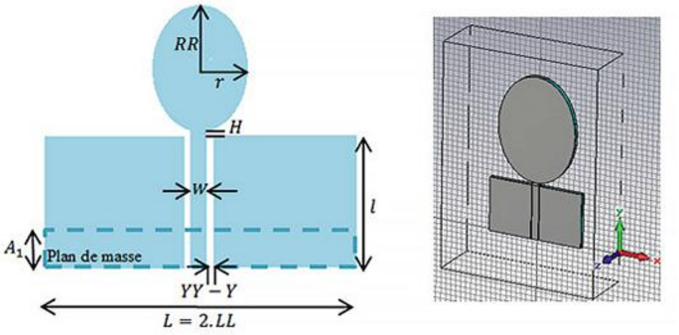
In a radio system, an antenna sends and detects electromagnetic (EM) waves and is considered one of the more important components in a wireless communications system.[1] Numerous configurations are available for RF/microwave applications. One option, a planar monopole antenna, is a good candidate for wireless communication services because of its wide impedance bandwidth, omnidirectional radiation pattern, high radiation efficiency, and compact size.[2,3]

By designing a single antenna that can cover a large bandwidth, it can be used for various applications.[4,5] A monopole antenna is one-half of a dipole antenna, almost always mounted above some sort of ground plane. Among the range of broadband monopole configurations that have been developed are circular, square, elliptical, pentagonal, and hexagonal forms *(Fig. 1)*, which can easily be integrated into RF/microwave circuits as well as ultrawideband (UWB) devices.[6-8]

When the planar radiating elements of a monopole antenna are etched on a dielectric substrate, a ground plane can be in the form of CPW transmission lines with the radiating elements or in the frame of the dielectric substrate. The radiating elements can be fed by a coaxial cable or microribbon line. Modifying the ground plane in certain ways can increase the antenna bandwidth. CPW enables good impedance matching, omnidirectional radiation patterns,



1. These drawings depict some of the different planar antenna geometries used for broad bandwidths.



2. The design structure of the elliptical monopole antenna (left) and its key dimensions, such as l, LL, and h, is shown next to the antenna modeled in the CST Microwave Studio editor design and simulation software (right).

TABLE 1: DIMENSIONS OF THE ELLIPTIC ANTENNA

Ellipse	Coplanar waveguide (mm)
RR	9.75
r	7.5
H	0.5
I	10
L	18
W	1.3

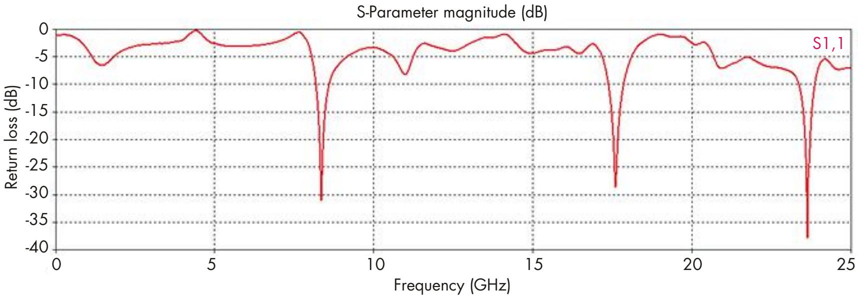
and wide bandwidths at RF, microwave, and millimeter-wave (mmWave) frequencies. These CPW benefits make it a preferable method to feed antennas and to integrate with active devices.[9]

To achieve wideband frequency coverage, an antenna was designed based on an elliptical radiating disk fed by CPW. The antenna is designed on 2-mm-thick substrate material with high permittivity. *Fig. 2* shows the initial design of this elliptical monopole antenna as it appears in the CST Microwave Studio computer design and EM simulation software from CST. The initial parametric values of the antenna are listed in *Table 1*.[10]

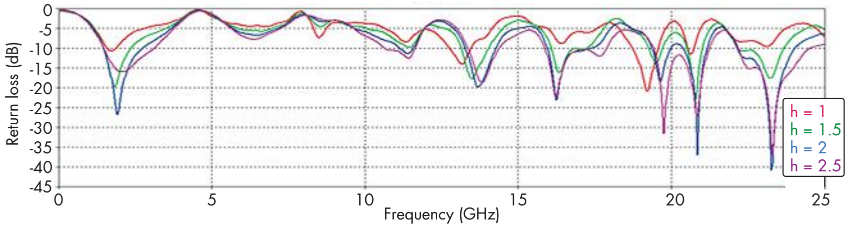
The return loss as a function of frequency for the initial monopulse antenna design is plotted in *Fig. 3*, although the performance can be improved. By experimenting with the antenna's design parameters, the return loss can be optimized over a wide bandwidth while achieving a compact final antenna structure.

ROLE OF SUBSTRATE THICKNESS

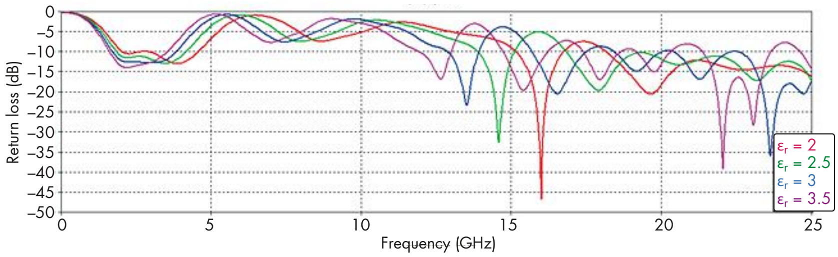
The optimization process consists of a number of steps. The first step involves changing substrate thickness (h) in simulation in pursuit of broadband operation. After simulations with different substrate thicknesses, the results were plotted in *Fig. 4*. The resonance number for each curve is around 9. Substrate thickness is found to have a significant effect on antenna return loss. Bandwidth is found to increase linearly with increasing h, with the best results at h = 2.5 mm and with the bandwidth exceeding 9%.



3. The return loss behavior is plotted versus frequency for the proposed broadband antenna.



4. This plot shows the influence of substrate thickness on return loss.



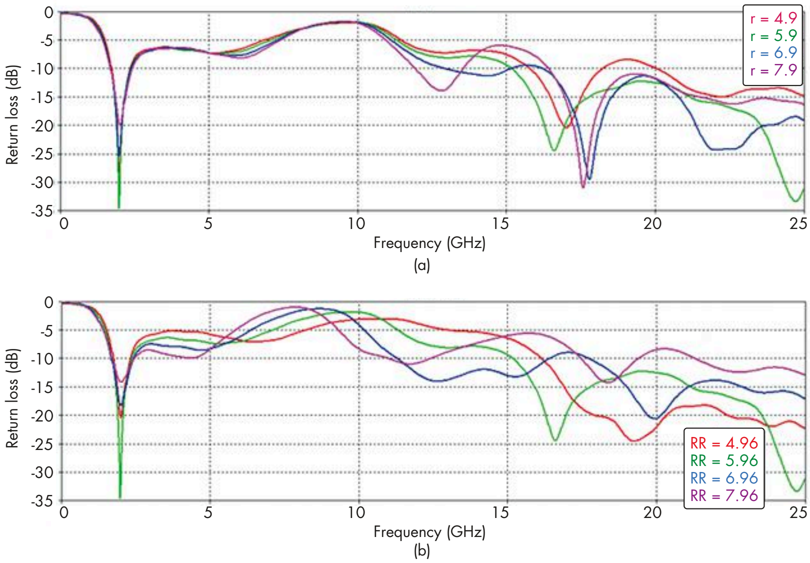
5. This plot predicts the influence of substrate permittivity on return loss.

Knowledge of the effects of substrate dielectric permittivity on antenna performance can also be useful in optimizing the antenna design for broadband performance. For example, when the value of dielectric substrate permittivity is between 3.0 and 3.5, several resonant peaks appear at the higher frequencies, representing minimal reflected power levels and a slight increase in bandwidth *(Fig. 5)*. The most interesting permittivity value is equal to 2, such that the return loss presents three resonances peaks with bandwidth exceeding 682.5 MHz for the third resonance frequency of 19.65 GHz.

The effects of an antenna's elliptical dimensions on its electrical behavior should also be examined when optimizing the antenna for wide bandwidth. Computer simulations were performed with Microwave Studio on different antenna configurations to better understand the effects of changing these dimensions.

The vertical half-side (RR) of the ellipse was first modeled to understand its influence over the frequency range from dc to 25 GHz. Then, a similar analysis was performed on the horizontal half-side (r) of the ellipse so that an ultrawideband structure could be created for the antenna. In this analysis, the two parameters h and ε_r previously studied remained fixed and equal to 2.5 and 2 mm, respectively, while parameters r and RR vary according to *Figs. 6a* and *6b*.

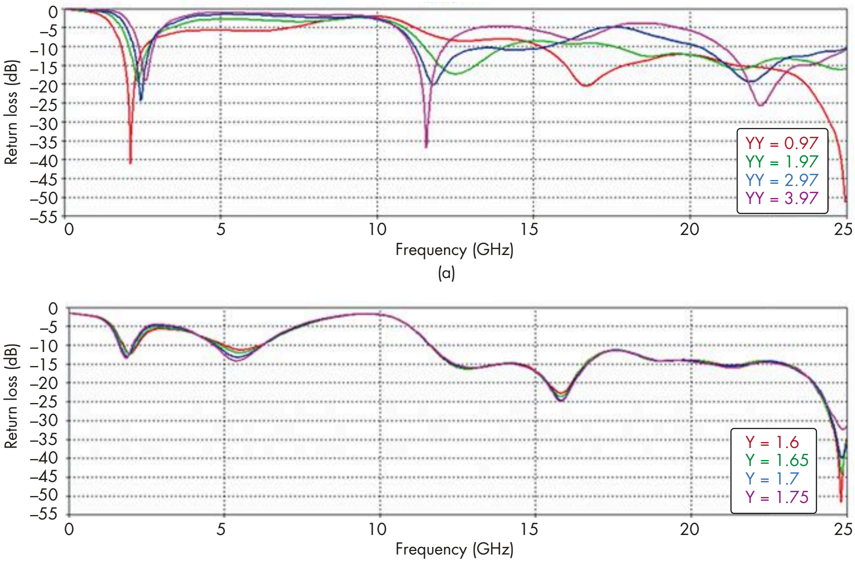
Variations in the ellipse dimension r have a comparable effect to what was observed in the case of parameter RR for the elliptic monopole. The two return-loss curves determined mainly by the dimensions r = 5.9 mm and RR = 5.96 mm are almost identical where the bandwidth is greater at 982.5 MHz. As



(a)

(b)

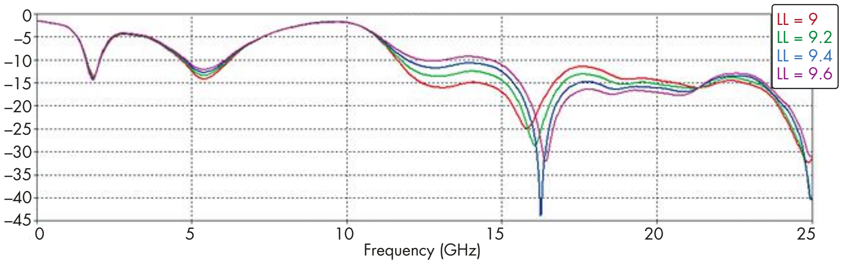
6. These plots show the influence of the ellipse vertical side on return loss (a) and the influence of the ellipse horizontal side on return loss (b).



(a)

(b)

7. The size of the gap between antenna position YY (a) and Y (b) dictates the performance of the antenna in terms of return loss.



8. The antenna side lengths also have an impact on its return-loss performance across a wide bandwidth.

a result, it can be determined that these changes will have a significant impact on adapting an antenna to broad bandwidth use.

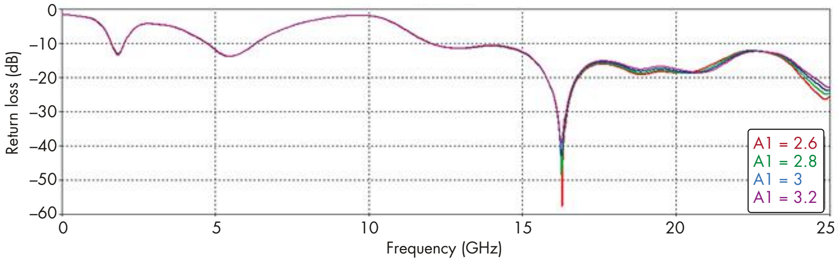
SIZING UP CPW SLOTS

By means of the CPW slot width inserted next to the feed line, it was possible to understand the contributions of that slot width on antenna return loss. The width of the slot is limited in practical terms by the positions Y and the multiple YY positions along the abscissas axis, and ultimately determined by the difference between positions Y and YY.

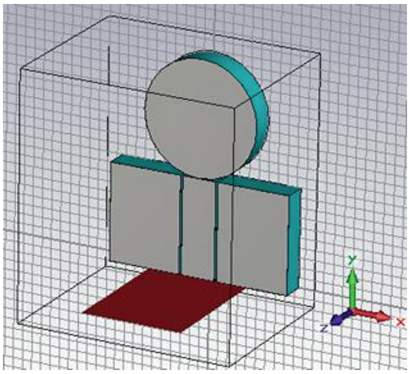
Setting the YY parameter was found to essentially impact the antenna bandwidth, the resonant frequency, and the amplitude of the antenna. Plotting the YY parameter versus Y values as in *Fig. 7b*, the bandwidth can be found to increase with the size of the gap between the two positions. The slot width that appears most attractive for optimum bandwidth is around 0.22 mm (from 1.97 to 1.75 mm), for which the antenna presents a bandwidth of 11.65 to 25.00 GHz with a return loss (S_{11}) of better than −10 dB (i.e., for a bandwidth that exceeds 1335 MHz rather than 982.5 MHz).

To better understand the influence of the antenna lateral lengths (LL), they were reduced from 9.6 mm to 9.0 mm to investigate the effects of the smaller dimension on electrical performance. The bandwidths for the reductions in size, from 9.6 mm to 9.4 mm to 9.2 mm, are relatively similar, with each exhibiting its own return-loss characteristics. The return loss for LL = 9.4 mm has two peaks of better than −40 dB and a bandwidth exceeding 1305 MHz. *Fig. 8* shows the simulated return loss for antenna designs with reductions in side lengths (LL) from 9.6 to 9.0 mm.

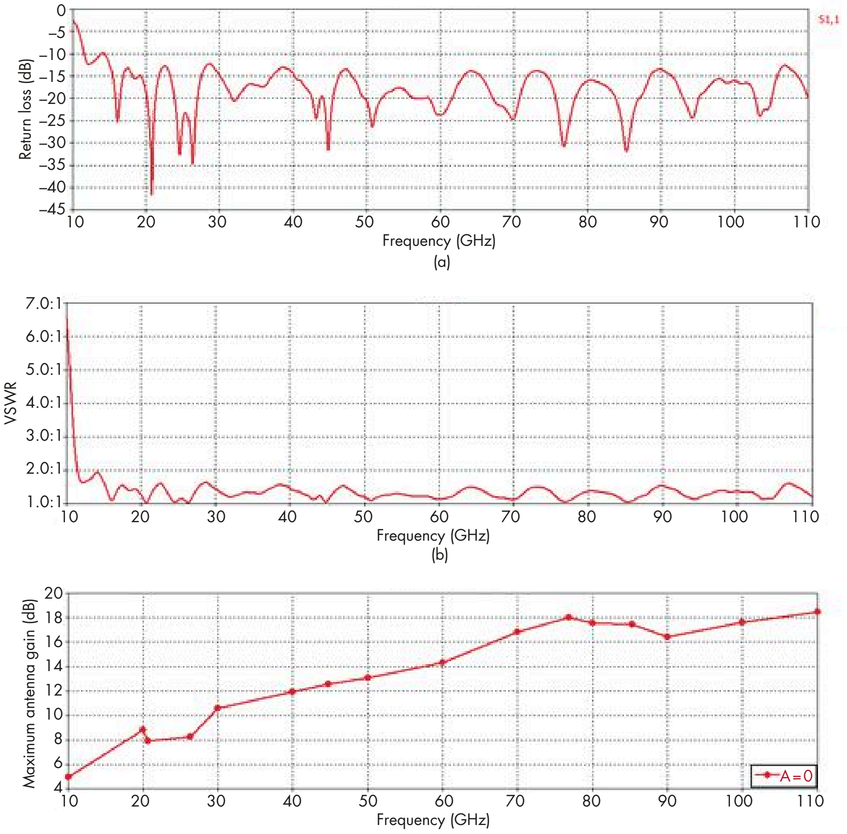
As part of exploring the influence of the ground plane length on antenna electrical performance, it was changed from 2.6 mm to 3.2 mm in 0.2-mm steps as illustrated in *Fig. 9*. The initial value of the ground plane width (A1 = 2.6 mm) yields an antenna return loss



9. The length of the ground plane also has a bearing on the antenna's ultimate return-loss performance.



10. This is the final elliptic monopole antenna structure as it appears in the CST Microwave Studio editor.



(a)

(b)

(c)

11. The plots show return loss (a), VSWR (b), and gain (c) within the antenna's wide bandwidth.

TABLE 2: FINAL ELLIPTIC ANTENNA DIMENSIONS

Parameters	Value (mm)
h: substrate thickness	2.5
ε_r: substrate dielectric permittivity	2.0
r, RR: ellipse sides	5.9 (r), 5.96 (RR)
YY-Y: width of the coplanar waveguide slots	0.22
L, LL: antenna side lengths	2.0 (L), 18.8 (LL)
A1: ground plane width	2.6

of less than −57.58 dB at the desired frequency of 16.3 GHz, while other configurations (A1 = 2.8 mm, 3.0 mm, and 3.2 mm) present lower-level return-loss peaks.

