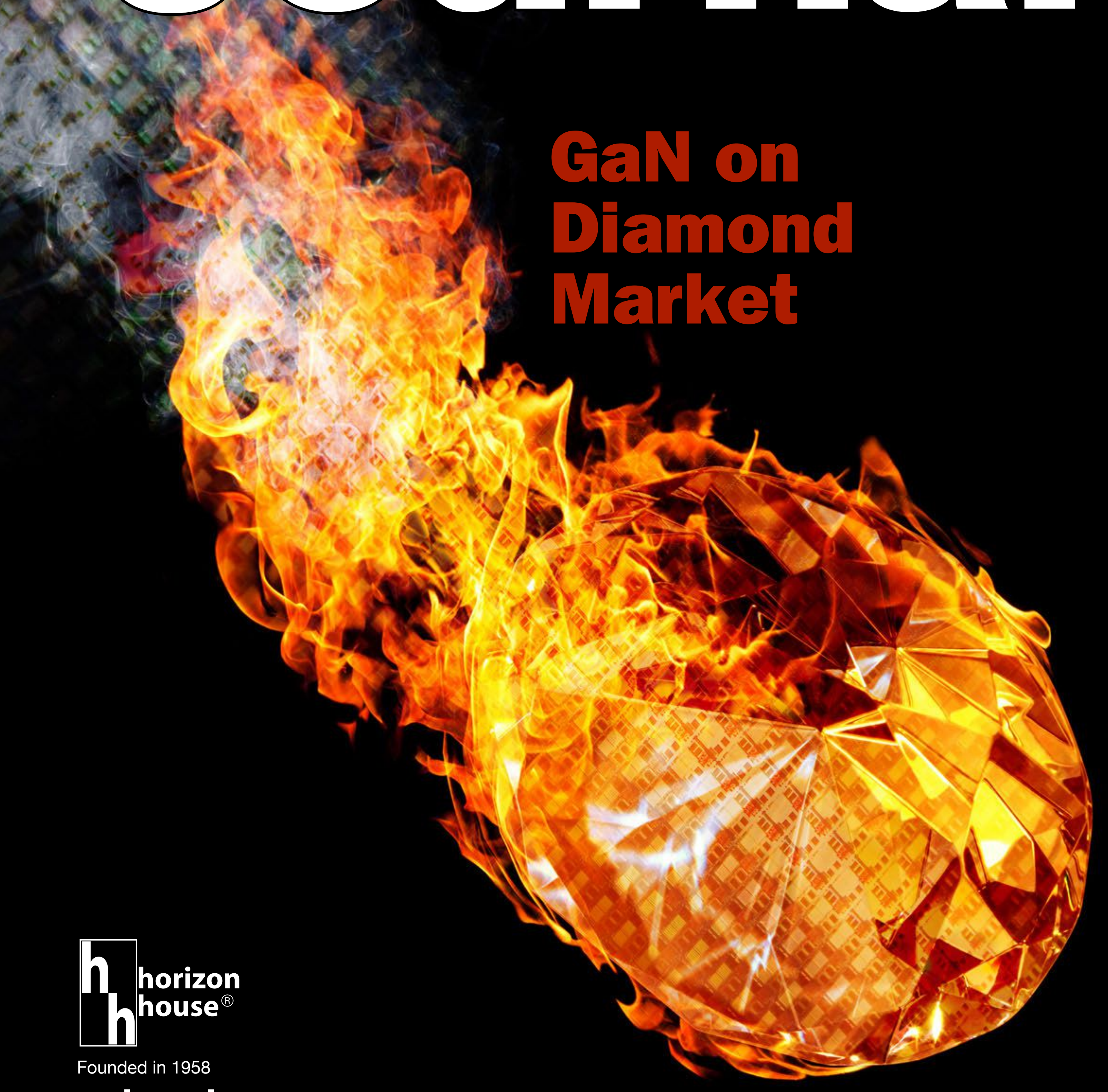
Vol. 67 • No. 6

June 2024

Microwave Journal



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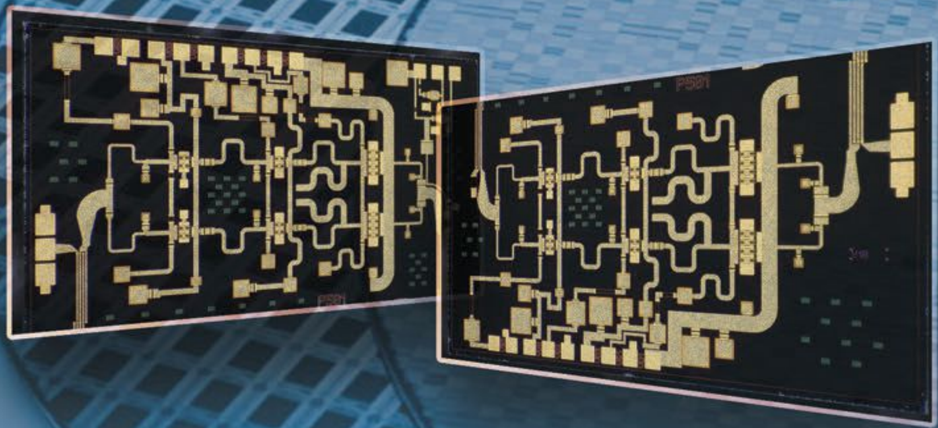


RF Distributed Low Noise Amplifiers

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MMW001T	DC	20.0	17~19	1~3.5	23 @ 10GHz	8.0	145	die
MMW4FP	DC	50.00	16.00	4.00	24.00	10	200	die
MMW507	0.20	22.0	14.0	4 - 6	28.0	10.0	350	die
MMW508	DC	30.0	14.0	2.5dB @ 15GHz	24.5	10.0	200	die
MMW509	30KHz	45.0	15.0		20.0	6.0	190	die
MMW510	DC	45.0	11.0	4.5	15.5	6.0	100	die
MMW510F	DC	30.00	20.00	2.50	22.00			die
MMW511	0.04	65.0	10.0	9.0	18.0	8.0	250	die
MMW512	DC	65.0	10.0	5.0	14.5	4.5	85	die
MMW5FN	DC	67.00	14.00	2.00	19.00	4.5	81	die
MMW5FP	DC	67.00	14.00	4.00	21.00	8	140	die
MMW011	DC	12.0	14.0		30.5	12.0	350	die

Low Noise Amplifiers

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MML040	6.0	18.0	24.0	1.5	14.0	5.0	35	die
MML058	1.0	18.0	15.0	1.7	17.0	5.0	35	die
MML063	18.0	40.0	11.0	2.9	15.0	5.0	52	die
MML080	0.8	18.0	16.5/15.5	1.9/1.7	18/17.5	5.0	65/40	die
MML081	2.0	18.0	25/23	1.0/1.0	16/9.5	5.0	37/24	die
MML083	0.1	20.0	23.0	1.6	11.0	5.0	58	die

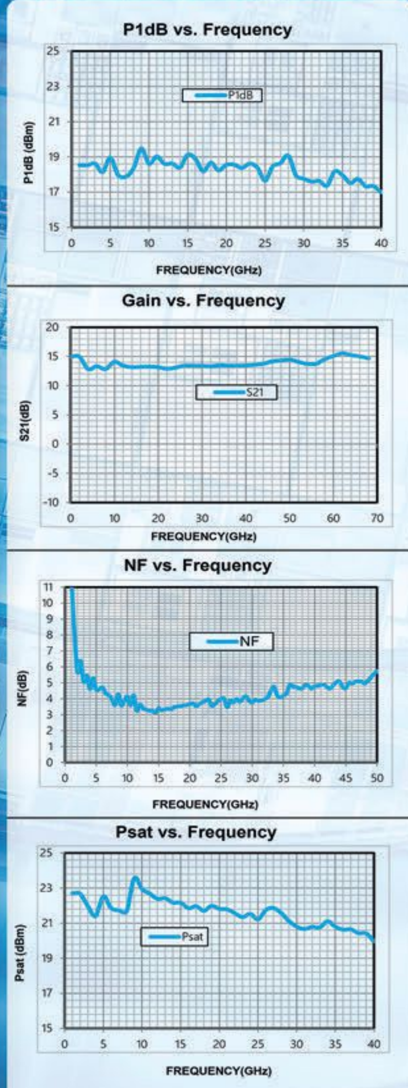
RF Driver Amplifier

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MM3006	2.0	20.0	19.5	2.5	22.0	7.0	130	die
MM3014	6.0	20.0	15.0	-	19.5	5.0	107	die
MM3017T	17.0	43.0	25.0		22.0	5.0	140	die
MM3031T	20.0	43.0	20.0		24.0	5.0	480	die
MM3051	17.0	24.0	25.0	-	25.0	5.0	220	die
MM3058	18.0	40.0	20/19.5	2.5/2.3	16/14	5/4	69/52	die
MM3059	18.0	40.0	16/16	2.5/2.3	16/15	5/4	67/50	die