By means of this parametric study of the elliptical antenna, it was possible to achieve broadband operation in its high-frequency range. The final parameter values of the antenna used for broadband operation are summarized in *Table 2*, with the final antenna simulation performed in the frequency range from 10 to 110 GHz. According to *Fig. 10*, where the bandwidth exceeds 98.10 GHz, this optimizing of antenna parameters for wide bandwidth is one approach for achieving a fundamental antenna design with broad bandwidth.

Figures 11a, 11b, and *11c* depict the return loss, voltage standing wave ratio (VSWR), and gain of the final antenna design, respectively.

The return loss ($|S_{11}|$) amplitude usually provides details on an antenna's various resonances, its bandwidth, and its adaptation. The return loss curve of the optimized antenna is adapted perfectly between 11.9 and 110.0 GHz. Therefore, final structure exhibits better behavior than obtained at the beginning of the design process by simulating the proposed antenna with the indicated new parameters of *Table 2*. The consequences of modifying the antenna parameters result in the wide bandwidth, which exceeds the 98.10 GHz to a resonance level of −10 dB.

Fig. 11b plots the VSWR for the wideband antenna design. The VSWR can be seen as stable and coherent, with a value lower than 2.0:1 starting from the level of 11.9 dB at the resonance frequency. *Fig. 11c* shows the gain versus frequency for the elliptical monopole. The gain increases with frequency from 5 dB at

(Continued on page 77)

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Develop Repeatable RF Measurement Methods

These practices can lead to consistent results with test equipment, including those routines that help ensure the safety of the equipment as well as those who are at the controls.

Aerospace applications rely on many RF/microwave active and passive components and the test equipment that maintains them. Such applications are highly subject to performance variations with temperature, and understanding the performance changes with sudden variations in temperature requires proper test methodologies to replicate the aerospace operating conditions during on-ground measurements.

But it doesn't begin and end with developing proper measurement strategies and understanding the roles of different test instruments. Reliable fault diagnosis, and the recognition of generic errors that can impact the characterization of high-end electronic systems for aerospace applications are key factors, too, when it comes to optimizing RF/microwave components and systems for space.

Intentional or unintentional spurious signals are present in the RF ranges and used for applications from space exploration to military warfare. Electronic systems needed for such functions as navigation, communications, and data processing are often limited by their requirements to operate in hostile environments. RF designers must make RF systems compatible with their intended operating environments.

High-end systems such as space-based RF electronic systems consist of a transmitter and receiver for on-board receiving and transmitting of signals at desired frequencies and specified power levels.[1] Multiple, closely spaced transmitters are prone to greater levels of interference at higher frequencies. Furthermore, a hybrid approach adopted in realization of such systems poses certain challenges associated with the performance variations due to radiation effects and temperature variations. This presents the risk of total system failure due to overstressing and rendering an entire spacecraft as debris in space.

To avoid such a scenario, attempts have been made to replicate this hybrid aerospace systems design approach during ground testing prior to full system implementation, in order to better understand system operating conditions under actual aerospace conditions and set the stage for a reliable system.[2] This poses challenges to the measurement techniques used in the process, since error margins in newer systems are narrow. A general trend in commercial communications is the use of higher frequencies, including 5G wireless systems that are reaching millimeter-wave frequencies. This further challenges test equipment and measurement methods since signal losses tend to increase at higher frequencies.

OVERCOMING THE MAIN ISSUES

Many factors affect the accuracy of measurements performed on RF/microwave aerospace systems:

- Electromagnetic interference (EMI) and electromagnetic compatibility (EMC)
- Electrostatic discharge (ESD)
- The contributions of cables and printed-circuit boards (PCBs)
- RF equipment
- Equipment calibration
- Fault diagnosis and component selection
- General precautions

Electrical/electronic equipment must achieve compatibility without any deterioration in function within a defined time and space. It's imperative to identify any unintentional emission sources and coupling paths that may result in interference. The various standards set down limits for conducted and radiated EMI emissions, with limits defined in dBµV for conducted voltage and dBµV/m for radiated field strength.

EMC involves carrying out design and layout practices so that uninterrupted signal flow is ensured in the circuit. EMC refers to two aspects: electromagnetic interference (EMI) and electromagnetic susceptibility (EMS). EMI refers to the noise level generated by the equipment, which causes intrasystem interference within a given system and intersystem interference with others, while EMS refers to the immunity of equipment against EM noise from the environment.

EMI can affect circuit performance, and in RF systems, a main contributor is the via transitions through resonances.[3] A simple methodology for avoiding EMI problems is to incorporate stitching, Faraday shielding, filtering, grounding, physical separation, or orientation and loop reduction in a design to minimize its susceptibility to EMI.

The norms devised for the capability of a device under test (DUT) to operate in the typical operating environment are conducted emissions (CE), radiated emissions (RE), conducted susceptibility (CS), and radiated susceptibility (RS). The emissions tests (CE and RE) record any undesirable emissions from the DUT. Conducted emission testing is carried out to check the interference from the DUT to the power supply in the range of 150 kHz to 30 MHz.

For measurement of conducted emissions, a line impedance stabilization network (LISN) is inserted into the mains power supply of a DUT. The LISN leads the RF signals from the equipment under test (EUT) to the output for the measurement receiver, while at the same time blocking the ac input voltage from the receiver. The susceptibility tests (CS and RS) determine the DUT's capability to operate in a typical operating environment.

ESD, typically generated by friction, separation, and induction between components, can cause damage to those components. The effects of the discharge of static charges can be latent or catastrophic in nature. The parameters affecting ESD include material characteristics, humidity, clothing, speed, and mannerism of working, as well as body resistance.

ESD-related failures can be attributed to various parameters, such as voltage, current, electrostatic energy, distance from charge, and shape of charge. The generated charges induce voltage that directly leads to the EMI with nearby circuits. Active devices are sensitive to this energy and more prone to ESD-related failures, which are difficult to diagnose at later design stages. The charges, Q, (generated/induced) are related to capacitance and voltage per the following relation:

$$Q = CV \quad (1)$$

The position of the operator is related to the capacitance. In a sitting position, the operator's capacitance is 250 pF. In a standing or walking position, the operator's capacitance reduces to 150 pF or 50 pF, respectively. The capacitance is correlated with the voltage as per Eq. 1, with a higher value of capacitance related with a lower voltage. The use of metal plate for fast dissipation of charges relates with a higher failure rate and needs to be replaced with a more dissipative material. Control of the static charges can be carried out by grounding, isolation, neutralization, and prevention. The main considerations for the avoidance of ESD-related failures are:

- Placement and use of ionizers at appropriate distances
- Availability of various materials such as tweezers, mats, and equipment grounding
- Use of slow dissipative material instead of highly conductive material
- PCB track routing, along with component placement and handling
- Avoid induced charges by properly isolating sensitive devices
- Keeping electrostatic generating materials at a sufficient distance (> 1 m)
- Using ESD protective covers for all connectors

RF/microwave cable is constructed with a center conductor, dielectric insulator (such as PTFE), shield, braid, and jacket. The important parameters are impedance, time delay, cutoff frequency, temperature range, bending radius, and RF leakage.

The main consideration for high-frequency cables stems from the shielding efficiency, which depends entirely on the outer conductor. The shielding protects the conductor from outside interference and prevents internal energy transferred by the cable from interfering with outside circuitry. Commonly employed shields include single braid, double braid, triaxial, strip braids, and solid sheath. Such cables generate acoustical noise associated with mechanical motion and electrical noise associated with electrical disturbances and electrostatic effects. Another criterion of cable is the flexibility, where larger diameter cables with more dielectric yield greater internal forces and affect the RF performances due to the phase change, φ (for a given length l_{inches} as shown in Eq. 2:

$$\varphi = [l_{inches} \times f_{GHz} \times 360 \times (\varepsilon)^{0.5}]/11.808 \qquad (2)$$

with

$$\Delta\varphi = (\varphi \times \text{change in ppm})/\text{freq (GHz)}$$

The capacitance of a coaxial cable can be given by Eq. 3:

$$C = 7.354\varepsilon/[\log10(D/d)] \quad \text{pF/ft} \qquad (3)$$

where T (time delay) = $1.016(\varepsilon)^{0.5}$; ε = the dielectric constant between the center conductor and the cable shield; d = the outer diameter of the inner conductor; and D = the inner diameter of the outer conductor.

Consideration of various parameters, such as impedance, reflection, rise time, amplitude, overshoot, and pulse echos, is important in case of pulse operation, whereas for continuous-wave (CW) operation, surge current protection must be provided. Signal attenuation depends on the length of the cable and the operating frequency. Routing and bunching of the cables in any box can lead to oscillations. Routing is carried out to keep away from cables, PCBs, and potential radiator points, whereas any bunching-related issue either requires segregation or tying with the box wall. Routing is generally carried out along the box walls to avoid unwanted pickups *(Fig. 1)*.

1. Signal routing in a test system is meant to avoid unwanted radiation of high-frequency signals that can be re-radiated within the system.

TABLE 1: SUMMARY OF CONNECTORS AT VARIOUS FREQUENCIES	
Frequency (GHz)	**Connector**
18.0	SMA
26.5	3.5 mm
40.0	2.9 mm
50.0	2.4 mm
67.0	1.85 mm

Standard RF cables are prone to damage due to bending, which also causes reflections in the circuit. Bending, bumping, or flexing of a DUT connected to the input of the instrument causes strain on the cable's input connector and the mounting hardware. Selection of the connector is also an important consideration in a test setup and, as seen in *Table 1*, is chosen based on the required frequency of operations.

The overall loss of a test cable assembly can be written as:

$$\text{Loss (dB)} = \{[\text{Cable attenuation (dB)}/100\text{ ft.}]/1200\} \times (L_{\text{inches}} + \text{connector loss}) \quad (4)$$

PCBs for RF/microwave circuits typically involve microstrip, coplanar waveguide (CPW), and stripline circuit configurations. These circuit structures are often used in multilayer PCB designs, and each has its own set of capabilities and limitations. An RF PCB can be fabricated with FR-4 substrate materials having glass fiber and copper in layers bonded by epoxy resins. The main features are high resistance to mechanical stress, good resistance to thermal shock, lightweight but suitable for circuit functions < 2 GHz due to low associated power loss, and interferences.[4]

PCB routing is divided into two phases: global and detailed routing. Global routing involves the study of optimal component placements, whereas detailed routing is about tracing components between other components. The main design aspects involve avoiding routing near splits and placement of viaholes to avoid disruption of any signal in its return path as a viahole couples it to the plane and causes excitation of parallel-plate modes. Also, an important design step is identification of potential radiators in the circuit and incorporation of preventive methodologies in the design and layout stages, such as a control impedance technique.

Various analyses such as circuit resonances, emission and enclosure effects must be taken into account separate from any techniques meant to minimize distortion, crosstalk, and ground bounce to ensure clean signal transmission and minimal radiation from the PCB. Higher power handling can be provided by employing a heat sink, thermal vias, and stitching to avoid EMI. *Table 2* shows the common causes[5] and reasons associated with PCB problems.

TABLE 2: PCB DEGRADATION FACTORS	
Factors	**Reasons**
CTE mismatch	Copper and PCB laminate materials expand at different rates with temperature
Laminate material degradation	Thermal stress
Decomposition of PCB laminate	Thermal stress due to Pb-free soldering (Sn-Ag-Cu) at +260-+280°C
Popcorning	Expansion of trapped moisture and gasses
PCB warpage	Heat
Copper balance	Twist and warpage
Thermo-mechanical stress	CTE mismatch
PCB measling	Higher temperature for long duration

MAKING MEASUREMENTS

The essential instruments needed for RF//microwave measurements include network analyzers, signal/spectrum analyzers, power meters, oscilloscopes, and signal generators. Of course, unintentional spurious signals can occur inside any of these instruments and propagate through a test system and ultimately be read as a measurement.

RF/microwave test equipment is also prone to the damage caused by improper grounding and handling due to the buildup of electrostatic charge. In case of an extension cable or power cable, a protective ground conductor should be employed for any measurement. For safety, the ground resistance should be checked (<1 Ω) and the voltage between the neutral and ground line should be < 1 V.

A multimeter is one of the fundamental pieces of equipment for measuring ac/dc currents and voltages, resistances, and even temperatures and harmonic frequencies using integrated probes. When choosing a multimeter, main considerations are range, accuracy, and resolution. The accuracy depends on resolution; an improvement in resolution is associated with the measurement range.[6] The range selected includes peak hold, min/max for capture of lowest and highest readings, and auto hold/data hold. Safety is a key consideration, too, and various safety features such as voltage arrestors, spark gap, and fuse protection should be incorporated in every unit.

The network and spectrum analyzers differ in the type of signals they explore. A network analyzer is suited for finding signal gain compression and AM/PM conversion, while a spectrum analyzer reads harmonics and makes intermodulation-distortion (IMD) measurements. The network analyzer is equipped with a dedicated source and receiver for displaying ratioed amplitude and phase, while the spectrum analyzer is a sensitive receiver for measuring signal levels, sidebands, harmonics, and demodulated signals.

The main parameters for both the signal generator and network analyzer are frequency range, frequency resolution, spectral purity, output power, and crosstalk. In the case of the spectrum analyzer, it's a matter of how wide a frequency span it can measure and with what resolution bandwidth (RBW). Spectrum analyzers include selectable input attenuation for choosing which signals to view within a given bandwidth. Various other parameters, such as averaging techniques and amplitude flatness, are selected based on the consideration of measurement accuracy, along with spurious measurements, which in turn affects the measurement speed. Verification of various equipment parameters like spurious-free dynamic range (SFDR), displayed average noise level (DANL), and residual responses is important for freezing the equipment setting at a given time, since an improper setting may incur spurs in the measurement system.

EQUIPMENT CALIBRATION

Equipment calibration plays an important part in the overall measurement repeatability of RF/microwave test equipment. Measurements at extremely low levels present challenges to a wide range of test equipment due to the drift and aging of the equipment and other equipment factors.[7] Proper calibration practices can help to remove uncertainty errors associated with aging test equipment or to environmental changes. The important aspects in the calibration are traceability and uncertainty. The test calibration of the specific equipment is carried out as per this methodology:

- *Signal-generator calibration:* The signal-generator output level at assigned frequency is checked with the power meter, and the output level linearity is checked with a power meter and spectrum analyzer. The spectral purity of the signal-generator output is checked for the assigned frequency range with the tunable analyzer.
- *Spectrum-analyzer calibration:* The spectrum analyzer is initially calibrated with the internal source and then calibrated with the calibrated signal generator for the assigned frequency range.
- *Power-supply calibration:* The power supply is calibrated for the operating voltage using a calibrated multimeter. Also, the performance of any overvoltage protection is verified using the multimeter. Current limiting is done for the assigned voltage and current and checked with the multimeter.

- *Multimeter calibration:* The multimeter is calibrated for the operating voltage range using a calibrated power supply.
- *Calibration of RF cables:* The RF cables used for testing are calibrated for their insertion loss and return loss with a calibrated RF signal generator, spectrum analyzer, and a reference cable.
- *Coaxial dc-block calibration:* The coaxial dc block is calibrated for its insertion loss with a calibrated RF signal generator, spectrum analyzer, and a reference cable.