GaAs Medium Power Amplifier

PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	P1dB (dBm)	Psat (dBm)	Voltage (VDC)	Current (mA)	Package
MMP107	17.0	21.0	19.0	30.0	30.0	6.0	400	die
MMP108	18.0	28.0	14.0	31.5	31.0	6.0	650	die
MMP111	26.0	34.0	25.5	33.5	33.5	6.0	1300	die
MMP112	2.0	6.0	20.0	31.5	32.0	8.0	365	die
MMP501	20.0	44.0	15.0	27 -- 32	29 - 34	5.0	1200	die
MMP502	18.0	47.0	14.0	28.0	30.0	5.0	1500	die

PN: MMW5FP
RF GaAs MMIC DC-67GHz



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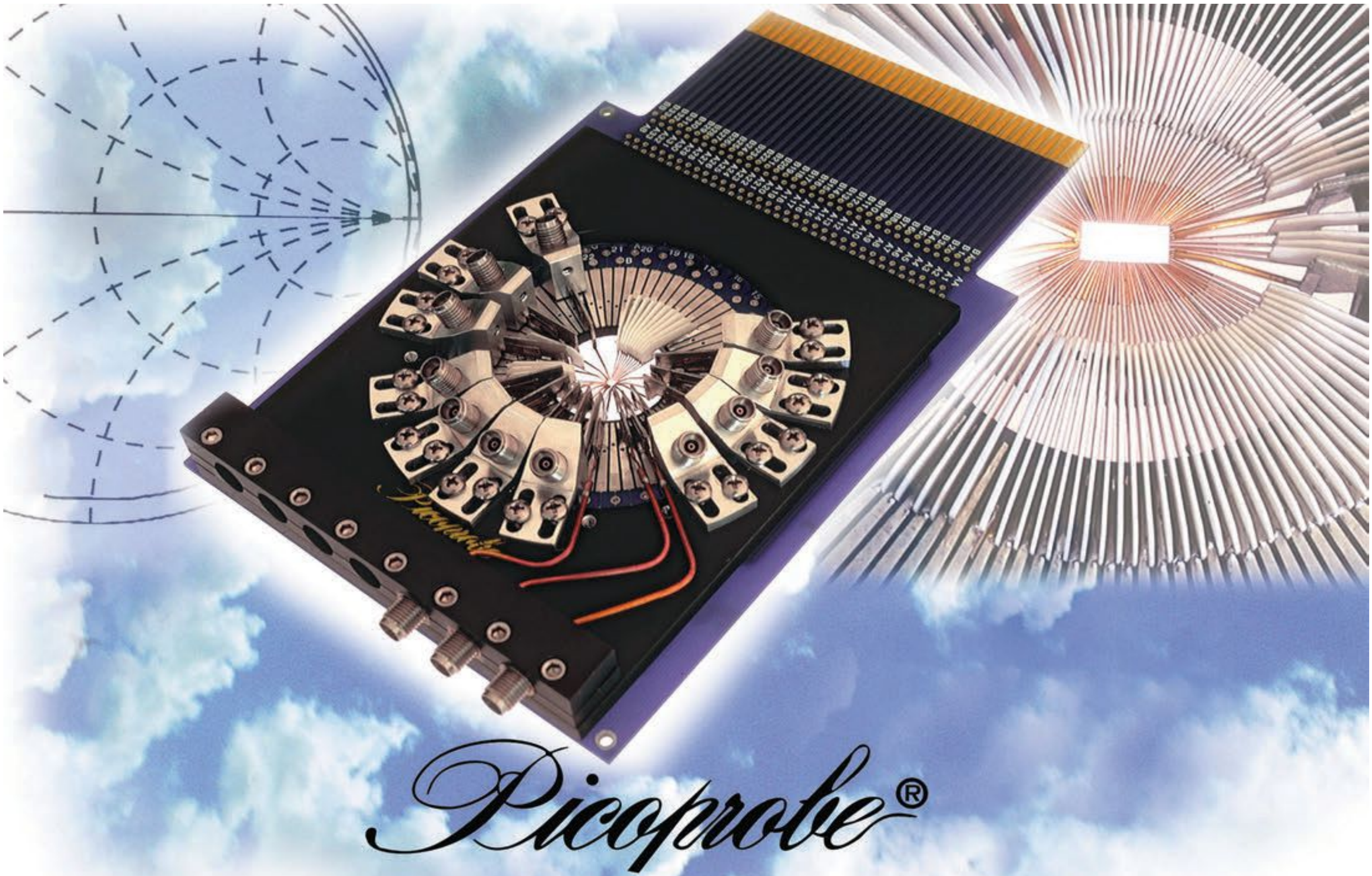

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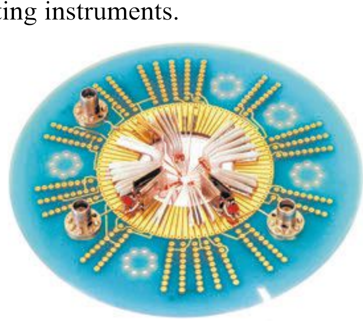

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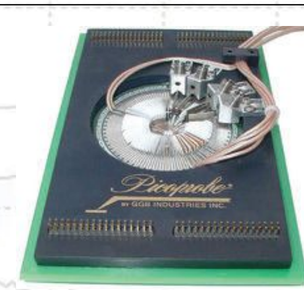

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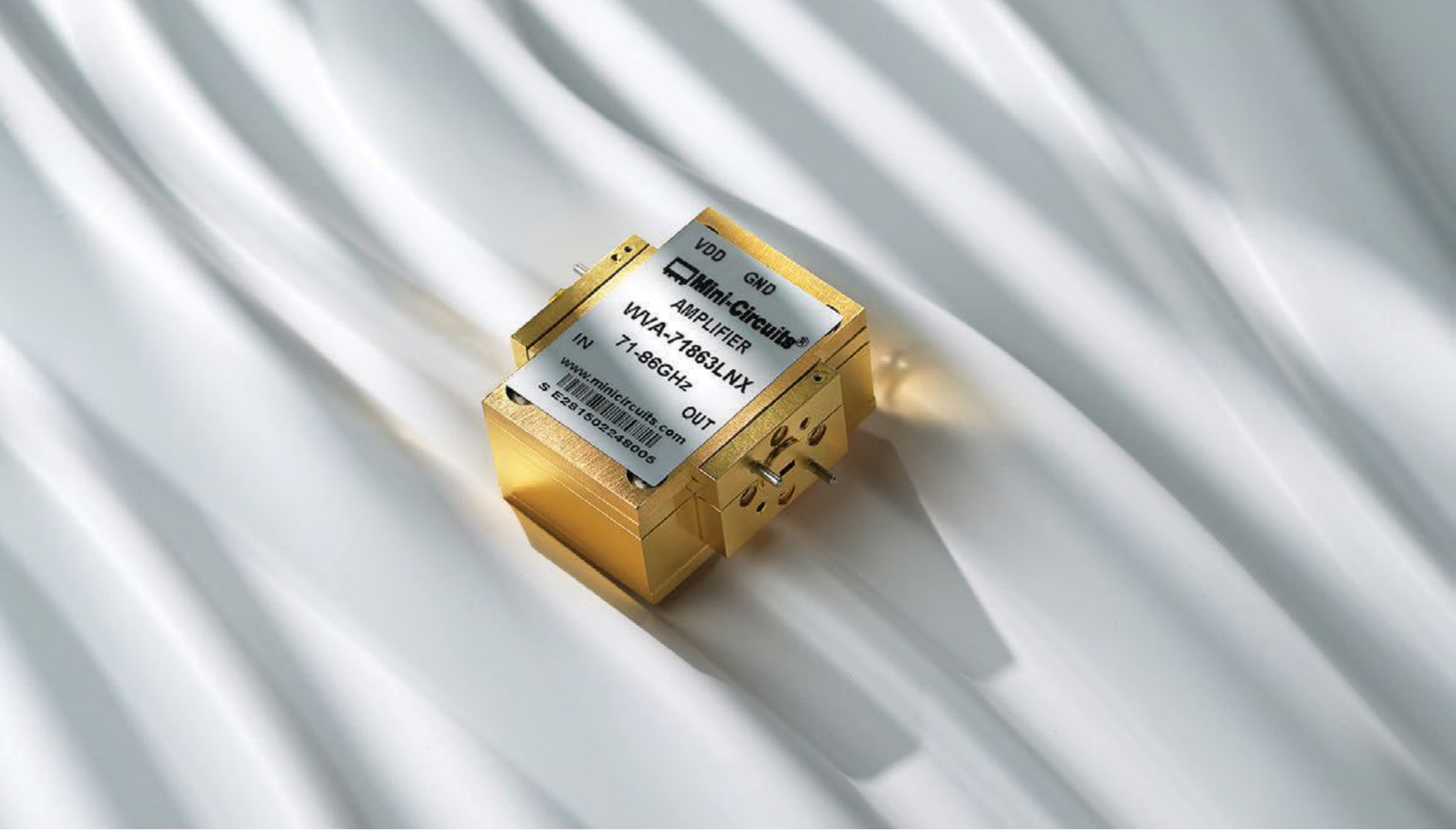