The main techniques for calibration are the though-reflect-line (TRL), short-open-load-through (SOLT), open-short-load (OSL), and line-reflect-match (LRM) methods.[8,9] Nonlinear distortion measurements like intermodulation and third-order intercept (TOI) with standard stimulus such as two-tone and multitone sources are used, but with complex stimuli, e.g., digitally modulated carriers needed for measurements such as error vector magnitude (EVM) and adjacent channel power ratio (ACPR) measurements. The measurement error modeling can be categorized as systematic errors, random errors, and drift errors. Proper calibration techniques will help minimize these errors.

Measurement errors can lead to system failures and delay a production schedule. The diagnosis of the fault may be aggravated with the temperature cycling associated with the component or workmanship. Improper selection of the component, placement, and attachment can attribute to performance deviation. The same can be corroborated with the measurement equipment by carefully monitoring the performance of each parameter, such as power variation, frequency variation, spurious levels, and noise levels.[10]

Further integrated package tuning is required to quench oscillations due to parasitic circuit elements. Improper component values, tolerances, volt-

(Continues on page 78)

RF/Microwave Switches

Patent Pending

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What's the Difference?

JACK BROWNE | Technical Contributor

Pulsed vs. CW Signals: Both Loom on a Designer's Radar

The power consumption and ultimate output power of an RF/microwave system can vary significantly, depending on whether it's designed for pulsed or CW signals.

Pulsed and continuous-wave (CW) signals serve numerous purposes in RF/microwave systems, including for voice, video, and data communications, electronic warfare (EW), surveillance, and radar. Pulsed signals remain powered for short periods of time, working with and without some form of modulation, such as amplitude, frequency, or phase modulation. CW signals remain on constantly and may be modulated to function as radars or in communications systems.

Both types of systems rely on many types of active and passive components for signal processing, which are characterized in different ways. However, each can effectively accomplish system-level functions in different shapes, sizes, and power levels, giving system designers a great deal of flexibility when setting performance goals.

A CW transmitter operates without interruption, as does its receiver. In contrast, a pulsed transmitter sends very short-duration signals that may even contain encoded information within the rise time of the pulsed signals. An extreme version of a pulsed system is a single-pulse system in which all critical data is carried by a single pulse. The operating tradeoffs between CW and pulsed systems start with the energy consumption, since the comparison is between amplifying continuous signals versus boosting the amplitudes of signals that only need to be processed part of the time.

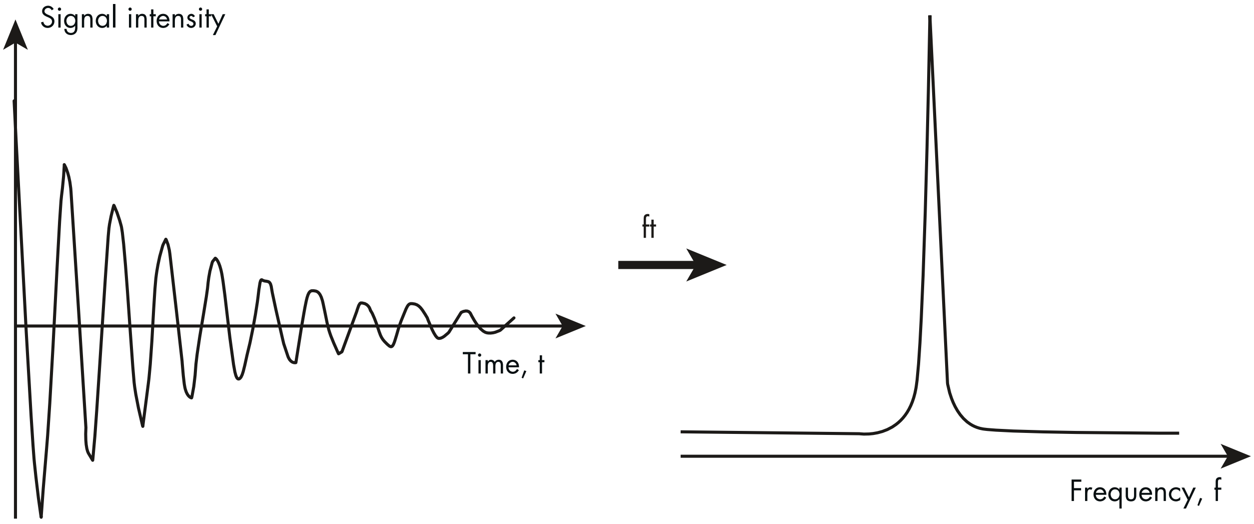
RADAR APPLICATIONS

Pulsed signals are often associated with radar systems, but radar designs exploit both CW and pulsed signals, particularly commercial radars that are part of adaptive driver-assistance system (ADAS) equipment in newer automotive electronic safety systems. Pulsed radar systems transmit short pulses and calculate the distance to an illuminated target by measuring the time delay between a transmitted pulse and the returning reflected signal. A radar using CW signals, such as a frequency-modulated CW (FMCW) radar, transmits a steady stream of linearly modulated CW signals and calculates the distance from the transmitter to an illuminated target by determining the difference between the transmitted and received signal frequencies.

An FMCW radar system, with its continuous measuring signals, is capable of good range resolution, often as fine as 0.5 m. A pulsed radar system, on the other hand, is not quite as good on range resolution. It typically suffers a large "blind spot" in front of the radar of 50 m or more, resulting in poor range resolution. But for measuring long-range distance to a target, a pulsed radar system can produce the high signal power needed for high signal-to-noise ratio (SNR) and excellent range resolution.

RANGE AND DETECTABILITY

A pulsed radar system typically provides greater measurement range compared to a CW radar, such as an FMCW radar system, with lower power consumption. A CW radar system delivers continuous updating of target information with higher measurement resolution than a pulsed radar system, and the lack of a minimum target distance. But due to those continuous signals, CW radar systems are more easily detected than pulsed radar systems, especially those with shorter duty cycles. CW radar systems are also more easily jammed than pulsed radar systems because the signal is more easily detected and characterized



Both continuous-wave (CW) (left) and pulsed (right) signals are used throughout RF/microwave systems, such as communications and radar equipment, with differences in performance and behavior.

to know the type of jammer signal that's needed to disrupt the system.

UWB SYSTEMS

Systems operating with extremely short pulses, such as ultrawideband (UWB) radar systems, are very difficult to detect, especially when the signal levels are very low. A 24-GHz UWB pulsed radar system that operates with pulses that are only nanoseconds in duration may have a bandwidth that's approximately 8 GHz wide, but the signal power required for radar operation is only about 4 mW. As a result, when a 24-GHz UWB radar system is transmitting, the pulsed power is not really much different than the surrounding environmental noise, and is extremely difficult to detect compared to a CW signal, such as used in FMCW radar systems.

An UWB pulsed radar system operates by generating a sequence of pulses of finite duration; during the times between each pulse, the transmitter is in an "off" or no-power state. Although the transmitter is not powered during this time, the receiver is powered and active so that it is able to detect any signals reflected by radar targets or returned by corresponding radio transmitters.

In a CW radar system, the transmitter and receiver are always operating. Therefore, adequate isolation must be achieved between the receiver and transmitter to prevent them from jamming each other. This is usually accomplished by using low transmit power levels in a CW radar system, although this also limits the distance across which a CW radar system can detect a target.

DOPPLER AND FMCW

When a radar's target is moving, the motion results in a Doppler shift in the frequency of the reflected pulse signals. As a result, a pulse Doppler radar can measure the relative speed of the illuminated target. But in an FMCW radar system, which uses the frequency of the reflected signals, the movement of the target causes additional frequency shift in these reflected FMCW radar signals, which can make it difficult to measure the distance to the illuminated target. By using different patterns of changing frequency, such as frequency decreasing or increasing with time, a radar system with FMCW signals can accurately measure the distance to a target.

For amplification, both solid-state and electron-tube amplifiers are used for pulsed and CW radar and communications systems. Typically more power is available for a pulsed amplifier than for the same-size unit operating at the same frequency and using CW signals. As an example, when comparing helix traveling-wave tubes (TWTs) from L-3 Electron Devices, which are designed for high power amplification at microwave frequencies but can also produce lots of excess heat due to the nature of their active devices, the difference in output power is quite dramatic. Such helix TWTs are used in electronic-countermeasures (ECM) systems, medium-range radar, and missile seekers, often in unmanned aerial vehicles (UAVs).

For instance, model L2086 is a robust TWT weighing 14 lbs. and producing 0.5 kW output power from 2 to 4 GHz. It's capable of 30-dB gain while operating with CW signals. At more than twice the size, model L5714 is a helix TWT that weighs 30 lbs. but provides 40 times the output power over a slightly lower frequency range when operating with short pulses and a short duty cycle. It's capable of 20 kW output power with 45-dB gain from 2.0 to 2.6 GHz when operating at a 0.4% duty cycle.

RECOGNIZE THE FLAVORS of RF Power Transistors

When designing a solid-state high-power amplifier (HPA), the appropriate RF power transistors must be used. An RF power transistor can be categorized by its semiconductor technology. Among them are silicon (Si) bipolar, laterally diffused metal oxide semiconductor (LDMOS), and gallium-nitride (GaN). In the technical brief, "Zero-in on the Best RF Transistor Technology for Your Radar's High Power Amplifier Designs," Integra Technologies examines these three technologies, explaining the advantages and disadvantages of each one in terms of HPA design.

The tech brief begins by noting that an RF power transistor is usually characterized based on the type of signal it will handle, i.e., continuous-wave (CW) or pulsed. The document also states that no "silver bullet" technology exists for all high-power amplification requirements. Rather, the solution involves determining how a transistor's key characteristics correspond with the important requirements of the given application.

Discussion then turns to Si bipolar-junction transistors (BJT). Although Si BJT technology is the oldest among those used in pulsed applications, it's not obsolete. Si BJT devices offer some benefits, which are listed in the tech brief. However, it also mentions that newer HPA designs generally don't include Si BJT devices due to their low gain, as well as their need for expensive and environmentally unfriendly beryllium-oxide (BeO) packages.

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The brief subsequently delves into Si LDMOS technology. Newer than Si BJT, this technology has achieved widespread usage in high-linearity communication applications and broadband CW amplifiers. The document notes that Si LDMOS is a good choice for pulsed applications at frequencies up to L-band.

Wrapping up the brief is a discussion on GaN technology. GaN high-electron-mobility-transistors (HEMTs) represent the latest in RF/microwave power transistors. They offer benefits like high gain and high power levels at S-band frequencies and higher. Product examples for each of the three technologies under investigation are included in the tech brief. In addition, there's a table that lists various attributes of each, allowing readers to see their advantages and disadvantages.

TAKE ADVANTAGE OF Amplifier MMICs with Positive Gain Slopes

MODERN WIDEBAND MICROWAVE systems often require a flat overall gain response with respect to frequency. However, this performance can be difficult to achieve since the gain of most wideband microwave components decreases as the frequency increases. In the tech brief, "Realizing the SWaP-C Benefits of Designing with Positive Gain Slope MMIC Amplifiers," Custom MMIC explains how distributed-amplifier monolithic microwave integrated circuits (MMICs) that exhibit a positive gain slope can be advantageous for system designs.

The tech brief illustrates the response of a typical wideband distributed amplifier, revealing a negative gain slope of around 3 dB from dc to 20 GHz. A wideband system typically incorporates multiple amplifiers, as well as passive elements and transmission lines. Thus, a cascaded system design that includes amplifiers, passive elements, and transmission lines can result in a system with a significant negative gain slope.

As an example, a frequency response is shown of a cascaded lineup that consists of five typical wideband microwave amplifiers along with passive components and transmission lines. The lineup results in approximately 20 dB of negative gain slope from dc to 20 GHz, demonstrating how negative gain slopes must be taken into account.

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Passive equalization is a common approach to compensate for a negative gain slope. However, the document explains some of its drawbacks, such as the addition of components that will increase the size and cost of the overall system. Another concern is additional loss, which affects system sensitivity and noise.

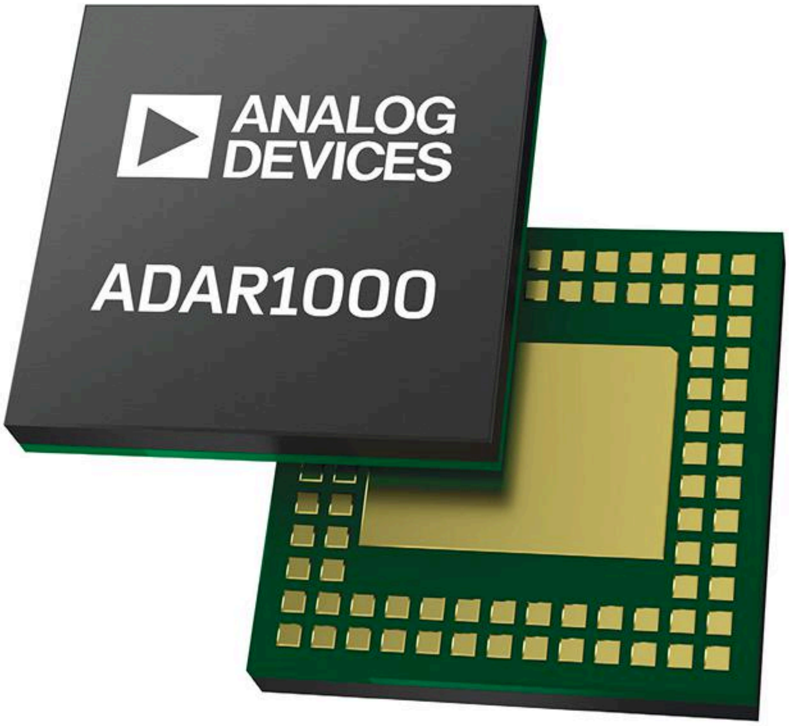
The tech brief explains how a distributed-amplifier MMIC with a positive gain slope can aid system designers. By using these amplifier MMICs to design a system, the system's gain can be equalized without needing additional components. A wideband system performance analysis is presented to demonstrate the benefit of using distributed-amplifier MMICs with a positive gain slope. The brief lays out the performance of typical lineups both with and without equalization. On top of that, it illustrates the performance of two other lineups: one with five amplifier MMICs with positive gain slopes and another with only four.


2-50 GHz
and Beyond
Mini-Circuits

JACK BROWNE | Technical Contributor

Beamformer IC Shrinks Size of X/Ku-Band Antennas

This four-channel antenna beamforming device provides better than 3-deg. resolution for transmission and reception from 8 to 16 GHz.



1. The ADAR1000 active antenna beamforming chip provides the operation of the receiving and transmitting of the cycle from 8 to 16 GHz.

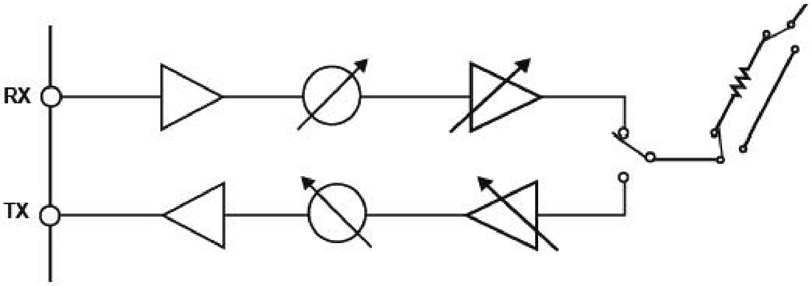
Electronically steerable antennas are gaining favor in radar, communications, and satellite communications (satcom) applications due to several key benefits. The capability to re-position an antenna quickly, the availability of low-profile designs, and longer operating lifetimes continue to make active electronically steered antennas (AESAs) attractive choices compared to mechanically steered dish antennas.

All of these applications require a transmit and receive function with gain and phase controls that can significantly increase the size of the antenna with many radiating elements. However, that's not the case with the ADAR1000 active antenna integrated circuit (IC) developed by Analog Devices *(www.analog.com)*. This four-channel X/Ku-band antenna beamforming chip provides 31-dB gain from 8 to 16 GHz with full 360-deg. phase control. It also includes dedicated memory and power detectors for ease of use. All that in a 88-pin LGA package measuring just 7 × 7 mm.