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Key features:

- 71 to 86 GHz
- WR12 Waveguide Interface
- 4.5 dB Noise Figure
- 39 dB Gain

E-Band Amplifiers

ZVA-50953G+

E-Band Medium Power Amplifier

- 50 to 95 GHz
- +21 dBm P_{OUT} at Saturation
- 28 dB gain
- ±2.0 dB gain flatness
- Single supply voltage, +10 to +15V

ZVA-71863HP+

E-Band Medium Power Amplifier

- 71 to 86 GHz
- +24 dBm P_{OUT} at Saturation
- 38 dB gain
- ±1.5 dB gain flatness
- Single supply voltage, +10 to +15V

ZVA-71863LNX+

E-Band Low Noise Amplifier

- 71 to 86 GHz
- 4.5 dB noise figure
- 37 dB gain
- +13.8 dBm P1dB, +18 dBm P_{SAT}
- Single-supply voltage, +10 to +15V

K — V-Band Amplifiers

ZVA-35703+

Medium Power Amplifier

- 35 to 71 GHz
- +21 dBm P_{SAT}
- 17.5 dB gain
- ±1.5 dB gain flatness
- Single supply voltage, +10 to +15V

ZVA-543HP+

Medium Power Amplifier

- 18 to 54 GHz
- +29 dBm P_{SAT}
- High gain, 31 dB
- ±2.0 dB gain flatness
- Single supply voltage, +10 to +15V

ZVA-0.5W303G+

Medium Power Amplifier

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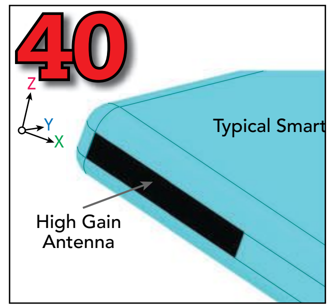

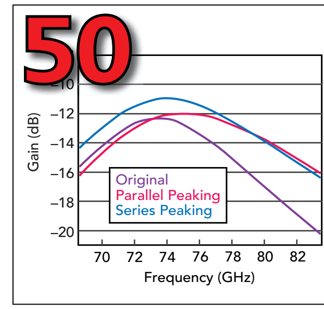

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Ibrahim Haroun, Senior Member, IEEE Research Scientist/RF Systems Developer (retired)

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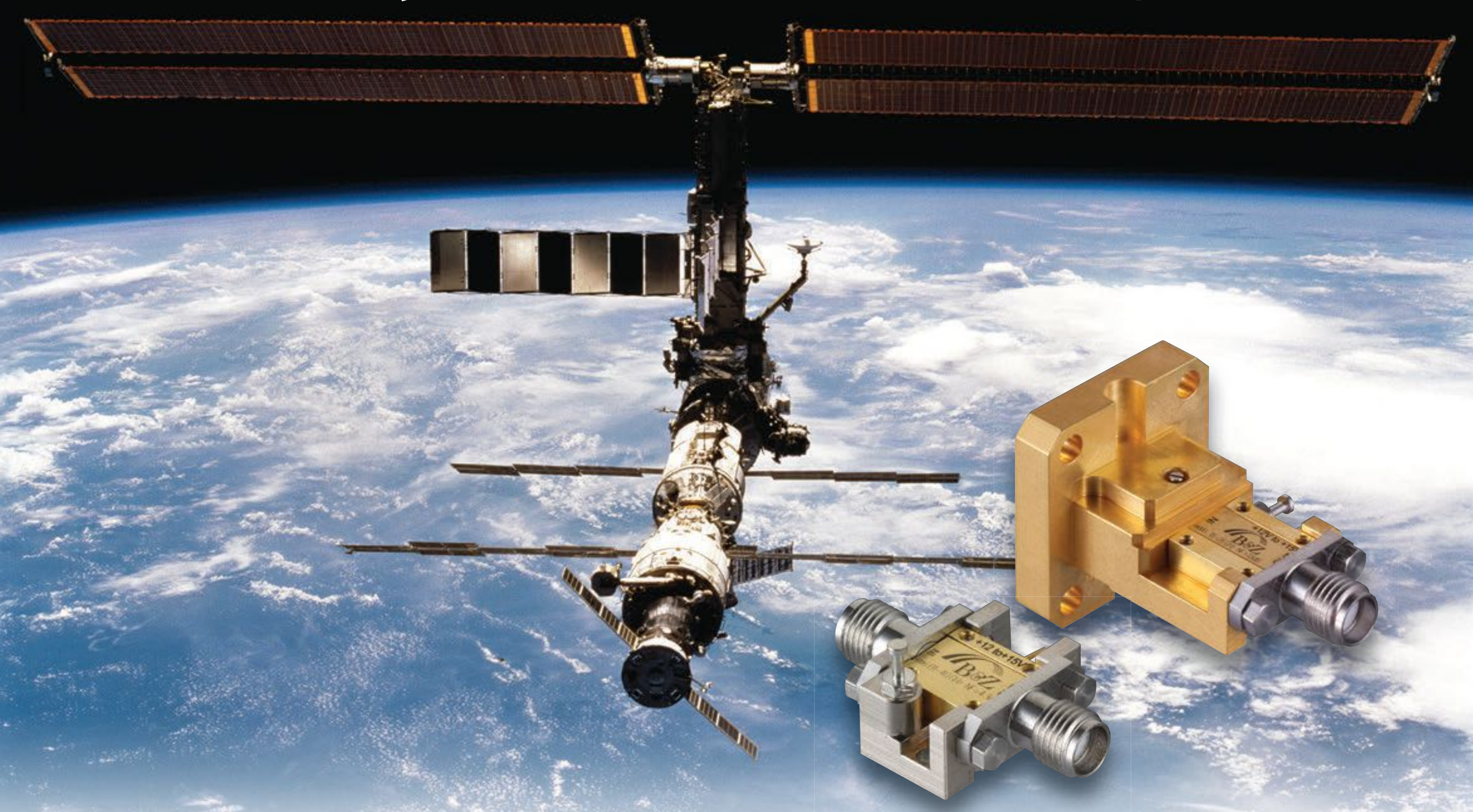

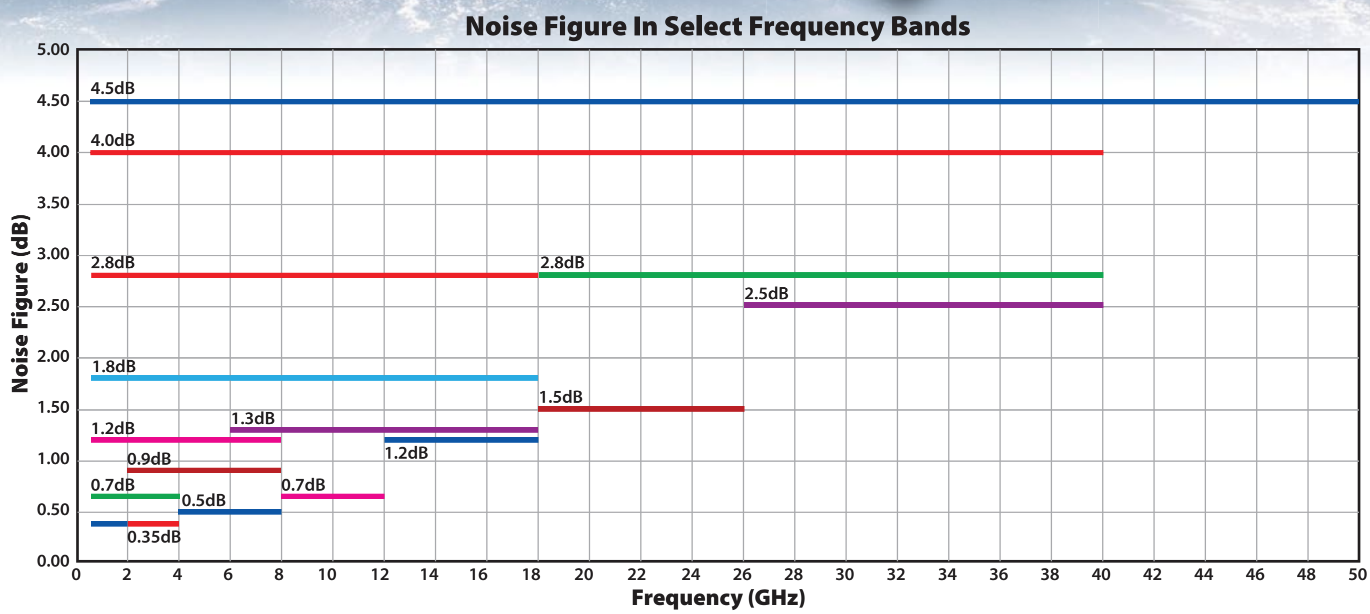

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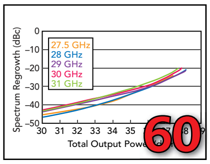