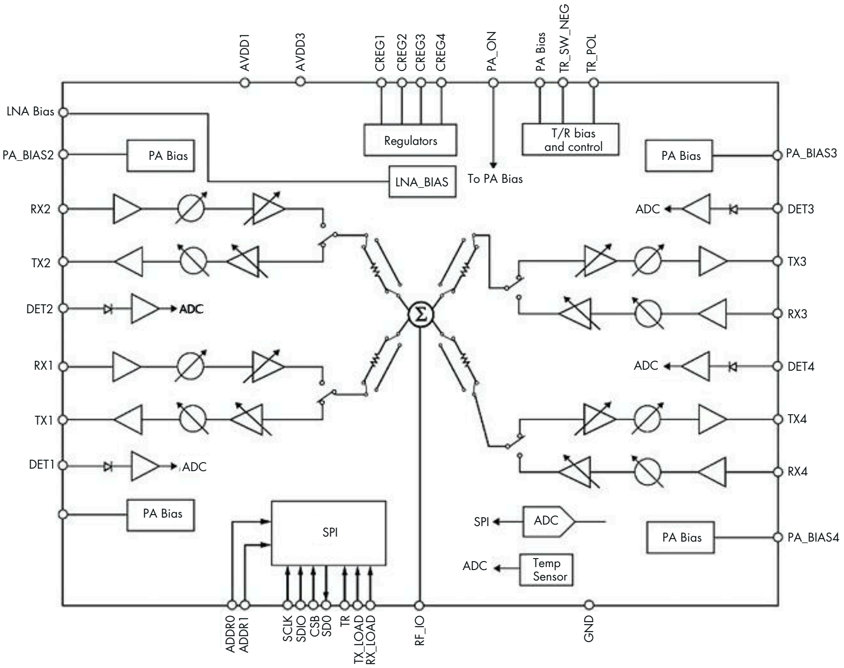
TDD AND FDD

The ADAR1000 *(Fig. 1)* isn't simply an active antenna chip—it's a programmable antenna array in a miniature chip-sized package that enables four channels of efficient transmission and reception across its wide frequency range. It supports time-division-duplex (TDD) operation, replacing as many as 12 discrete components for antenna phase and gain adjustments from 8 to 16 GHz.

The chip also can be configured to work in a frequency-division-duplex (FDD) system, such as a satcom application, by running the transmit (Tx) function only in one IC and the receive (Rx) function only in a second IC, powering off the unused portion of the circuit. The densely packed active circuit



2. The beamformer IC accomplishes TDD operation by means of four identical Tx/Rx channels.



3. An active vector modulator architecture helps achieve phase control where needed in the ADAR1000 system.

is fabricated in a commercial SiGe BiCMOS semiconductor process with high repeatability.

The ADAR1000 may simplify the design of communications systems antennas, but it does not sacrifice performance. It maintains gain flatness of typically ±1 dB for any 1-GHz bandwidth between 9 and 14 GHz, with gain flatness of typically ±2 dB from 9 to 14 GHz and typically ±3 dB from 8 to 15 GHz. The gain variations with temperature are typically ±3.5 dB for operating temperatures from −40 to +85°C.

Four power detectors in the IC have 30-dB detection ranges; an 8-b analog-to-digital converter (ADC) can be used with the power detectors and temperature sensor. It even includes bias and control circuitry for use with external Tx/Rx modules to further simplify the design process.

With its high level of integration, the four-channel ADAR1000 active antenna beamforming chip supports communications, surveillance, and next-generation radar systems. The gain and phase of all four receive and transmit channels can be independently programmed for flexibility, with settings stored in built-in memory or external memory for ease of access and construction of multiple-channel antenna configurations.

In receive mode, the four Rx input signals are combined to a common RF input-output (IO) package pin. In transmit mode, the RF IO signal is divided into four Tx signals for transmission. The better than 6-b digital resolution results in gain resolution that's finer than 0.5 dB and phase resolution better than 2.8 deg.

A four-wire serial programming interface (SPI) provides control of the on-chip registers for the ADAR1000. In receive (Rx) mode, the four Rx inputs are combined to a common RF_IO pin. In transmit (Tx) mode, the RF_IO signal is split into n additional signals, with two address pins to allow software selection of one out of four core chips on the same serial lines. Furthermore, dedicated Tx and Rx load lines provide synchronization of all core chips in the same array, and a single TR pin enables very fast switching between transmit and receive modes.

The ADAR1000 accomplishes time-division-duplex (TDD) operation by means of four identical transmit/receive (Tx/Rx) channels *(Fig. 2)*. Each Rx channel has its own low-noise amplifier (LNA) as well as a phase shifter and a variable-gain amplifier (VGA). Each Tx channel has a VGA followed by a phase shifter and a driver amplifier *(Fig. 3)*.

The Tx or Rx signal path is selected by means of a high-speed Tx/Rx switch. An attenuation stage with switched 0- or 15-dB attenuation is included in the Tx/Rx common path between the Tx and Rx modes before connecting to a passive 4:1 combining/dividing network. Gain control is provided for each channel to compensate for the effects of temperature and processing, and to be able to taper the beam for low side-lobe levels.

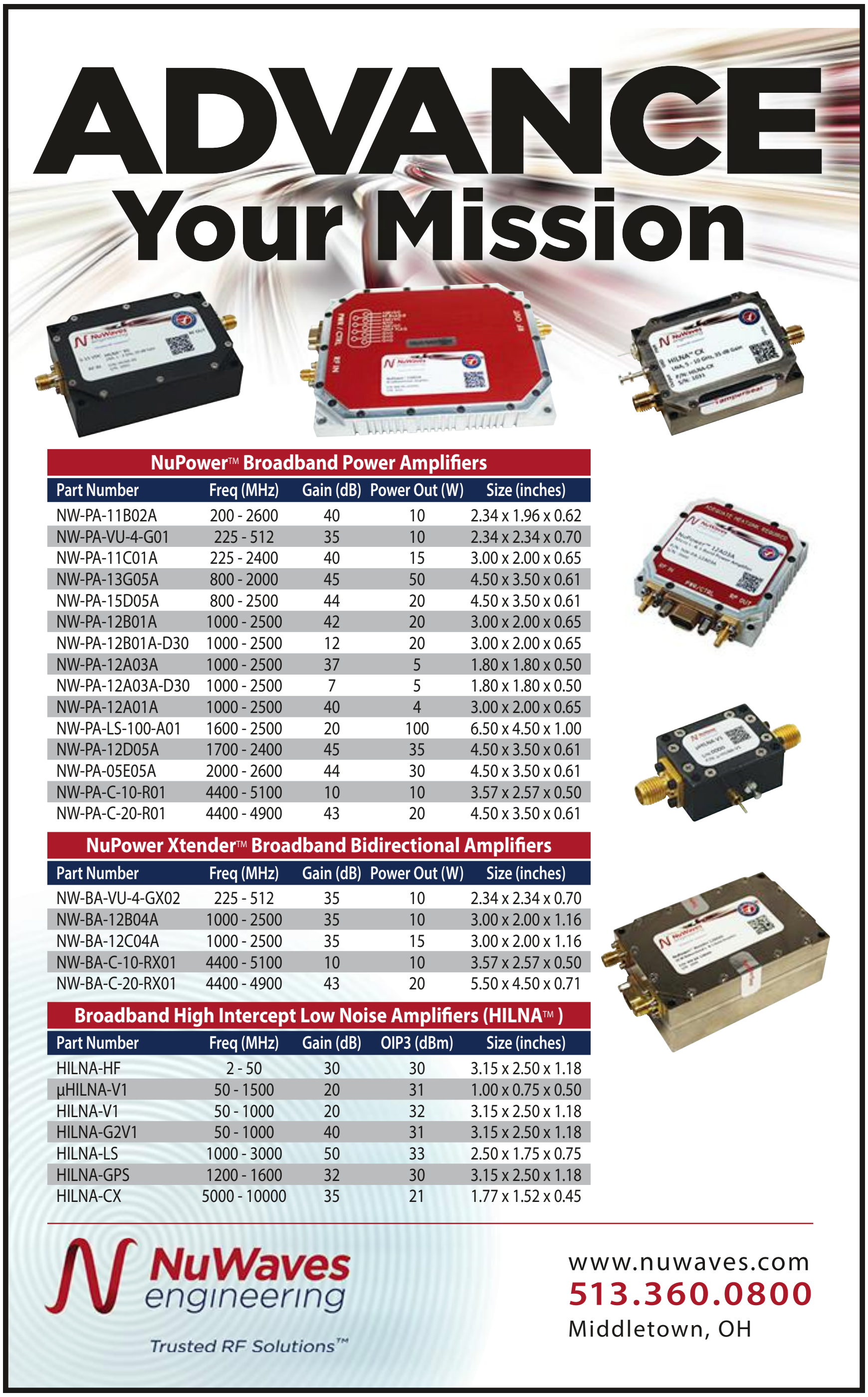
In terms of density, the ADAR1000 is more like a system than a device, packing in the aforementioned temperature sensor, 30-dB power sensors, and ADC. It accomplishes amplitude control though a combination of independent Rx and Tx path VGA adjustments, which provide a gain control range of more than 16 dB, and a switched 0/15-dB attenuator shared between the Tx and Rx channels. The amplitude control range between the two devices is effectively more than 31 dB.

A total of 8 b of digital control is used by either the Rx or Tx channel for amplitude control. The VGAs require 7 b of control to ensure a minimum step size of 0.5 dB with less than 0.25-dB error for all operating conditions. The eighth bit controls the state of the switched attenuator. A portion of the amplitude control range would typically be used to compensate the channel gain for temperature, process variations, and amplitude variations in the phase shifter as a function of phase setting. The remaining portion of the control range can be used for other amplitude control functions, such as tapering for side-lobe control.

Beyond its flexibility and programmability, the ADAR1000 features power-saving bias modes. It's designed to simplify the addition of antennas, at least to the frequency range of 8 to 16 GHz, without occupying too much of an electronic product's total package.

Beyond its flexibility and programmability, the ADAR1000 features power-saving bias modes. It's designed to simplify the addition of antennas, at least to the frequency range of 8 to 16 GHz, without occupying too much of an electronic product's total package. In addition to easing the design process, it provides a generous number of options in terms of final product size, weight, and power (SWaP), without overly sacrificing product performance. mw

ANALOG DEVICES INC., One Technology Way, Norwood, MA 02062; www.analog.com



MARK MILLER | Product Manager, L-com Global Connectivity
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Differentiate Between 4G LTE and Non-Standalone 5G NR Antennas

Due to its more advanced technology, non-standalone (NSA) 5G New Radio will require different antenna requirements than those of 4G LTE systems.

In December 2017, the Third Generation Partnership Project (3GPP) issued Release 15, which created an early version of 5G, called 5G non-standalone (NSA). NSA 5G New Radio (NR) implements some of the key 5G application features, namely enhanced mobile broadband (eMBB) and ultra-reliable low-latency communications (URLLC), as well as detailing new sub-6-GHz frequencies and introducing millimeter-wave (mmWave) frequency bands.

Some of the methods enabling new NSA 5G NR specifications have been available in 4G LTE Advanced Pro, namely multiple-input, multiple-output (MIMO) and carrier aggregation (CA). However, Release 15 defines advanced versions of these technologies alongside the need for co-location and compatibility between 4G and 5G RF hardware.

The migration and incorporation of 4G LTE frequency bands, new technologies, new frequencies, and new methods of deployment are significantly changing NSA 5G NR antenna requirements in comparison to 4G LTE antennas. This article aims to describe how the new specifications of NSA 5G NR lead to design, performance, and infrastructure changes in the implementation of next-generation antennas for base stations and user equipment (UE).

INTRODUCTION

As stated, the key features of 3GPP Release 15 NSA 5G NR are eMBB and URLLC.[1] These features are enabled by advanced antenna techniques, antenna tuning, and infrastructure changes regarding deployment of base stations and UEs. These changes directly impact antenna design and technologies, creating a rift between previous 4G LTE antennas and future 5G versions. Beyond opening up additional sub-6-GHz spectrum and assigning new mmWave spectrum for NSA 5G NR, many other operational dynamics exist that define the differences between 4G LTE and NSA 5G NR antennas *(Fig. 1).*

4G LTE BASE-STATION ANTENNAS VS. NSA 5G NR

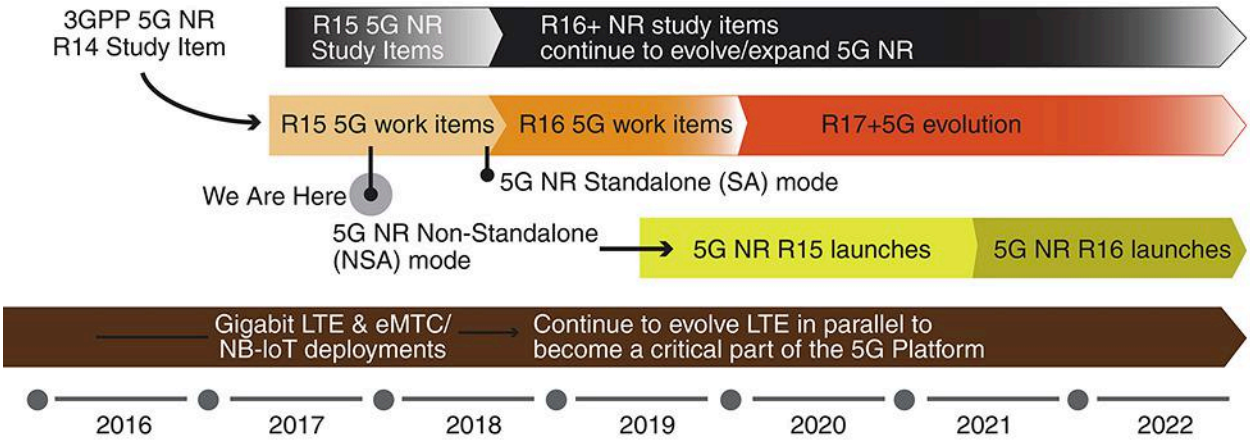
It's important to note that the rollout of NSA 5G NR will likely only include the eMBB features of MIMO and CA, along with much lower latencies. And its rollout will pick up as 4G LTE continues to roll out. However, it will be several years before viable mmWave 5G is introduced. So, the upcoming NSA 5G NR base-station equipment will likely be enhanced 4G LTE technology with additional bands and features. This is the likely scenario until 3GPP Release 16 defines standalone (SA) 5G NR, in which mmWave control plane and communications occur simultaneously, SA 5G NR trials and deployments begin, and 4G LTE bands are refarmed into 5G bands as the technology generations merge.

4×4 MIMO DOWNLINK FOR BASE STATIONS

For NSA 5G NR, MIMO means more antennas, typically implemented as arrays of antennas, or similar to MIMO-capable Wi-Fi routers with several distinct external antennas. Given the cost, reliability, and size constraints for already congested tower sites and future pole and small-cell sites, NSA 5G NR base-station antennas need to be compact and integrated. Otherwise, carriers may incur additional costs for deploying complex, larger, and heavier MIMO antennas.[2.1.1]

As the initial rollouts of NSA 5G NR will likely be below 6 GHz, the 4G LTE base-station antennas will either be co-located or replaced with NSA 5G NR antennas that support 4G LTE bands and the new 3.5-GHz NSA 5G NR band. Also, 4×4 MIMO is required with NSA 5G NR, whereas it was optional with 4G LTE—and not all 4G LTE antennas and base-station equipment have been updated to enable MIMO.

Hence, the main differences between 4G LTE and NSA 5G NR antennas will be that NSA 5G NR antennas will incorporate 4G LTE bands, along with



1. The 3GPP Release timeline for 5G coincides with developments of LTE, which will eventually merge, posing interim challenges for hardware manufacturers designing antennas to serve multiple specifications.

extended frequency operation to the 3.5-GHz band, and possibly lower frequencies to enable more CA combinations. As an interim solution, 4G LTE base stations may be augmented with wideband 3.5-GHz 4×4 MIMO antennas alongside existing 4G LTE antennas and equipment.

MICRO CELLS AND SMALL CELLS

Many telecom companies have already begun deploying 4G LTE pole sites, small cells, and distributed antenna systems (DASs) to provide higher throughput, lower latency, and better coverage in congested and otherwise underserved locations. As a result, a trend of deploying microsite base stations can already be seen in many regions, which will be a key dynamic of the 5G infrastructure.

Some sub-6-GHz NSA 5G NR frequencies, namely the 3.5-GHz band, are significantly higher than other 4G LTE bands. Thus, the RF signals attenuate greater and require better alignment between tower antennas and UEs than lower-frequency 4G LTE signals.

This is where a micro-site expansion to compliment macro-cell coverage is necessary to provide the promised higher throughput and lower-latency NSA 5G NR performance. Micro-cell/small-cell antennas are typically more integrated than larger base-station types. And they may only include the higher-frequency 4G LTE bands and new 3.5-GHz NSA 5G NR band, as nearby macro cells could accommodate lower-priority communications and legacy features.

Many 4G LTE antennas for small cells offer a narrow range of bands. NSA 5G NR micro sites and small cells, on the other hand, will need to field antennas that can serve several of the higher frequency and bandwidth 4G LTE and NSA 5G NR frequencies in more compact packages.

MASSIVE MIMO

One of the future 5G applications is massive MIMO, where a single base-station system can support tens to hundreds of user devices *(Fig. 2)*. This feature enables massive machine type communications (mMTC). A key aspect of massive MIMO is advanced antennas with complex digital beamforming, or hybrid analog/digital beamforming, and large antenna arrays.

For future mmWave NSA 5G NR, an active antenna array with tens to hundreds of elements is only a few inches on a side. For sub-6-GHz frequencies, an active antenna array with a similar number of elements will typically exceed 15 in. on a side, leading to much larger antenna structures for sub-6-GHz massive MIMO. With Release 15, massive-MIMO antenna systems are extended to support a maximum of 256 antenna elements, compared to 64 elements in Release 13.

This contrasts with commonly deployed 4G LTE antennas, which are discrete and not designed with consideration to massive-MIMO applications until Release 13 (which is largely unrealized). Also, with lower-frequency 4G LTE, the antennas typically have lower directivity than higher-frequency NSA 5G NR bands.

Though higher directivity can improve signal propagation to a specific target, serving several moving targets within a region pose a challenge. Hence, NSA 5G NR antenna systems will likely need to be active arrays with some level of steering to account for a new 3D spatial dynamic.[2.2.2] This is especially true for mmWave 5G, where the antenna beams are extremely narrow compared to sub-6-GHz frequencies, and will need to accurately track several moving targets simultaneously.

2. 5G massive MIMO requires active antennas with advanced beamforming technologies to direct narrow beams to stationary and moving targets in real time.

USER EQUIPMENT/HANDSET ANTENNAS

Many hardware manufacturers designate next year, 2019, to produce the first 5G smartphones. These devices will only be augmented 4G LTE smartphones enhanced with 3.5-GHz NSA 5G NR capacity.[3.1.1] However, the RF front-end (RFFE) is already a complex combination of densely integrated antennas, antenna tuners, and RF chips. An additional extremely wideband 3.5-GHz antenna would exceed the available space requirements of most flagship smartphones already boasting a wide range of 4G LTE bands. Thus, NSA 5G NR smartphones may be equipped with antenna technologies capable of serving older-generation and NSA 5G NR bands.

4×4 DOWNLINK MIMO FOR HANDSETS, ANTENNA TUNING, AND LATENCY

NSA 5G NR requires twice the number of downlink (DL) MIMO antennas in a handset, which may be a significant consideration when 4G LTE bands are refarmed to 5G bands. Some handset manufacturers have already addressed this challenge by adopting 4×4 MIMO for the DL. However, even these pioneers must address the 2×2 MIMO uplink (UL) requirement for 5G NR bands n77, n78, n79, and n41.

These new requirements translate to a total of three extra antennas, RFFEs, and subsequent interconnect and RF pathways—even more if separate RF hardware and antennas are used for the 3.5-GHz NSA 5G NR bands and 4G LTE bands. Doubling, or more, the number of antennas compared to 4G LTE also increases the need for wider-bandwidth antennas and more capable antenna tuning and antenna multiplexers.

4G LTE handsets use fast-switching antenna tuning units closely coupled to the several prior-generation and 4G LTE antennas included in a handset. This antenna-tuning technology and antennas, along with their filters, are designed around a much more forgiving latency specification (about 10 ms) than the new NSA 5G NR specifications (1 ms). Hence, future 5G smartphones will require much faster antenna tuners, which can also tune over much wider spectrum with greater bandwidth.

Though near-term sub-6-GHz 5G hardware in handsets will likely be separate from the existing 4G LTE hardware, future integration will presumably reduce the number of antennas and increase the frequency range and tuning capability for each antenna. This also does not consider 5G NR mmWave capability, which should be fully specified in the next few 3GPP Releases.

Once 5G NR Release 16 deployments begin, handset manufacturers will probably want to offer devices capable of tapping into mmWave 5G. This will require co-location of 4G LTE, NSA 5G NR sub-6-GHz, and 5G NR mmWave antennas and hardware in a single slim device.

DUAL CONNECTIVITY FOR HANDSETS

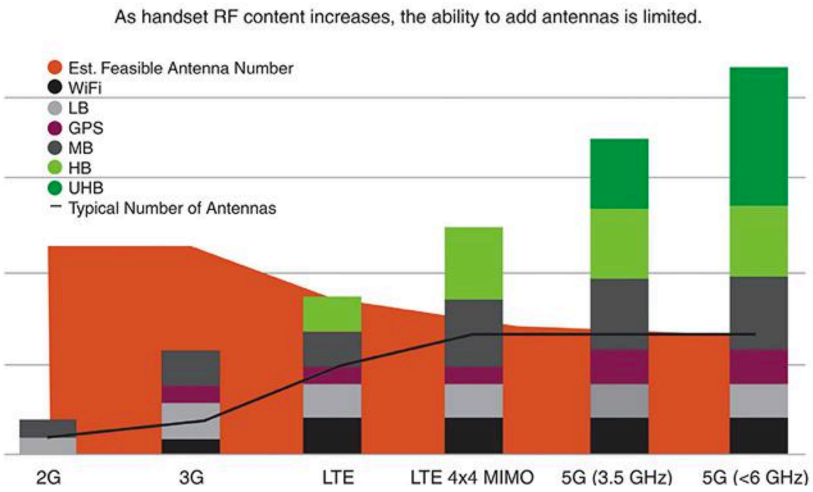
There's already a struggle to fit a desirable number of 4G LTE bands and antennas in today's handsets *(Fig. 3)*. Accounting for the growth in size of modern handsets, 5G handsets will experience a great challenge. The early 5G handsets may have to contend with both 4G LTE and NSA 5G NR dual connectivity.

Thus, it's possible that a handset broadcasting in the higher-frequency 4G LTE bands produces harmonics that bleed into the 3.5-GHz NSA 5G NR band while it's receiving with its 4×4 MIMO antennas. This is due to co-located antennas in near proximity, and is typically solved through more aggressive filtering, which is already needed to serve the number of CA channels.

Current solutions may incorporate additional hardware and antennas to serve the new 3.5-GHz band. Future 5G handsets should benefit from 4G LTE refarming to 5G, as well as enhanced antenna tuning and filtering serving a single ultra-wideband sub-6-GHz 5G antenna that will likely not interfere with 5G mmWave frequencies. This benefit will be offset by the inclusion of additional mmWave 5G hardware, and though higher-frequency antennas are typically smaller, 3D spatial requirements will probably lead to larger and more complex 5G mmWave active antenna arrays.[3.2.1]

ANTENNAS FOR FIXED-WIRELESS BROADBAND

Though portable or fixed 4G LTE modems do exist, these devices are



3. Each evolution of mobile wireless standards has introduced additional frequencies, which requires either additional antennas and RF hardware, or advances in antenna design to include the new bands without sacrificing performance for existing services.

based on essentially the same technology as handsets. Hence, 4G LTE modems offer similar performance as data services to handsets, which isn't viewed as a competitive solution to landline internet service. 4G LTE fixed wireless broadband (FWBB), or fixed wireless access (FWA), services are typically more expensive, have reduced bandwidth, and higher latency than landline services, especially when compared to fiber.

This is likely not the case for upcoming NSA 5G NR FWBB services, which may replace landline fiber in select areas and contribute to a growth market in the next few years.[3.3.1] Unlike 4G LTE modems, NSA 5G NR modems, or consumer premise equipment (CPE), will be more akin to the professionally installed home internet and satellite services, with CPE designed to provide competitive performance to fiber and a high quality of service (QoS). This is accomplished by using the sub-6-GHz spectrum, LTE, for control plane signals, and the mmWave hardware of the CPE and base station to provide extremely high throughput and low latency internet services.

Given these dynamics, the antennas for NSA 5G NR FWBB CPEs will need to be much more than the "rubber duck" antennas commonly used with 4G LTE modems. NSA 5G NR FWBB CPE antennas will be implemented much like NSA 5G NR small-cell or DAS antennas, with robust MIMO, CA, beamsteering, and co-location of sub-6-GHz and mmWave RF hardware.

These requirements will likely require multiple antenna types, including omnidirectional and directional antenna arrays, most likely integrated with onboard antenna tuning and RFFE hardware. These antennas may also need to be designed to remain outdoors, as building materials can significantly attenuate mmWave frequencies. In some cases, there may need to be outdoor antenna systems to connect to indoor CPEs.

The first round of NSA 5G NR FWBB CPEs currently don't offer mmWave functionality, and instead incorporate 4G LTE and 3.5-GHz NSA 5G NR, with 4×4 MIMO and CA to offer higher data speeds and lower latency than standard 4G LTE modems. In this case, these CPEs use more similar antenna technology to 4G LTE modems, but with extended wideband performance to 3.8 GHz, and possibly much lower frequency coverage to 698 MHz to account for nearly the entire LTE spectrum.

CONCLUSION

NSA 5G NR base stations and UE, including handsets, will see additional and more advanced antenna technology compared to earlier 4G LTE systems. Even considering the changes in 3GPP Release 13/14 and 4G LTE Advanced Pro specifications, which implemented many features previously thought pending 5G specification releases, substantial changes have been made to the number, bandwidth, antenna architecture, and deployment of NSA 5G NR antennas.

Though co-location of 4G LTE and 5G antennas is the likely starting position, 4G LTE refarming to 5G and advances in antenna design, antenna tuners, and antenna multiplexers will enable more compact integrated antenna solutions. Massive MIMO and the advent of mmWave SA 5G NR deployments after 3GPP Release 15 will also add mmWave active antenna arrays with advanced digital/hybrid beamforming, extremely wide bandwidth operation, and a large number of antenna elements.

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Design Feature

JACK BROWNE | Technical Contributor

Foundry Builds on InP, GaAs, and GaN Wafers

Providing a diverse array of semiconductor processes, this foundry offers the design and measurement tools as well as the experience to achieve successful wafer runs.

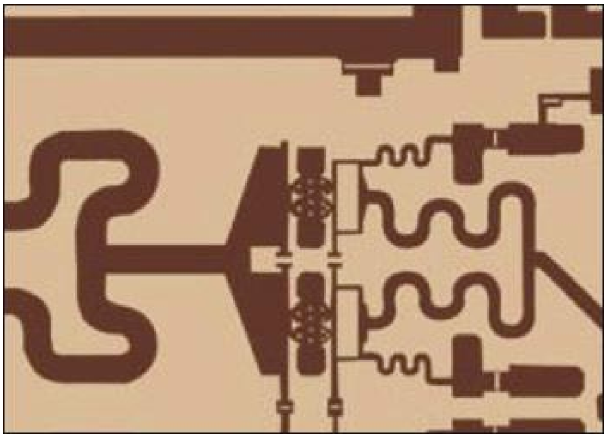
Advanced defense electronics systems often start with microscopic devices like semiconductors as building blocks, and that's certainly the case with Northrop Grumman and its high-volume, high-frequency semiconductor foundry. In addition to selling semiconductor devices such as amplifiers and transistors fabricated in the foundry, the company offers foundry services for its gallium-arsenide (GaAs), gallium-nitride (GaN), and indium-phosphide (InP) wafer processes. Thus, customers can try their own monolithic-microwave-integrated-circuit (MMIC) designs on these high-volume microwave/millimeter-wave semiconductor processes.

The high-volume semiconductor foundry constructs MMICs using heterojunction bipolar transistors (HBTs) and pseudomorphic high-electron-mobility transistors (pHEMTs), depending on the process. Each process starts with a 100-mm-diameter wafer, enabling customers to achieve a healthy volume of MMIC devices for a successful run. To improve the chances for a successful run, final design rule checks (DRCs) are performed by foundry personnel, who have more than a little experience on the requirements for each process.

The various foundry processes share a number of features, including availability of air-bridged metal and back-side via-holes. As a DoD Trusted Foundry, the facility relies on mature computer-aided-engineering (CAE) models within simulation tools such as Keysight Technologies' Advanced Design System (ADS) and the Microwave Office from National Instruments/Applied Wave Research, as well as extensive on-wafer measurement capabilities well into the mmWave frequency range.

Each semiconductor process has different benefits and limits—a designer can choose a process based on the design's goals, such as low noise rather than high output power. Smaller transistor feature sizes will typically deliver higher transition frequencies (f_T's, the frequency at which device gain drops to unity) and higher maximum frequencies of oscillation (f_{max}'s), although usually with less power-handling capabilities for those smaller device features.

Four different InP processes are available, favoring power, high-speed digital, and low-noise/high-frequency (as in mmWave circuits) architectures. All are fabricated on 75-µm-thick InP wafers The first three use Schottky diodes; the low-noise process employs gate-source diodes *(see figure)*. For example, the 1-µm TF2P power process achieves a peak f_T of 80 GHz with peak f_{max} of 150 GHz and is specified for maximum collector-emitter/drain-source voltages (V_{ce}/V_{ds}) of 7.5 V dc.



This microphotograph shows a low-noise InP amplifier fabricated at the Northrop Grumman multiple-semiconductor-process foundry.

The 0.8-µm TF2 digital InP process, which offers a peak f_T of 160 GHz and peak f_{max} of greater than 200 GHz, is tailored for maximum V_{ce}/V_{ds} of 5.0 V dc. For those in need of higher digital speeds and willing to operate with slightly less voltage, the 0.6-µm TF4 digital InP process reaches f_T's of greater than 250 GHz and f_{max}'s in excess of 300 GHz for maximum V_{ce}/V_{ds} voltage of 4.0 V dc.

When state-of-the-art digital speeds are required, the foundry offers its N60D 0.1-µm InP pHEMT process on 75-µm-thick InP wafers. The small feature sizes result in extremely low V_{ce}/V_{ds} of typically 1.2 V dc, but the process is capable of peak f_T of 180 GHz and peak f_{max} of 350 GHz. mw

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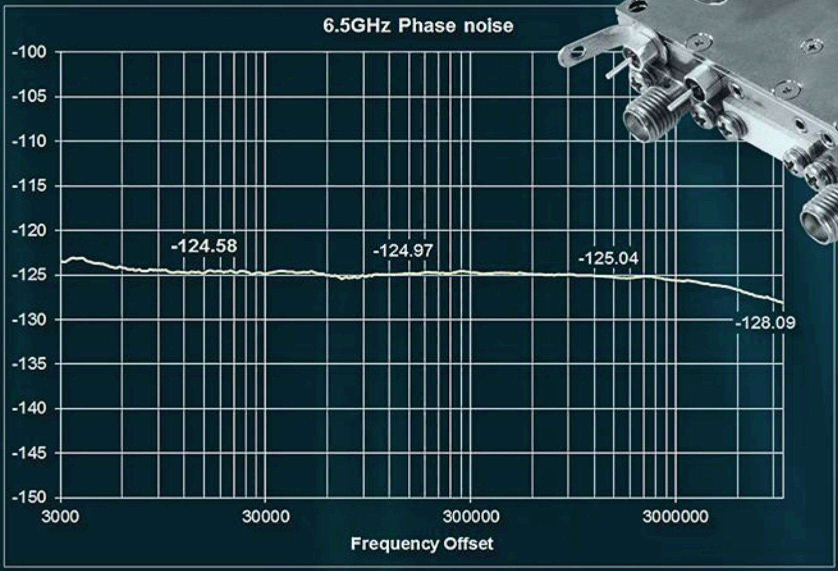

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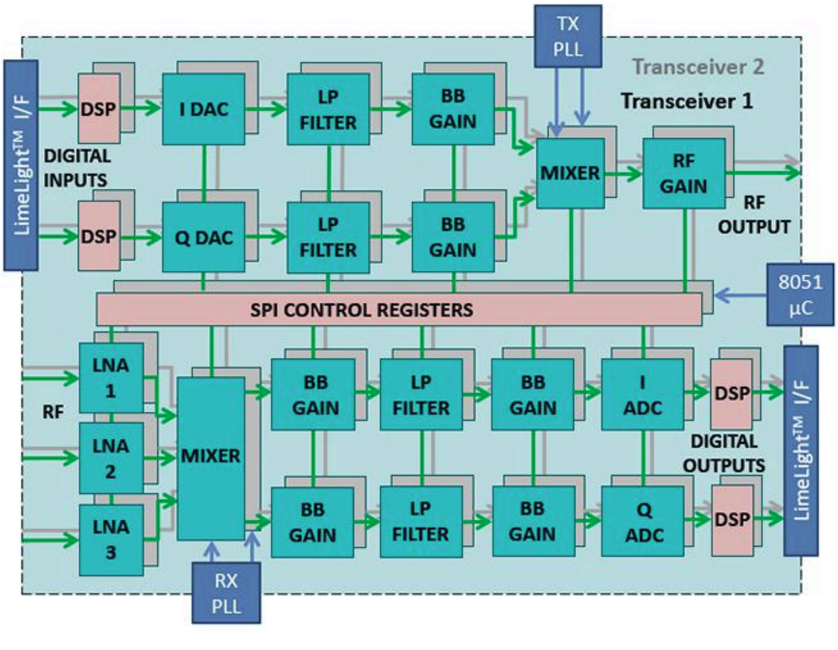
Moving Beyond TETRA and P25

To improve mission-critical communications, countries are turning to LTE. Low-power programmable transceivers and open-source small cells can help ease the transition.