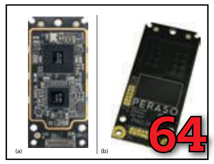

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Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

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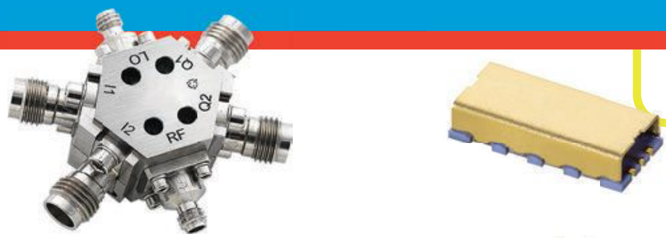

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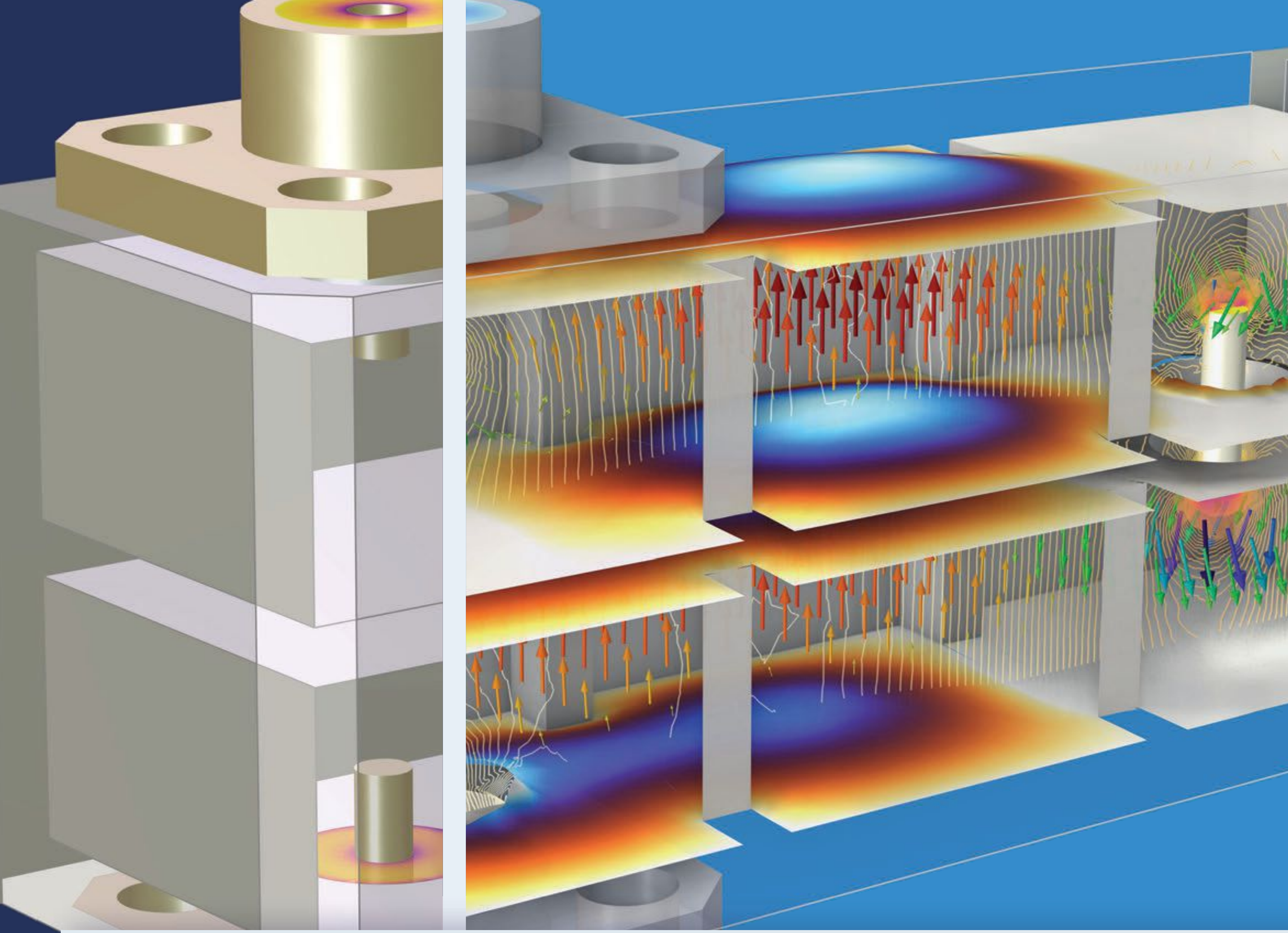

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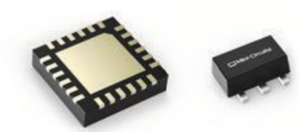

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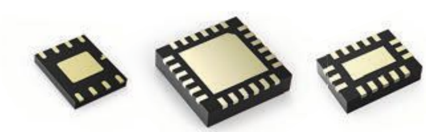

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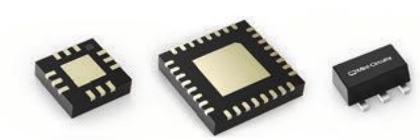

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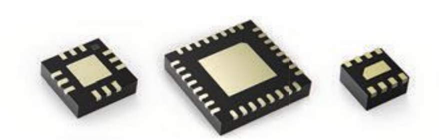

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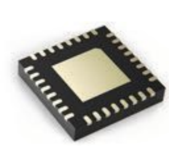

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Rémi Comyn
KnowMade, Sophia Antipolis, France

GaN electronic devices, especially GaN-based high electron mobility transistors (HEMTs), are increasingly used in RF and power conversion applications. Yet in the most demanding applications, GaN device performance and reliability may be limited by thermal considerations such as the channel temperature. Some forms of enriched monocrystalline synthetic diamond have been shown to have the highest thermal conductivity of any known solid at room temperature.[1] Because of this thermal conductivity, the integration of diamond into GaN electronic structures can significantly improve the thermal management of GaN devices. However, such integration has been technically challenging so far. In its latest GaN electronics reports,[2] KnowMade highlights endeavors to leverage GaN with diamond integration in electronic devices based on the recent patent applications filed in this space.

MANY IP NEWCOMERS ENTER THE FIELD

The patent analysis is broad. It considers all patent applications claiming the integration of diamond with GaN electronics without distinction of the material, so it includes applications using single-crystal diamond, polycrystalline diamond and other varieties. The analysis does not differentiate as to the stage of the process where the diamond was integrated. This integration can be a passivation layer, a substrate, a heat sink or another use. It also does not distinguish whether the diamond was integrated as epitaxy, bonding or in some other fashion.

With these guidelines, ***Figure 1*** describes the time evolution of intellectual property (IP) activities related to the technical challenge of integrating diamond materials with GaN. As Figure 1 shows, patenting activities were very limited in the 2000s, but they took off in the early 2010s. The driving forces behind the increase in patent activity were the efforts of pioneers such as Element Six and Group4 Labs.

Founded in 2003 as a U.S. start-up company, Group4 partnered with Element Six in 2008. Group4 was subsequently acquired by Element Six in 2013. In 2016, newly established Akash Systems agreed with RFHIC to jointly negotiate the repurchase of Element Six's GaN-on-diamond IP. Akash acquired all patents and other IP rights related to GaN-on-diamond technology for use in satellite communications and related markets.