A government's prime responsibility is to protect and defend its citizens. Civil protection is performed by organizations like the police, fire, and ambulance services, while the armed forces defends against military interventions. Secure, reliable, and robust wireless communications form vital aspects of each service.

Historically, the systems have migrated from analog to narrowband digital transmissions that support voice and some restricted data capabilities. The network of each service would typically have been conceived as standalone and usually unable to interoperate with any other system. Therefore, the task of coordinating—for example, police and fire services at an emergency—is fraught with difficulties.



1. The dual-transceiver LMS7002M covers all LTE, TETRA, and P25 frequencies.

Regrettably, it takes major incidences such as 9/11 in America, or the Sewol ferry capsizing off the Korean coast, to focus attention on the problems. Following these and other tragedies, the governments of the U.S., South Korea, and U.K. each decided that better integration between the different branches of emergency responders was an important issue to address. As such, these governments have already legislated to update their emergency service systems in light of these requirements.

The current standards of traditional land-mobile-radio (LMR) technologies such as P25 and TETRA provide voice with limited data. In contrast, commercial cellular smartphones are used by billions of people to speak, browse the internet, stream video, and view photos, demonstrating that user-friendly technology is available for much richer communications. A similar realization in the armed forces has spurred the move toward software-defined radios (SDRs) and cognitive radios.

IMPLEMENTING LTE

Some countries have chosen to bite the bullet and update their systems. The plans are to base the new network for the emergency services on the LTE system, which is often called 4G. This would leverage the vast research and development work that has produced the commercial systems and bring the latest capabilities to the public-safety community. Importantly, spectrum in the U.S. has been made available in the 700-MHz band—it offers excellent propagation characteristics for penetrating buildings and providing large geographical coverage from each base station.

The 3rd Generation Partnership Project (3GPP) is a body that sets global standards for cellular telecommunications, including LTE. This specifies network technologies, including radio access, the core transport network, and service capabilities. The 3GPP requests suggestions from its members for addressing new capabilities, and then assesses and agrees on the technical details that are published as a new specification release. This gives manufacturers the confidence to build equipment with the knowledge that complying with the standards enables them to participate in a mass market and lower costs through economies of scale.

LTE employs an all-Internet-Protocol (all-IP) architecture designed for low latency and high resilience that supports interoperability of both data and Voice over LTE (VoLTE) transmissions. It also can exploit sophisticated digital encryption.

In 2015, 3GPP issued Release 12, which had a focus on technical specifications for mission-critical applications. It included a feature called Proximity Services (ProSe) that allows direct broadcast communication between nearby phones used by safety personnel in the event of a disaster taking down the network. It also includes enhancements in a capability called Multimedia Broadcast Multicast Services, which is required for push-to-talk.

The specification for Release 13 was finalized in 2016 and includes support for Mission Critical Push-to-Talk (MCPTT). This provides group calling, person-to-person calls, as well as prioritization of calls, which are all needed by first responders. It supports direct-mode voice communications, along with a "discovery" feature that lets the user know of other radios within direct-mode range. In addition, a relay capability allows an out-of-range user to hop via another LTE device to access a fixed LTE network. The work continues with Release 14 to include features such as mission-critical data and mission-critical video together with lower latency and enhanced quality of service.

The LTE specification now includes the "must-have" features for public-safety radios, but that does not mean users will switch over immediately. As an example, Germany has around 500,000 users of TETRA and just placed a sizable order for 20,000 more sets. Like many countries, Germany has made significant investments in equipment and infrastructure. Equally obvious is the fact that reliance on outdated technology could hamper its users by denying them the benefits of a broadband system.

One possible implementation strategy would be the gradual introduction of LTE as a parallel service. This would avoid the need to obsolete equipment before the end of its serviceable life, while avoiding the "big bang" of a radical overhaul.

BUILDING FLEXIBILITY INTO PHONES

Handset manufacturers now have a viable solution from Lime Microsystems to produce a very flexible multi-standard phone that supports both LMR and LTE technologies in a single unit. The technology would provide interoperability, which is a very important issue for public safety communications during joint-response efforts. This would allow for a hybrid or blended mix, where the phone can communicate with users of LMR equipment, as well as provide access to LTE networks.

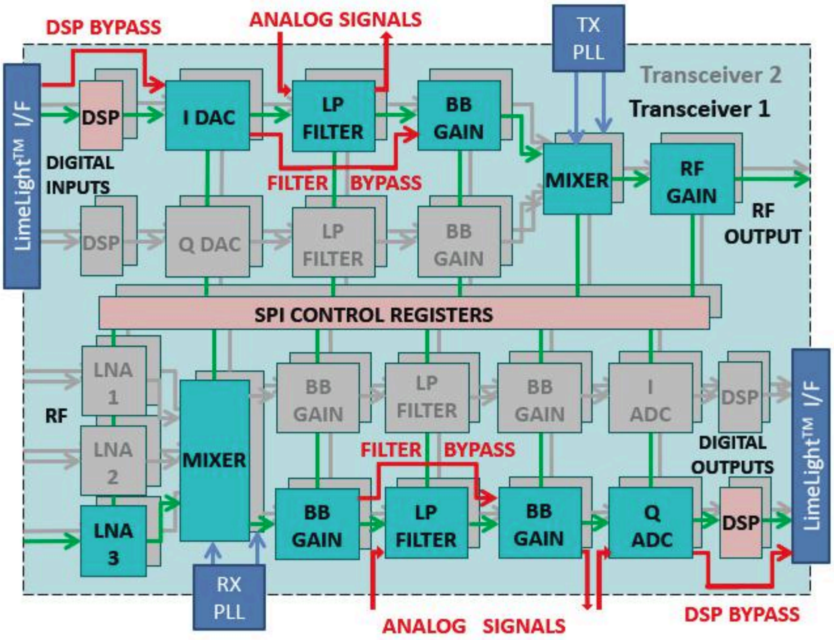
Lime manufactures a range of highly integrated and low-power programmable transceivers, called field-programmable RF (FPRF) devices. These open-source devices are used in a wide range of applications that spans commercial and military communications, as well as industrial and scientific use. The dual-transceiver LMS7002M, for example, covers all LTE, TETRA, and P25 frequencies with in-system programmable frequency, gain, and bandwidth *(Fig. 1)*. The device is compatible with digital formats such as OFDM, WCDMA, and QAM. It also supports 2×2 multiple-input, multiple-output (MIMO) operation in a single device, as well as higher levels, such as 4×4, using multiple chips.

The RF inputs to the receivers can use one of three low-noise amplifier (LNA) blocks, optimized for high-band, low-band, or wideband signals. The architecture features direct conversion, or zero-IF, which is made possible using modern semiconductor technology and astute design techniques. These are then mixed with a local oscillator (LO) and can directly yield a baseband signal.

The chip can be used in a heterodyne system, too, because the device is designed with the flexibility to break out the signal chain to use external components. Therefore, if required, the mixer is able to produce an IF of, say 10.7 MHz, which can then be further filtered and mixed down to baseband.

The receiver baseband gain and low-pass filter networks are fully programmable. The device features both analog and digital filters to provide a powerful combined capability to meet exacting requirements. The signal can be digitized using the on-board analog-to-digital converter (ADC), and is further processed to filter out any converter aliasing artifacts.

The transmit paths accept the in-phase and quadrature (I&Q) components of the signal, which is filtered by programmable digital signal processing



2. Illustrated are external signal paths and bypass options for the transceiver.

(DSP). The data is then passed through the on-chip digital-to-analog converters (DACs) to produce an analog signal that's further filtered and amplified before being mixed up to the required modulated RF waveform. A programmable RF gain block is used to amplify the signal prior to its output from the chip.

The transceiver has been designed to meet the demands of a wide range of applications. However, when system demands are extreme, the designer can use external components to work in conjunction with the LMS7002M.

For example, any of the transceiver lowpass filters can be either replaced or supplemented by external filters. In addition, designers who need higher resolution than the on-chip 12-bit ADCs can output the analog signal to external devices *(Fig. 2)*. Any unused blocks are able to be depowered to minimize consumption.

Low power and ease of design are both enhanced by the ability to run the device from a single 1.8-V rail. The reduction in the number and complexity of external regulators saves both printed-circuit-board (PCB) space and cost, and helps enhance reliability. The device's power consumption is typically 550 mW, which rises to 880 mW in full 2×2 MIMO mode.

The open nature of the FPRF devices and the ability to output or inject anywhere along the signal path means that it can also be used in analog systems. It's therefore possible to consider a dual-mode handset that supports both LTE and legacy LMR using the same devices.

MAXIMIZING COVERAGE

To date, population coverage rather than geographical coverage has driven LTE service providers. This is one aspect that must be addressed for emergency services, which may be called to operate in remote or devastated areas. Fortunately, there are several options.

The maximum transmitted power is covered by 3GPP, and so would need revised standardization first. However, LTE allows for the option of adding fixed small cells to a network. Another option afforded by LTE is to use temporary cells either on a ground vehicle (cells on wheels, known as COWs) or even held aloft by a tethered unmanned aerial vehicle (UAV) or drone. These cells can supplement poor coverage or fill in for first responders where the infrastructure has been destroyed.

The design of a specialist small cell for a limited market such as emergency services can be both complex and expensive, and at first glance would appear to be an insurmountable barrier. However, Lime has created open-source small cells under the banner of LimeNET. The open hardware units are based around SDR cards together with additional CPU processor and memory resources *(Fig. 3)*.

The range of pre-qualified hardware features SDR units that include FPRF and programmable logic to provide the wireless subsystem. The software running on the CPU handles the higher-layer protocols. The SDR can be programmed to the frequency (Band 14 in USA, Band 28 in South Korea) and bandwidth required at any one time.

The open-source community around the world has embraced the concept of freely configurable wireless connections, and already designed numerous paid and free applications that are loaded onto an app store depository. For example, Quortus software could be used on LimeNET hardware to implement what the company terms "bring your own coverage" solutions, resulting in an LTE network that includes both data and VoLTE connectivity. The system is able to connect mobiles internally or wirelessly link to a cell tower functioning on a 2G, 3G, or LTE/4G network.

Open-source hardware and software allow the system to be easily customized by running apps on top. For instance, engineers can modify the hardware to include support for legacy analog wireless links by supplementing the FPRF with additional components. Equally, software engineers can create code that supports features such as ProSe and MCPTT, which are essential for first responders.

3. The LimeSDR SDR card is a key component of the LimeNET open-source small-cell hardware. *(Courtesy of Lime Microsystems)*

4. This is one of the LimeNET open-source base stations. *(Courtesy of Lime Microsystems)*

Similarly, in systems where the spectrum is shared with the public, the emergency-service traffic can be prioritized on a preemptive basis. Designers could conceivably modify the LimeNET to act as a gateway between analog and digital handsets, as well as provide voice interoperability to ease the transition to a fully LTE-based system *(Fig. 4)*.

It's a time of transition for first responders, as advances in their secure wireless systems will provide voice communication along with location tracking, messages, images, floorplans, live-video feeds, and mugshots. A flexible and open system is required to avoid expensive vendor lock-in with proprietary software, while also making it quick and easy to upgrade existing deployed infrastructure with future enhancements to LTE.

To quote from the FirstNet web, "FirstNet was created to be a force-multiplier for first responders—to give public safety 21st century communication tools to help save lives, solve crimes, and keep our communities and emergency responders safe." mw

CHRIS DeMARTINO | Technical Engineering Editor

Familiarize Yourself with the Latest in Vector Network Analysis

This company's non-traditional approach continues to impact the market. Here's a closer look at its 4-port vector network analyzer.

Last fall, I wrote an article titled "Copper Mountain Technologies Takes 1-Port VNAs to the Next Level," which focused on the company's *(www.coppermountaintech.com)* R180 1-port vector network analyzer (VNA). Introduced last year, the R180 covers a frequency range of 1 MHz to 18 GHz, and is well suited for measuring cables, antennas, and more.

I recently had the chance to spend some time with Copper Mountain Technologies' C4409 4-port VNA, so we'll continue that previous article's theme here by taking a closer look at this instrument. *(Fig. 1)*. The C4409 is part of the Cobalt Series of VNAs, which operate in conjunction with a laptop or desktop computer. Specifically, a Cobalt VNA connects to a computer via a USB cable, and that computer is used to display all VNA measurements. This functionality differs in comparison with traditional benchtop VNAs, which have a built-in measurement display.

GENERAL OVERVIEW

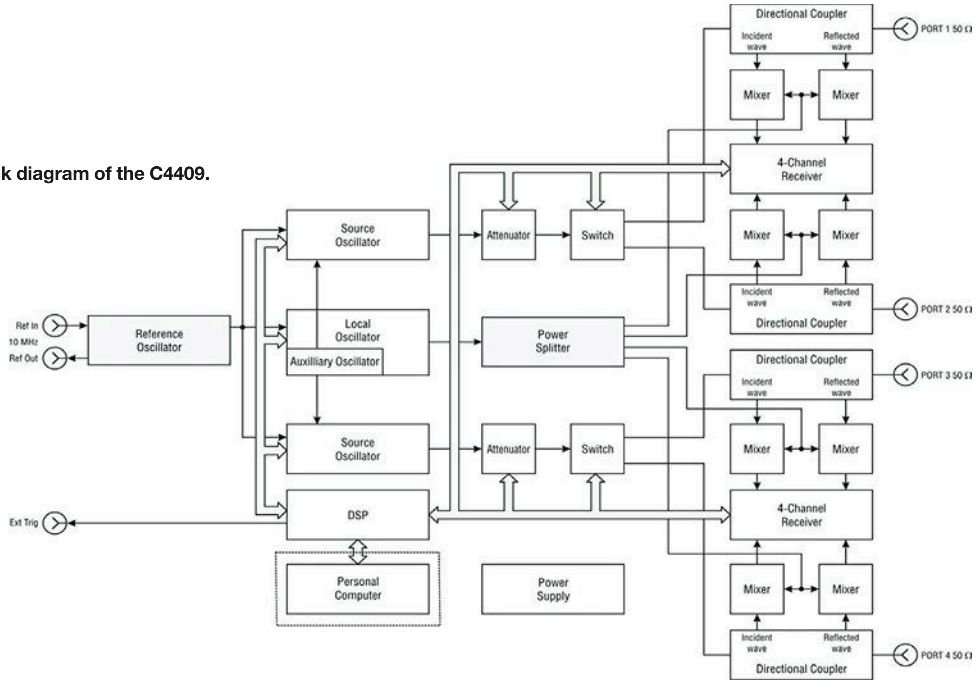
The C4409 VNA covers a frequency range of 100 kHz to 9 GHz. Of particular note is the C4409, as well as three other Cobalt VNAs, can be used in conjunction with the CobaltFX millimeter-wave (mmWave) frequency extension systems. Using these frequency extenders together with a Cobalt VNA allows measurements to be performed at mmWave frequencies, thereby creating a measurement solution suitable for higher-frequency applications like 5G communications.

For purposes of this article, the C4409 VNA was used by itself. The *table* lists some of the main specifications of the C4409, such as measurement bandwidth and dynamic range. The C4409 is built with type-N female test port connectors. Output power from the test ports ranges from −60 to +15 dBm.