In 2021, the number of patent

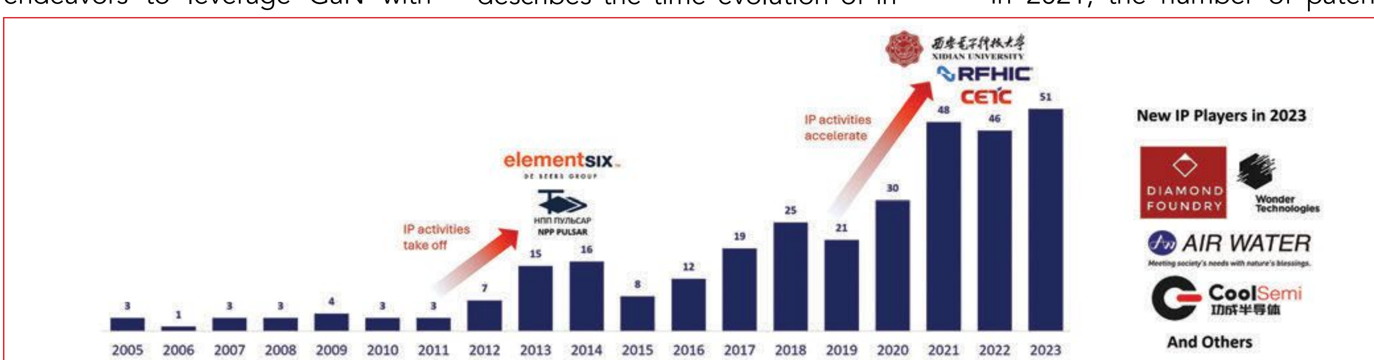

Fig. 1 **Number of inventions (patent families) related to diamond materials with GaN electronics.** ***Source:*** **KnowMade.**

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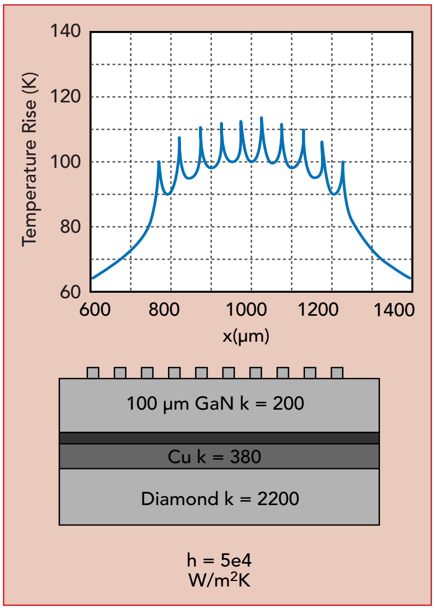

Fig. 2 Diamond Foundry patent drawing for a single-crystal diamond wafer.

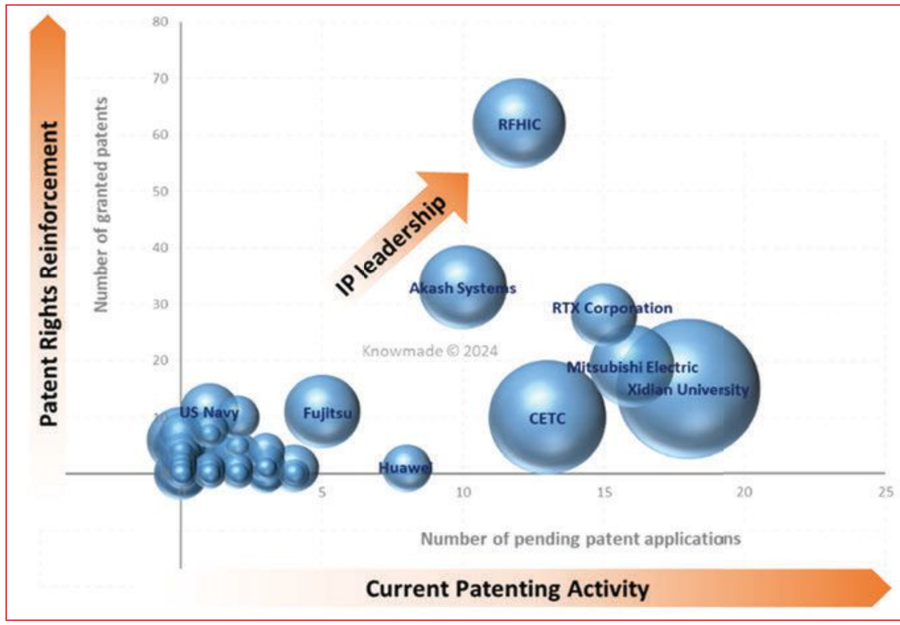

Fig. 3 Integrating diamond into GaN IP leadership. *Source:* KnowMade.

filings increased sharply, mainly due to the acceleration of Chinese players such as CETC with 29 inventions and Xidian University with 44 inventions. Since 2021, a relatively stable patenting activity has been observed, supported by the entrance of more than 30 new IP players, especially Chinese research organizations like Wuhan University, Shenzhen University and Taiyuan University of Technology, along with Chinese industrial players like CoolSemi, CSMH and others.

Besides China, several players like Air Water in Japan, which collaborated with Osaka Metropolitan University, have entered the field recently. This collaboration co-filed patent WO2023/048160, published in early 2023. The patent publication was followed by a scientific paper released in late 2023.[3] In this paper, researchers described a method based on the heteroepitaxy of GaN on a 3C-SiC layer formed on a silicon substrate. Then, the silicon substrate is removed and the GaN-on-3C-SiC stack is bonded to a thermally conductive support layer that can be made of either diamond or polySiC, according to the first patent claim. So far, about 30 patent families have disclosed methods based on bonding techniques to integrate diamond materials with GaN electronic devices.

However, the bonding of GaN materials with a diamond substrate is technically challenging and alternative methods have been developed. For instance, Wonder CVD, a startup company founded in 2016 and headquartered in Dubai, entered the GaN electronics patent landscape in 2023, filing patent application US20230307249. It describes the growth of polydiamond on the silicon (111) thin layer of an SOI substrate, the removal of the

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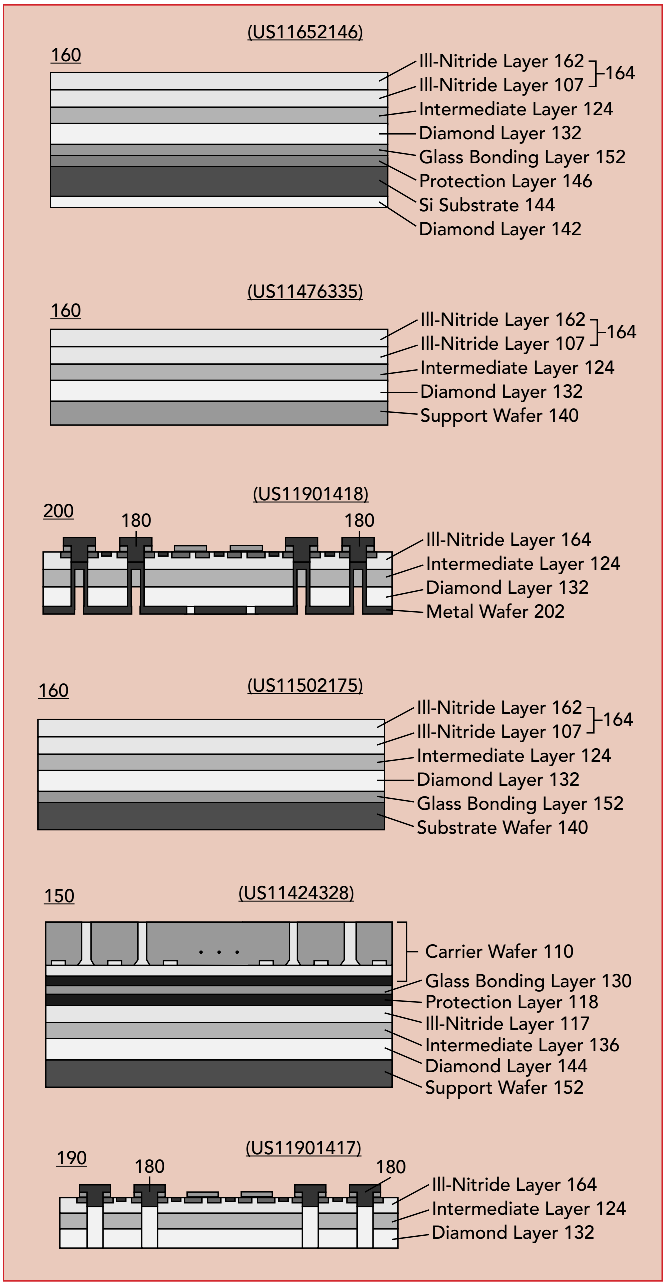

Fig. 4 U.S. patents related to GaN/diamond wafers recently granted to RFHIC.

base and oxide layers, followed by the heteroepitaxy of GaN on the other surface of the silicon (111) thin layer.