1. The C4409 4-port VNA is a member of Copper Mountain Technologies' Cobalt series.

PRIMARY SPECIFICATIONS	
Impedance	50 Ω
Test port connector	Type-N female
Number of test ports	4
Frequency extender compatible	Yes; CobaltFx (4 ports)
Frequency range	100 kHz to 9.0 GHz
Full CW Frequency	$\pm 2 \times 10^{-6}$
Frequency-setting resolution	1 Hz
Number of measurement points	2 to 500,001
Measurement bandwidths with 1/1.5/2/3/5/7 steps	1 Hz to 2 MHz
Dynamic range	100 kHz to 1 MHz; 1-Hz IF BW: 115 dB 1 MHz to 8 GHz; 1-Hz IF BW: 158 dB/162 dB, typ. 8 GHz to 9 GHz; 1-Hz IF BW: 148 dB/152 dB, typ.
Time per point (typ.)	10 µs
Port switchover time (typ.)	0.2 ms

2. Here's a block diagram of the C4409.



Since the C4409 is a four-port VNA, it's not limited to just measuring two-port components. It's also well-equipped to measure multi-port devices-under-test (DUTs), as it can provide users with 3- or 4-port S-parameter measurement data (i.e., $S_{11}\ldots S_{44}$). *Figure 2* shows a block diagram of the C4409.

ADDITIONAL CAPABILITIES

In addition to S-parameter measurements, several other measurements are made possible by using the C4409 (and the other Cobalt VNAs). For example, mixer/converter measurements can be performed using one of two different methods. The first is the scalar method based on the frequency offset mode, which allows users to measure reflections in vector form and transmissions in scalar form (magnitude only) of mixers/converters. An external mixer is not needed to perform the measurement, but a calibration requires an external power meter.

The second approach is the vector method. It allows for measurements of both reflections and transmissions in vector form, including phase and group delay of the transmission coefficient. Utilizing the vector method requires an external mixer, as well as a local oscillator (LO) that's common to both the external mixer and the mixer-under-test. The C4409 and other 4-port VNAs allow one to use the unused port as the auxiliary source to supply the external LO signal to the mixer.

Among the other capabilities of the Cobalt VNAs are time-domain measurements, which enable users to determine the DUT response to various time-domain stimulus types. With time-domain analysis, users can detect physical impairments in cables. It also allows for surface-acoustic-wave (SAW) filter measurements, such as time delay and feedthrough signal suppression.

VNA ANALYSIS SOFTWARE

As mentioned earlier, the Cobalt VNAs differ from traditional benchtop VNAs, as the measurements are not displayed on the VNA itself. To operate a Cobalt VNA, one must connect it to an external computer with a USB cable. That computer then assumes the responsibility of displaying the VNA measurements.

Of course, the first task is to install the appropriate software. Copper Mountain Technologies currently offers a few different software programs free of charge on its website. In the previous article, the RVNA program was used, because it's intended to be used with the company's 1-port VNAs. Also available are the TRVNA and S2VNA programs for its 2-port VNAs (the TRVNA program with instruments capable of 2-port, 1-path measurements, while the S2VNA program is used with instruments capable of 2-port, 2-path measurements). Lastly, the S4VNA program is intended to be used with the 4-port VNAs, which is obviously the one used here.

3. This figure illustrates the interface of the S4VNA software.


RIGOL
Spectrum Analyzer
RSA5065
9kHz-6.5GHz
UltraReal
Center Freq : 2.436125000 GHz
Span : 40.000000 MHz
Atten: 10.00 dB
Ref Level: 0.00 dBm
Trig: Free Run
21:52:30
2017/11/30
Center Freq : 2.4361 GHz
RBW : 200.91 kHz
Span : 40.000 MHz
Acq Time : 31.9960 ms
Total:8060,Cur Trace:1,Time:257.888 s
Meas
Normal
Density
Spectrogram
Density Spectrogram
PvT
PvT Spectrum
PvT Spectrogram
1/2
Mode
FREQ
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AMPT
Help
Key Lock
Touch Lock
Spectrum Analyzer


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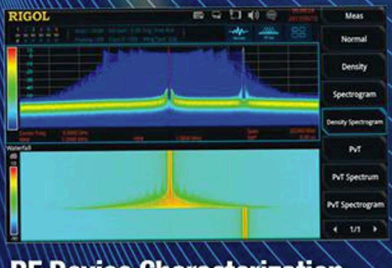
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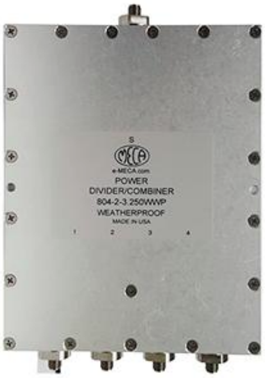
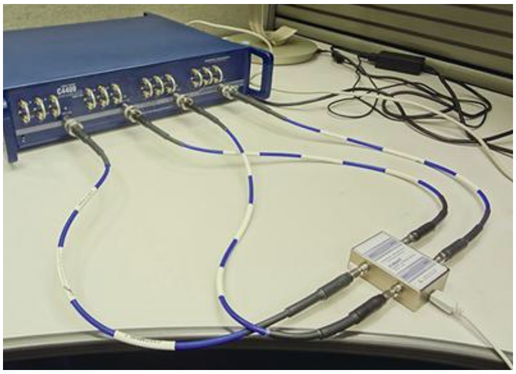
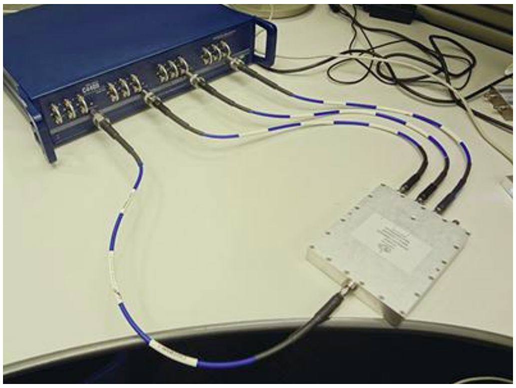


4. This power divider served as the DUT when using the C4409 VNA.

5. Shown here is the automatic calibration module.



6. The VNA is connected to the automatic calibration module. Once connected, calibration can be carried out with just a few mouse clicks.



7. In this figure, the DUT (power divider) is connected to the VNA.

Figure 3 illustrates the S4VNA program, revealing standard VNA functions that are likely already familiar to most VNA users. The user interface (UI) lets users select from various menu buttons, including *Stimulus, Measurement, Format, Scale, Average,* and *Display.* Additional menu buttons are *Calibration, Markers, Analysis, Save/Recall,* and *System*. These options can also be selected from the dropdown menu located at the top.

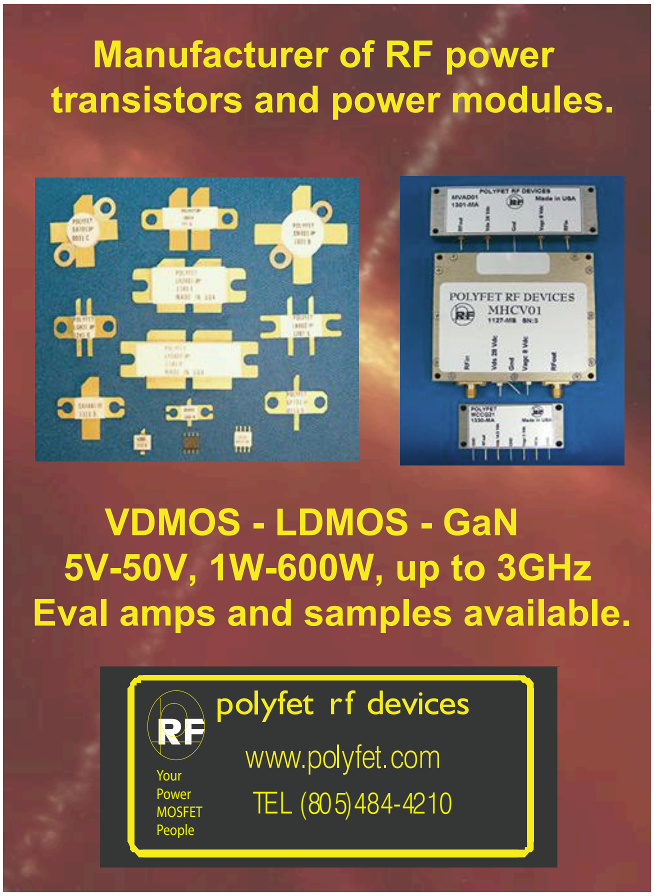
Selecting the *Stimulus* menu button subsequently allows users to enter start, stop, and center frequencies. The number of measurement points and the test port power levels can also be specified here. Furthermore, users are able to specify the IF bandwidth, which can be lowered to increase the VNA's dynamic range.

Not all of the options associated with each menu button will be discussed in detail here, but they should be mostly familiar to those who have already used VNAs. The software has the benefit of being easy-to-use, so it should be relatively pain-free for new users to get acclimated. And to make it even easier, the *Demo Mode* feature (also mentioned in the previous article) essentially displays a simulated VNA measurement, thus allowing users to explore the software without even needing an actual unit to test. The Demo Mode feature can be turned on or off at any time.

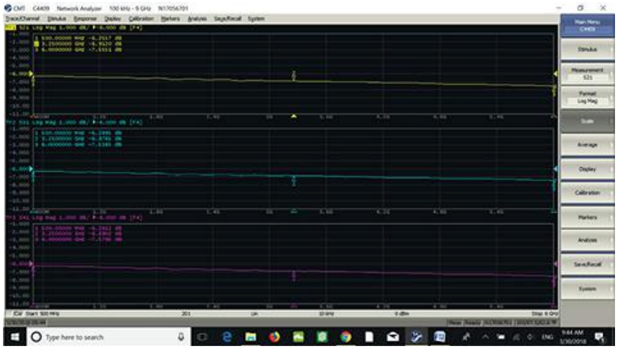
THE C4409 IN ACTION

To demonstrate the C4409 VNA, we'll do a simple measurement. Here, the C4409 VNA is used to measure a model 804-2-3.250WWP 4-way power divider from MECA Electronics *(www.e-meca.com; Fig. 4)*. This component operates from 500 MHz to 6 GHz.

The VNA was calibrated over the full DUT operating frequency range of 500 MHz to 6 GHz. Automatic calibration was performed thanks to the ACM8400T automatic calibration module *(Fig. 5)*. With this module, a 4-port VNA calibration can be performed with just a few mouse clicks.



> Like the R180 1-port VNA featured in the previous article, the C4409 4-port VNA is an effective and easy-to-use solution for anyone in need of a VNA. Whether you are looking for a 1-, 2-, or 4-port VNA, Copper Mountain Technologies products are worthy of consideration.



8. With the C4409, S_{21}, S_{31}, and S_{41} measurement data is displayed simultaneously.

9. These measurement results represent the return loss at each of the power divider ports.

Figure 6 shows the C4409 VNA connected to the ACM8400T. Of course, following calibration, the VNA was connected to the power divider *(Fig. 7)*. A 50-Ω termination was placed on the unused port of the power divider.

Figure 8 depicts the measured insertion loss of the power divider, showing data for S_{21}, S_{31}, and S_{41}. In addition, the measured return loss at each of the power divider ports is represented by the S_{11}, S_{22}, S_{33}, and S_{44} measurement plots *(Fig. 9)*.

While this example is simple, it helps demonstrate the capability of the C4409 to measure multi-port DUTs. In addition, the automatic calibration module greatly simplifies VNA calibration, saving a great deal of time and effort.

Another point to mention is that S-parameter data can be saved as a touchstone file. The S4VNA program also has the ability to load touchstone files, allowing previously measured data to be analyzed.

Like the R180 1-port VNA featured in the previous article, the C4409 4-port VNA is an effective and easy-to-use solution for anyone in need of a VNA. Whether you are looking for a 1-, 2-, or 4-port VNA, Copper Mountain Technologies products are worthy of consideration. And with the CobaltFX millimeter-wave (mmWave) frequency extenders, the company can now offer measurement solutions at mmWave frequencies to enable testing for 5G applications and more. mw

Product

SPOTLIGHT

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Low-Noise Amplifier Features Wide Dynamic Range to 2 GHz

Mini-Circuits' model LHA-23HLN+ monolithic amplifier combines extremely low noise figure with high intercept point from 30 to 2000 MHz. Based on E-PHEMT technology, the RoHS-compliant amplifier provides typical gain of 23.2 dB at 30 MHz, and 20.2 dB at 2000 MHz. It combines low noise figure of typically 1.3 dB at 30 MHz and 1.7 dB at 2000 MHz and high output power at 1-dB compression of typically +26.0 dBm at 30 MHz and +27.9 dBm at 2000 MHz. It has typical output third-order intercept (IP3) of +41.1 dBm at 30 MHz and +45.2 dBm at 2000 MHz. The 50-Ω amplifier is ideal for cable-television (CATV) and wireless communications infrastructure equipment. It is supplied in a 12-lead MCLP housing measuring only 3 × 3 mm. It has an operating temperature range of -40 to +95°C.

Wideband 10-dB Coupler Handles 20 W to 40 GHz

Mini-Circuits' model ZDC10-20403-K+ is a broadband, high-power bidirectional 10-dB coupler designed to handle power levels to 20 W from 20 to 40 GHz. The 50-Ω RoHS-compliant coupler can also pass as much as 3 A DC current. The full-band mainline insertion loss is typically only 1.2 dB while the worst-case full-band coupling flatness is ±1.2 dB and typically ±1.1 dB. The RoHS-compliant coupler is well suited for applications in instrumentation and communications systems. It is supplied in a rugged housing measuring 1.25 × 0.65 × 0.45 in. (31.75 × 16.51 × 11.43 mm) with 2.92-mm female coaxial connectors and rated for operating temperatures from -55 to +100°C.

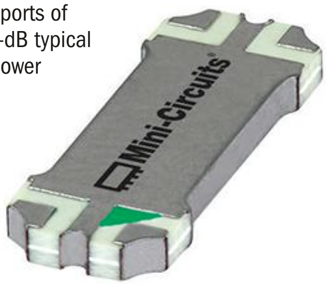
Flexible Coaxial Cable Links DC to 18 GHz

Mini-Circuits' model FL086-6SMNM+ flexible cable assembly is one member of the FL086 Series Flexible Coaxial Cables suitable for a wide range of applications from DC to 18 GHz. It is a 6-in.-long cable with male SMA coaxial connector at one end and Type N male connector at the other end. It is capable of a bend radius as tight as 6 mm. It is constructed with a silver-plated copper-clad steel center conductor and tin-soaked, copper-braided outer shield. The dielectric material is PTFE for low insertion loss, typically 0.3 dB or less from DC to 6 GHz, 0.4 dB from 6 to 10 GHz, and 0.3 dB from 10 to 18 GHz. Return loss is also low, typically 38 dB or better from DC to 6 GHz and 24 dB or better from 6 to 18 GHz. The RoHS-compliant cable assembly handles power levels to 198 W at 0.5 GHz, 140 W at 1 GHz, , and 33 W at 18 GHz and has an operating temperature range of -55 to +105°C.

Coaxial 2.92-mm Adapter Connects DC to 40 GHz

Mini-Circuits' model KFPM-KF50+ coaxial adapter mates female 2.92-mm coaxial connectors to female 2.92-mm coaxial connectors with minimal loss from DC to 40 GHz. It exhibits extremely flat amplitude and return-loss characteristics across its wide frequency range, with typical insertion loss of 0.12 dB or less from DC to 40 GHz with typical VSWR of 1.08:1 or less over the full frequency range. The 50-Ω coaxial adapter features a passivated stainless-steel body and panel-mount configuration for ease of making interconnections through assemblies with panels. The RoHS-compliant coaxial adapter is 0.76 in. (19.30 mm) long and 0.41 in. (10.41 mm) wide and has an operating temperature range of -45 to +100°C.

75-Ω Coupler Spans 40 to 1250 MHz



Mini-Circuits' model BDCH46-122-75+ is a 75-Ω bidirectional coupler that operates over the DOCSIS 3.1 CATV frequency range with excellent characteristics. The coupler achieves low mainline insertion loss of typically 0.15 dB across its full operating frequency range of 40 to 1250 MHz, with full band return loss at input, output, and coupling ports of typically 25 dB. It provides 19-dB typical directivity and handles input power to 2 W and passes DC current to 2 A. The RoHS-compliant coupler includes wrap-around terminations for good solderability. It measures 0.56 × 0.2 × 0.068 in. (14.22 × 5.08 × 1.73 mm) and is designed for operating temperatures from -55 to +105°C.