Another interesting example is the collaboration between imec and UHasselt in Europe that is described in patent EP4125113, although the patent application seems to have been abandoned since August 2023. The invention relates to the formation of a nanocrystalline diamond layer that forms a stable connection between a GaN material and a polydiamond material. In addition, the nanocrystalline diamond layer is expected to further facilitate heat dissipation for GaN electronic devices.

While the previous examples describe the integration of diamond materials in contact with or relatively close to the GaN device layer, U.S. startup company Diamond Foundry entered the GaN electronics patent landscape in 2023 with a different approach. In patent application US20230411459, Diamond Foundry disclosed a diamond substrate that could be used as a packaging substrate for GaN or SiC devices intended as an alternative to silicon-based IGBT chips used in electric vehicle applications. Diamond Foundry is one of the few companies in this space targeting power applications. Overall, less than 10 percent of all inventions related to diamond integration explicitly target power electronics. ***Figure 2*** shows a drawing from US20230411459 illustrating Diamond Foundry's idea for their diamond substrate.

THE IP LEADERS

Comparing the number of pending patent applications with the number of granted patents for the main patent assignees provides valuable insight into the global IP competition for a given technology. ***Figure 3*** shows this comparison for the integration of diamond materials with GaN electronics. Figure 3 plots the number of pending patent applications on the x-axis and the number of granted patents on the y-axis. At this intersection of these metrics, the size of the bubble represents the number of patent families selected for the study. The results of Figure 3 show that RFHIC stands as the current leader in GaN and diamond-related IP, but several RF GaN market players have positioned themselves as challengers. As can be seen, Akash Systems is the closest competitor to RFHIC, trailing slightly in patent applications and patents granted. However, companies like RTX Corporation, Mitsubishi Electric, Xidian University and CETC could pose strong future competition as all of them have more patent applications than RFHIC. Additionally, Mitsubishi Electric, Xidian University and CETC have comparable or much more breadth of GaN and diamond-related patent families. RFHIC's current IP leadership is largely inherited from the patenting activities of Group4 and Element Six, although a few inventions were disclosed by RFHIC soon after the patent transaction in 2018.

In its 2023 GaN electronics IP report,[4] KnowMade analyzed this IP leadership and pointed out RFHIC's IP strength in GaN-on-diamond wafers and epiwafers, which is the very upward part of the RF GaN supply chain. In this part of the supply chain, RFHIC has no serious IP challengers but Xidian University. Because most of its patents are recent and exclusively filed in China, Xidian University's IP leadership remains limited despite a relatively high number of inventions disclosed by the Chinese university. In contrast, RFHIC's patent portfolio protects inventions in many different countries, especially in Europe, Japan, the U.S. and South Korea.

Interestingly, RFHIC resumed its patenting activities in 2021 with the publication of seven new inventions related to GaN-on-diamond. At the same time, they confirmed a global IP strategy, especially for one invention protected by several foreign patents, including six U.S. patents. The invention relates to the transfer of a III-nitride layer from its silicon growth substrate to a support wafer via a diamond layer. Different aspects of the method have been protected through various patent applications. For instance, an intermediate layer between the III-nitride layer and the diamond

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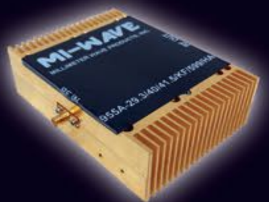

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970980A-35.61 /KF	Up-Down	35.61 GHz	Ka-Band	1,2,3,4
970B-38.25/387S	Down	38.0-38.5 GHz	Q-Band	1,2,3,4
970A-39.65/599	Down	39.4-39.9 GHz	Ka-Band	1,2,3,4
980B-43.25/387S	Up	42.0-43.5 GHz	Q-Band	1,2,3,4
970U-47.2/51 .4/1.85MMF	Down	42.2-51.4 GHz	U-Band	1,2,3,4
970980U B-47.2/51 .4/1.85MMF	Up-Down	47.2-51.4 GHz	U-Band	1,2,3,4
970E-70.4/86.4/387	Down	70.4-86.4 GHz	E-Band	1,2,3,4
970V-62.5/385	Down	65-75 GHz	E-Band	1,2,3,4
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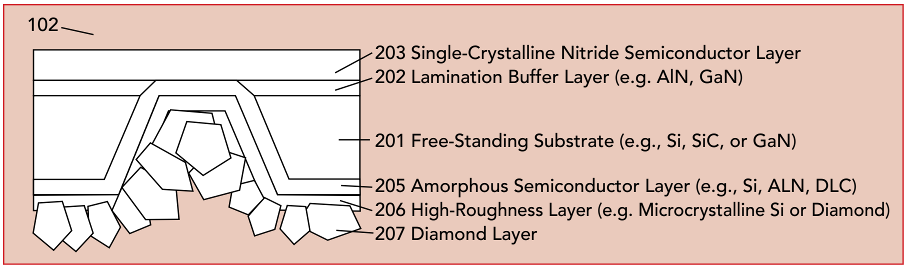

Fig. 5 **Formation of a diamond layer on a nitride layer.**

layer (US11652146), a composite silicon/diamond support wafer (US11652146) and the deposition of the support wafer (e.g., with poly-GaN or polysilicon in US11476335), the carrier wafer (e.g., a SiC carrier is mentioned in US11424328) and the formation of through holes in such engineered substrates, as described in patent applications US11901418 and US11901417. Drawings from these and other patents granted to RFHIC for GaN/diamond wafers are shown in ***Figure 4***.

Just like RFHIC, U.S. company Akash Systems published only a few inventions after the patent acquisition from Element Six. Akash published two patent families in 2018, mentioning the integration of diamond at the device level as a substrate and package level as a base for improved thermal management in transmitters used in satellite communication (US10332820, US10374553). Interestingly, the U.S. startup company resumed its IP activities in 2020, publishing seven inventions aiming to increase its coverage of the RF GaN supply chain. These recent inventions relate not only to packages, modules and systems but also to wafers, epiwafers and devices.

Mitsubishi Electric started its patenting efforts in 2017 and has maintained stable IP activity in the field. In contrast with other competitors aiming to protect inventions across the entire supply chain, Mitsubishi Electric's IP strategy seems to focus on developing various aspects related to GaN-on-diamond device technology. Starting from an epiwafer, GaN layer transfer (US20230083507) and GaN bonding (US20220230920) techniques have been disclosed to integrate GaN devices with a diamond substrate. In an alternative approach, diamond may be integrated locally below the GaN devices with good adhesion characteristics and limited damage to the GaN epilayer. This concept is shown in ***Figure 5*** with a drawing from US10720374 granted to Mitsubishi Electric in 2020. Additionally, the company has several patents related to the fabrication of GaN devices on recessed diamond substrates (e.g., US11482464).

CONCLUSION

IP activities related to the integration of diamond materials into GaN electronics devices have remained marginal in the GaN electronics patent landscape. For comparison, these activities represent less than 10 percent of all inventions related to RF GaN disclosed in 2023. Yet the analysis of the IP competition highlights a significant activity in recent years from several market players, in terms of the number of inventions disclosed by these players and the volume of patent applications filed to protect some of their key inventions in multiple countries. Additionally, since there is a limited number of well-established players in this space, there seems to be an opportunity for newcomers to make a breakthrough in this landscape, not only in terms of technology but also in terms of IP. ■

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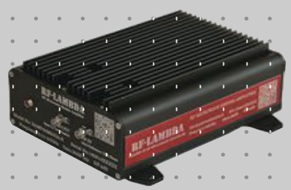

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CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	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

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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

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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

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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

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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

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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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LRDR provides the ability to simultaneously search and track multiple small objects, including all classes of ballistic missiles, at very long ranges, under continuous operation. Its discrimination capability will enable LRDR to identify lethal objects, such as enemy warheads and differentiate them from non-lethal decoys. LRDR, along with other elements of the Missile Defense System, will preserve the homeland defense interceptor inventory by conserving the number of ground-based interceptors required for threat engagement.

LRDR (Source: Lockheed Martin)

The highly adaptable LRDR operates in S-Band frequencies and features an open systems architecture designed to be scaled and extended to counter evolving threats without changing the hardware design. It is integrated into the Missile Defense System through the Command and Control, Battle Management and Communications element. As an example of LRDR's open systems architecture, Lockheed Martin is adding new capability in support of hypersonic defense, which will give decision makers actionable information to make timely decisions, faster.