Instrument-Grade Cables Help Analyze DC to 40 GHz

Mini-Circuits' VNAX Series FlexTest™ Instrumentation Test Cables are especially designed for maintaining stable amplitude and phase characteristics in critical wideband measurement applications, such as in DC to 40 GHz vector network analyzer (VNA) measurements. The precision cable assemblies, such as the model VNAX-2FT-KMVRF+, provide excellent VSWR across the wide frequency range with low insertion loss using a 2.4-mm female coaxial connector to a 2.92-mm male coaxial connector and 2-ft. length of torque-resistant coaxial cable. The RoHS-compliant instrumentation-grade cable assemblies feature low insertion loss of typically 0.8 dB to 6 GHz, 1.6 dB to 26.5 GHz, and 2.0 dB to 40 GHz. The return loss is typically 28 dB to 6 GHz, 20 dB to 26.5 GHz, and 19 dB to 40 GHz. The standard 2-ft. length makes these cables an excellent replacement for original-equipment VNA measurement system cables.

(Continued from page 45)

10 GHz until reaching 18.45 dB at 110 GHz. The trend of increasing gain with increasing frequency indicates that this antenna design is well-suited for a wide bandwidth.

Fig. 12 shows 2D and 3D radiation patterns for some of the resonant frequencies of the elliptical monopole antenna, for φ = 0° and θ = 90° (plane E) at the resonant frequencies of 10 GHz, 26.3 GHz, 44.8 GHz, and 85.3 GHz. For plane E, the angular widths at 3 dB are around 39.2°, 49.3°, 16.2°, and 12.8° for 10.0, 26.3, 44.8, and 85.3 GHz, respectively. For θ = 90°, the secondary lobes can be clearly seen in the 3D radiation patterns. The mainlobe amplitudes for each frequency are 8.6, 8.1, 13, and 17.7 dBi for 10.0, 26.3, 44.8, and 85.3 GHz, respectively.

As wireless communications networks continue to develop, the demand will grow for broadband components, such as antennas. To better understand how a particular form of antenna structure could be modified for broadband use, an elliptical monopole antenna was studied to learn what structural changes would result in more broadband operation. The antenna was simulated with the aid of CST Microwave Studio simulation software. Analysis was performed on the antenna feed, radiating element, and the ground plane to enhance the design for broader-bandwidth operation. Through this analysis, it was possible to adapt the basic design of the antenna to a broad bandwidth exceeding 98.10 GHz. mw

> As wireless communications networks continue to develop, the demand will grow for broadband components, such as antennas.

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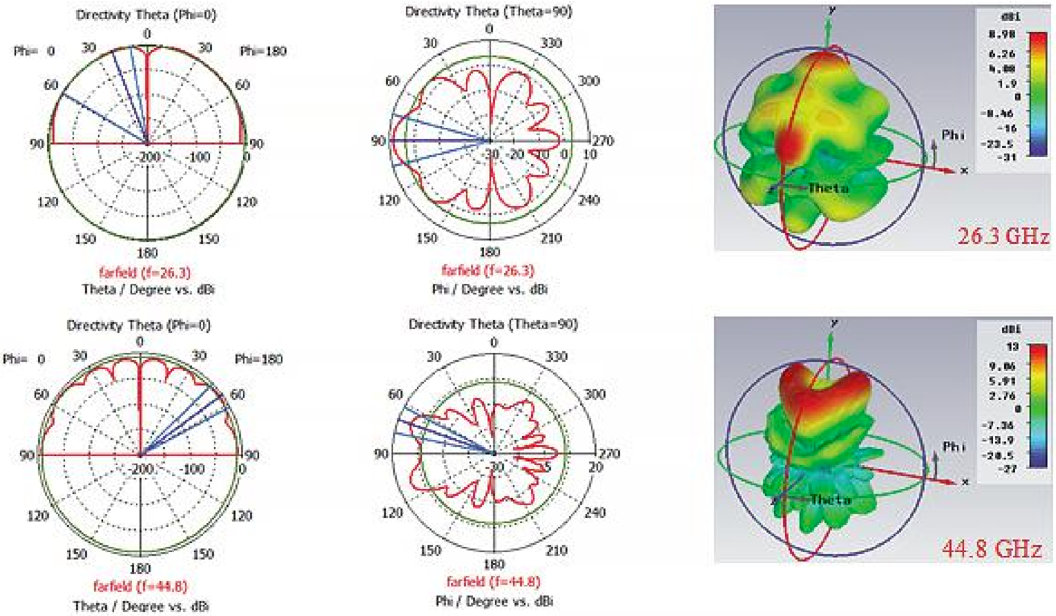


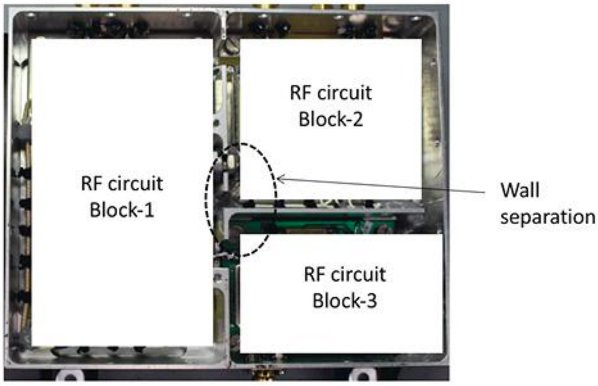
12. These 2D and 3D radiation patterns were plotted for the elliptic monopole antenna at many different frequencies within its range.

(Continued from page 50)

age rating, and series and parallel resonance frequencies can lead to fluctuations in measurement results. Understanding variations in component values with temperature can best be achieved by a test temperature sequence of ambient, cold, hot, and once again ambient temperatures.

MICROWAVE CASE STUDY

A case study of a microwave transmitter was performed to correlate the various aspects linked with the measurements. A single transmitter assembly consists of multiple cards integrated together in a mechanical box with components for active and passive devices *(Fig. 2)*. Testing of each individual card was meant to be performed and optimized for the intended applications.



2. Spacing and separation of RF/microwave circuits within the packaged portions of a high-frequency test system can avoid problems of interference from re-radiated signals.

Further integration and assembly is performed after taking into consideration various loadings and parasitics at the desired frequencies.[11] The main concern in the transponder is related with the off-band emissions, which can lead to triggering and disrupting the tracking function of the system *(Table 3)*.

TABLE 3: ELEMENTS CAUSING INTERFERENCE IN RF/MICROWAVE SYSTEMS

Devices	System effect	Error
Varactor	Drift in VCO	Spectral purity
Mixer diode	Harmonic generation	Rising harmonics levels
Amplifiers/oscillators	Arcing at higher power	Triggering for modulated signal
Heat sink	Ineffective heat dissipation	Radiation and less power

Other parameters, such as capacitor polarity, transistor mounting, and diode connections and handling, are important considerations in the overall performance of the system. Testing of the individual transmitter cards along with the package is intended to be carried out in various temperatures and vacuum conditions as encountered by the onboard package under actual operating conditions. The testing sequence of the microwave transmitter case study is as follows:

- Tightening of all connectors and adapters.
- Checking and accounting the losses of the components (e.g., couplers, attenuators) in the test setup.
- Connectors and cables to be mated properly
- Minimizing the bending of the cables.
- Setting the current limit in the power supply.
- Limiting the number of connections and disconnections.
- Prior to the connections, damage or wear such as dirt, nicks to be checked.
- Powering on the system through external console having in-built safety measures.
- Equipment setting to be adjusted as per the specifications and applications.
- Keeping intact the same equipment setting until the end of the package testing.

Current variations in the respective card or package indicate the degradation or shortening effects. Proper diagnosis involves discovering if the degraded device is part of an IC. The analysis sequence requires separation of the active and passive circuitry in the system and probing the pads to correlate the anomaly. In addition, the RF circuits placed in the package must be segregated to avoid the interference effect as shown in *Fig. 2*. This also helps in the effective grounding of the unwanted signals and further helps in routing of the cables along the walls. Separating susceptible and sensitive cards[12] in the package using separation walls, in conjunction with optimized individual circuit performance, results in avoidance of interference effects.

Any cover plate plays an important role due to the radiation phenomena inherently associated with RF/microwave circuits. The radiation-absorbing material at the appropriate locations of the cover plate minimizes the radiation effect. Any loose connections of either the cable or screw at that point leads to fluctuations due to the effect of radiated sources.

For any high-frequency circuit, RF initialization requires that certain precautionary measures be taken to ensure system integrity and accuracy. For example, the power level should be gradually increased to a desired level with continuous monitoring of the output port. For active device card testing, dc should be applied before RF power is applied.

All losses associated with couplers, attenuators, and other passive components should considered, particularly high-power devices that will operate in a shielded area. A loss of 0.5 dB in a 100-W system leads to a power loss of 10 W, so tightening all connectors and adapters should be carried out before beginning any testing.

Steps to be taken prior to powering up the system include:

- Grounding of all metal parts and terminals so that they have common potential.
- Reading the warning labels and not to exceed the values provided.
- Ensuring that body resistance is minimal.
- Tightening of all connectors and adapters.
- Proper routing of cable and wire inside the package.
- Avoiding sharp edges and avoiding nonlinear materials that generate passive intermodulation (PIM), such as copper and nickel.

Apart from the general precautions, other important aspects to consider include the environment, which should be properly ventilated and have humidity control, routing of PCBs to avoid any 90° twist, the power turning on/off sequence, segregation of nonlinear and sensitive PCBs, and the encasing aspects of ESD-prone devices that can minimize the testing-related failures. RF equipment, which is properly supported with a dc block, limiter, or external attenuator, helps to avoid failures related to over-powering. In contrast, improper handling and avoidance of safety precautions can lead to equipment damage and personal injury.[13]

There's growing need for testing equipment and test methodologies that can help speed mass market adoption. The choice of equipment and the test plan relates directly with the cost, productivity, cycle time, and throughput of the system. Aging and drift associated with the test equipment impact the system's overall measurement repeatability. The equipment employed for testing must be properly calibrated along with proper connectors and low-loss cables. By doing so, testing can ultimately be simplified and become more accurate.

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Fixed GaAs MMIC Attenuators Handle 2 W to 40 GHz

THE KAT-SERIES of miniature absorptive fixed attenuators can be supplied with a wide range of nominal attenuation values, including 0, 1, 2, 3, 4, 5, 10, 15, 20, and 30. The 50-Ω attenuators are fabricated with a highly repeatable GaAs MMIC Integrated Passive Device (IPD) process. They can handle as much as 2 W signal power from dc to 40 GHz and come in a miniature low-inductance surface-mount MCLP package measuring just 2 × 2 mm. The compact attenuators exhibit typical VSWR of 1.30:1. They are usable at operating temperatures from –40 to +85°C and are well-suited for applications in communications, radar, test-and-measurement, defense, and 5G systems.

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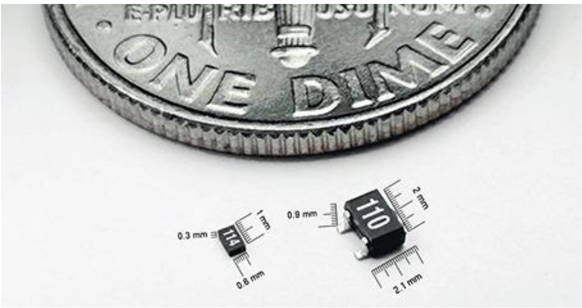

Receiver IC Converts RF Energy to DC Power

THE LATEST VERSION of the Powerharvester receiver, the PCC114 RF-to-dc converter integrated circuit (IC), is designed for energy-harvesting applications in terms of recharging batteries and supplying power where needed in systems. The IC measures just 1.0 × 0.6 × 0.3 mm for space-constrained designs, but can produce dc energy from RF signal levels of –17 to +20 dBm over a wide frequency range of 10 MHz to 6 GHz. It operates with as much as 75% efficiency and harvests energy from all signal modulation types. The chipset includes the complementary PCC210 boost-converter IC, which is supplied in an SOT-23 package and can work with inputs as low as 0.4 V. Reference designs are available and include schematic diagrams, circuit-board layouts, and required bill of materials (BOM).

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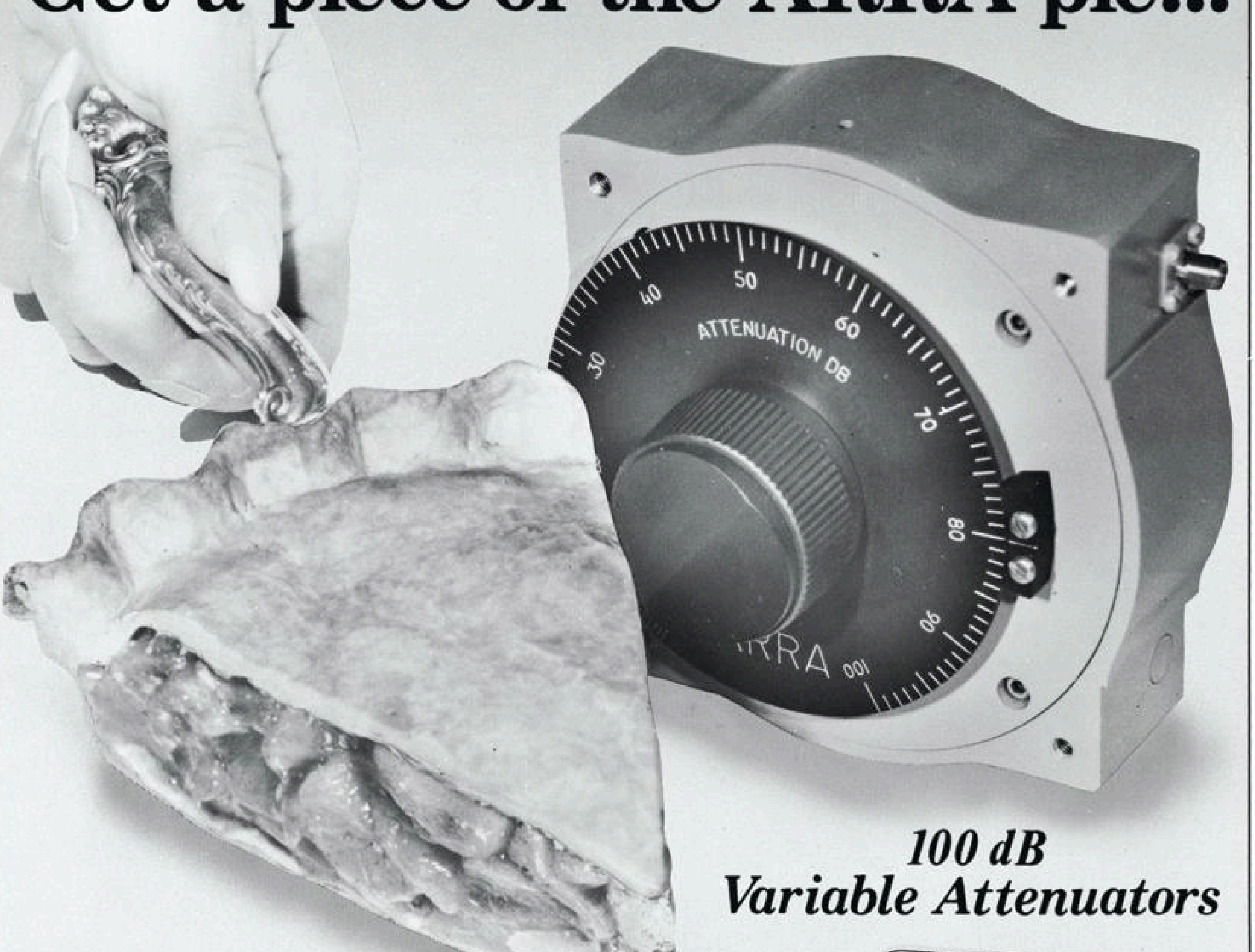

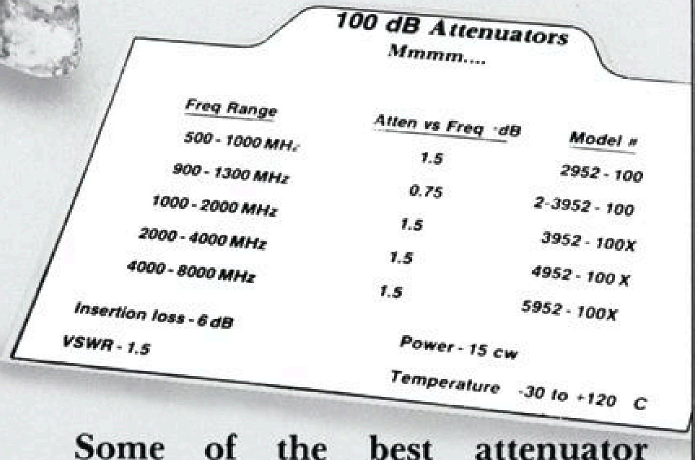

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