In addition to missile defense, the radar system supports Space Domain Awareness by monitoring satellites orbiting the earth, detecting, tracking and identifying active or inactive satellites, spent rocket bodies and debris.

DARPA's RACER Speeds into a Second Phase

DARPA's Robotic Autonomy in Complex Environments with Resiliency (RACER) program successfully tested autonomous movement on a new, much larger fleet vehicle – a significant step in scaling up the adaptability and capability of the underlying RACER algorithms.

RACER (Source: DARPA)

The RACER Heavy Platform (RHP) vehicles are 12-ton, 20 ft. long, skid-steer tracked vehicles – similar in size to forthcoming robotic and optionally manned combat/fighting vehicles. The RHPs complement the 2-ton, 11 ft. long, Ackermann-steered, wheeled RACER Fleet Vehicles (RFVs) already in use.

RACER's second phase began last fall with its fourth experiment (E4), which included first testing of RHPs and testing on RFVs by teams from the University of Washington and from NASA's Jet Propulsion Laboratory. RACER is on pace to continue its autonomy development and experiment spirals with a new round of development and testing roughly every six months.

RACER E4 took place in late 2023 at military training areas in Texas. Using fully unoccupied RFVs, RACER demonstrated autonomous movement within a 15 square-mile terrain area including highly diverse ground vegetation cover, trees, bushes, rocks, slopes, obstructed ditches and creek crossings typical of the varied, complex Texas terrain familiar to armored maneuver. Adaptability was further demonstrated by successful runs at night with equivalent performance results. Teams successfully completed over 30 autonomous runs on courses varying from 3 to 10 miles in length, achieving over 150 autonomous, unoccupied miles at speeds up to 30 miles per hour.

Additionally, the RACER program commissioned the RHP at E4 by operating for over 30 miles in an autonomous-route-following-mode over similarly complex terrain to test low-level autonomous control, collect sensor data sets, assess mobility and refine operations. Finally, E4 began software development of RACER global planning with tactics and performed focus groups with uniformed subject matter experts stationed at the E4 military base to assist with defining input of tactical reasoning.

The RHP uses the Textron M5 base platform previously developed and used in U.S. Army campaigns of learning for robotic combat vehicle requirements and acquisition and is upfitted and supported for RACER autonomy integration hardware stacks and software by Carnegie Robotics. RACER Phase 2 performer teams are the University of Washington and Overland AI; and NASA's Jet Propulsion Laboratory, Offroad Autonomy, Georgia Institute of Technology and Duality Robotics.

RACER is planning two experiments in 2024 to keep its every six-month cadence of field tests to keep robots constantly improving; in between, the two RACER Phase 2 teams will continue constant development and testing at multiple test sites local to each.

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

AI-Enabled EW Systems

Anduril Industries' first-of-its-kind family of modular, multi-mission-capable electromagnetic warfare (EW) systems uses artificial intelligence (AI) at the tactical edge to rapidly identify and defeat current and future threats across the electromagnetic spectrum, including small and medium-size drones.

Dominance of the electromagnetic spectrum is critical to operations on a modern battlefield of rapidly-evolving drone, counter-drone and jamming technologies. EW tactics are evolving faster than ever, with updates to EW and threat systems now happening over shorter timelines of weeks, days or even hours. The next generation of EW systems must enable real-time understanding of the spectrum and provide rapid delivery of effective countermeasures against known and new threats, across domains and modalities.

Pulsar integrates a software-defined radio, graphics processing unit and additional diverse computing into a compact and powerful capability that enables RF machine learning to rapidly identify and adapt to emerging threats at the edge. The system supports a range of capabilities in a multi-mission EW solution, including electronic countermeasures, counter-unmanned systems, electronic support, electronic attack, direction finding, geolocation and other advanced EW capabilities. Pulsar's modular form factor can be adapted and integrated onto ground vehicles and aircraft to support distributed EW operations across multiple domains.

Pulsar (Source: Anduril Industries)

Pulsar provides the capability to intelligently and autonomously interrogate a wider range of the electromagnetic spectrum, both for known threats and anomalous events, while reducing the time to deploy new EW effects to a matter of hours and days.

Its open architecture enables integration into common and joint EW and command and control systems to create a unified network of EW capabilities, providing more comprehensive coverage and coordinated effects across distributed operations. It also provides a software development kit that enables continuous development and integration with third-party providers and rapid integration of best-of-breed capabilities to keep pace with new threats and missions.

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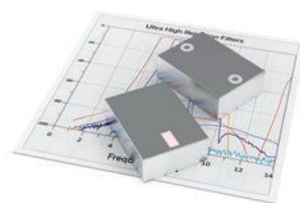

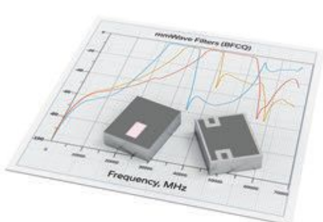

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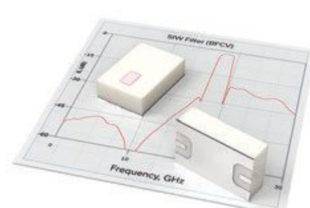

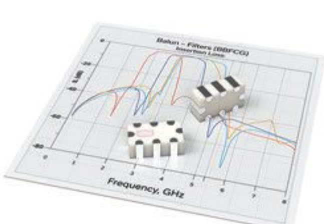

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Cliff Drubin, Associate Technical Editor

Radar Innovation: A Bright Future

In the ever-evolving field of automotive technology, the transition from GaAs to SiGe and now to CMOS radar modules has been revolutionary. This transition has not only drastically reduced costs but also hints at a future where the price of standard 77 GHz radar could drop as low as US$30 by 2030. However, the aspirations extend beyond cost reduction. There is a concerted effort to decrease the average selling price of state-of-the-art 4D imaging radar to align with original equipment manufacturers' (OEMs') budget constraints.

OEMs are leading a significant transition toward vehicle centralization, anticipated to be fully implemented between 2030 and 2035. This shift anticipates a future where more cost-effective, compact radars with advanced computational capabilities and superior system performance become normal, paving the way for a truly autonomous driving experience.

Radar usage is also extending beyond its conventional applications, spurred by fresh FCC regulations and advancements in radar technology. This shift is not limited to established sectors, such as automotive, industrial and defense; it is also penetrating emerging fields like consumer electronics and healthcare. Enhancements in precision, dimensions, affordability and energy efficiency are aligning radar perfectly with these burgeoning markets, unlocking substantial prospects.

> Recent technological advancements are poised to reshape the market.

The radar module market is fiercely competitive, with numerous companies vying for market dominance. This competition spans various sectors, from the crowded automotive radar sector to specialized niches in industrial applications. Consequently, module providers like Continental, Bosch, Aptiv, Smartmicro and InnosenT are consistently lowering prices to maintain their competitiveness. Recent partnerships among OEMs, Tier 1 suppliers, chipmakers and antenna manufacturers are gaining traction, highlighting the strategic positioning of each participant.

Recent technological advancements are poised to reshape the market, particularly with the integration of the transceiver and processing functionalities into single radar chips enabled by CMOS technology. This innovation promises cost efficiencies, space optimization and supply chain streamlining for OEMs. Additionally, in the automotive industry, companies are preparing for a transformative phase in E/E architecture, which will fundamentally redefine the roles of industry participants.

In this context, Yole Group has combined its semiconductor expertise and knowledge of RF technologies and markets to deliver its annual report, "Status of the Radar Industry." This study dives deep into the radar supply chain, the systems that use radar technology and the latest trends in radar technology at various levels, from entire systems to antennas and devices. It explains the key factors that influence the global radar market and analyzes the competitive landscape in detail.

Global Connectivity Demands Fuel Rapid Growth of Satellite IoT Market

The satellite IoT market is transforming remarkably, driven by technological advancements and an ever-increasing demand for global connectivity. As the world becomes more interconnected, the limitations of terrestrial networks become apparent, particularly in remote and underserved regions. This is where satellite IoT steps in, bridging the gap with its ability to provide widespread, reliable connectivity across the globe. ABI Research forecasts the market to surge past the US$4 billion mark by 2030, signaling significant growth potential in the market.

> Use cases for satellite IoT are emerging at an unprecedented rate.

"The rapid growth of the satellite IoT market is fueled by several factors, including the decreasing cost of satellite launches, advancements in satellite technology, such as low earth orbit constellations, CubeSats and nanosatellites, and increasing demand for untethered connectivity and remote asset management," explains Victor Xu, satcom research analyst at ABI Research.

Technological advancements in IoT devices have made new use cases for satellite IoT emerge at an unprecedented rate, from precision agriculture to ocean monitoring and from connected mines to disaster prediction and response. While satellite IoT currently accounts for only a small portion of overall satellite connectivity revenue, it is growing positively with major players like Inmarsat, Iridium and ORBCOMM driving the market.

The standardized satellite communication technologies, multi-technology/orbit connectivity solutions, and satellite IoT integration with terrestrial 5G networks are the key trends with significant opportunities for innovation and growth in the market. Xu concludes, "With the ongoing expansion of the satellite IoT market, the potential of this technology for innovative use cases is limitless, and the diverse applications of satellite IoT will drive the overall market."

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

IoT Markets Show Healthy Growth in Private Cellular Networks

Mission-critical use cases are driving private IoT connection growth in key industrial markets like manufacturing, logistics and transportation. Industrial IoT (IIoT) customers are eager to digitalize critical use cases with high-powered, dedicated networks, making these industries leaders in private 4G and 5G adoption. According to a new report from ABI Research, the manufacturing and transportation industries will have the most private cellular IoT connections in the future, with 108 and 71 million connections, respectively, predicted in 2030.

Dominant mission-critical IIoT use cases include automating heavy machinery in mining and manufacturing, replacing legacy networks in oil and gas and tracking containers in ports. Each of these use cases requires an ultra-reliable network. According to Lizzie Stokes, IoT networks and services analyst at ABI Research, "Heavy machinery automation, in particular, calls for the performance and low latency of a private 5G network. Industrial customers often initially invest in a private cellular network to connect employees' communication devices, such as smartphones or tablets, but eventually realize the value these networks can provide in more critical IoT applications."

Private wireless vendors like Ericsson and Nokia have been laser-focused on the needs of these industrial customers, given the criticality of their use cases. However, despite their relevance, mission-critical IIoT applications account for only a portion of total IoT use cases. Most IoT use cases do not require ultra-low latency networks and instead support disparate devices that send infrequent, low-payload communications. These non-mission-critical IoT use cases are better suited for non-cellular private network technologies, like Wi-Fi, private LoRaWAN or DECT-2020 NR.

Connected sensors in commercial buildings, hospitals and hotels, for example, do not require a high performing cellular network and are much more likely to benefit from a long-range and low-power option like private LoRaWAN. Wi-Fi's recent iterations, like Wi-Fi 6E and Wi-Fi HaLow, have made the technology more relevant to the non-mission-critical needs of large, complex campuses like universities and entertainment venues. DECT-2020 NR, the first non-cellular 5G standard, can support large device densities, making the technology highly applicable in smart metering use cases. When considering non-mission-critical applications, the competitive landscape of the private wireless industry expands to include non-cellular technologies that might not receive as much industry attention as private cellular networks. Important non-cellular private wireless market players include Wirepas, Semtech, the LoRa Alliance and Wi-Fi HaLow and Wi-Fi 6E suppliers like NEWRACOM, Qualcomm and Cisco.

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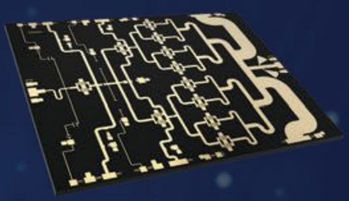
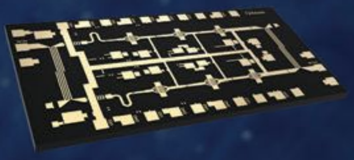


V

- NPA4000-DE | 47.0-52.0 GHz | 1.5 W
- NPA4010-DE | 47.0-52.0 GHz | 3.5 W



E

- NPA7000-DE | 65.0-76.0 GHz | 1 W
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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Mini-Circuits, a leading global supplier of RF, microwave and mmWave components, announced that it has acquired the CATV amplifier business from **Analog Devices**. The transaction includes Analog Devices' portfolio of 75 Ω GaAs and GaN amplifiers, related production test hardware, hiring of the product development team and conveyance of the office in Santa Rosa, Calif., where the team is based. Mini-Circuits' integration of the new business unit will include additional investment and staffing to expand the existing product line and provide full service for customers' needs. The amplifier portfolio supports both the DOCSIS® 3.1 and 4.0 cable infrastructure upgrades, which are now delivering multi-gigabit fixed broadband services to subscribers with rollouts planned over the next ten years.

Guerrilla RF Inc. has finalized the acquisition of **Gallium Semiconductor's** entire portfolio of GaN power amplifiers and front-end modules. Guerrilla RF acquired all previously released components as well as new cores under development at Gallium Semiconductor. Additionally, all associated intellectual property has been transferred to Guerrilla RF as part of this portfolio acquisition. By integrating these assets, the company intends to significantly enhance its ongoing efforts to develop and commercialize a new line of GaN devices tailored for wireless infrastructure, military and satellite communications applications.

COMROD Communication AS has acquired a majority share of **Triad RF Systems Inc.** The East Brunswick, N.J., company is an innovative designer and manufacturer of RF/microwave amplifiers and integrated radio solutions for long-range RF communication in challenging environments including defense applications and aerospace systems. The acquisition of Triad further positions COMROD as a premier radio ancillary manufacturer that helps customers reach further with cutting-edge technology. In addition to strengthening COMROD's RF capability and capacity, the combined companies will be able to cooperate on next-generation radio range extension solutions. Triad's constant push to extend the limits of data and distance, combined with their RF support and applications engineering, will enhance COMROD's development and technical capabilities in the U.S. and around the world.

COLLABORATIONS

Rohde & Schwarz has teamed up with **IPG Automotive**, a pioneer in virtual test driving, to redefine automotive radar hardware-in-the-loop integration testing and thereby reducing the cost by bringing autonomous driving (AD) testing from the proving ground to the development lab. Combining the CarMaker simulation software from IPG Automotive with the R&S AREG800A radar object simulator and the R&S QAT100 advanced antenna array provides vehicle manufacturers with the ability to simulate advanced driver-assistance systems/AD scenarios like those defined in the Euro NCAP in a controlled, safe, time-efficient and cost-reducing way. This combination provides automotive OEMs and radar sensor suppliers with a comprehensive radar sensor testing platform.

ZTE Corp. collaborated with **China Mobile's Zhejiang Branch** and **Qualcomm Technologies Inc.** to achieve a groundbreaking milestone in 5.4 Gbps peak data rates. Through the industry's first end-to-end field test of three carrier component carrier aggregation combined with 1024-state quadrature amplitude modulation in Jiaxing, the test showcased a single user downlink peak rate surpassing 5.4 Gbps. This achievement represents a significant boost in network capability and user experience. This validation harnessed new 5G-A features to fully unlock the spectrum potential of 5G commercial networks, thereby enhancing network capabilities and user experience.

NEW STARTS

Hughes Network Systems LLC, an EchoStar company, announced the opening of a new cutting-edge manufacturing facility and private 5G incubation center in Germantown, Md., underscoring the long-standing commitment of Hughes to technological advancement and fostering local talent in the region. The Hughes Manufacturing Facility (EXM) produces U.S.-made hardware that powers the networks on which people, enterprises and governments everywhere depend, like the Hughes HT3000W JUPITER™ System satellite modem and the Hughes HL1120W LEO satellite terminal. In addition to about 400 engineers, technicians and manufacturing staff, the Hughes EXM facility utilizes advanced robotics to assist in the manufacture of high-tech products such as satellite modems and terminals. The EXM facility will also serve as a testing ground for private 5G solutions just now reaching the market for enterprise applications as well as secure 5G networking applications critical to the U.S. Department of Defense.

Rohde & Schwarz India, the Indian subsidiary of the German-based, global technology company Rohde & Schwarz, celebrated the grand opening of its new future-oriented facility located in the heart of Bengaluru's prestigious Manyata Tech Park. For more than 90 years, Rohde & Schwarz has had a tradition of innovation, helping to develop current and future cutting-edge technologies. By expanding research and development (R&D) activities in India, Rohde & Schwarz is able to enhance technological excellence for the highly dynamic Indian market. The R&D team in Bengaluru is involved in developing next-generation solutions for the company's test and measurement division.

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VFCTS105-10	105	-156	-165	
VFCTS120-10	120	-156	-165	
VFCTS125-10	125	-156	-165	
VFCTS128-10	128	-155	-160	
FCTS800-10-5	800	-144	-158	
FCTS1000-10-5	1000	-141	-158	
FCTS1000-100-5	1000	-141	-158	
FSA1000-100	1000	-145	-160	
FXLNS-1000	1000	-149	-154	
KFCTS1000-10-5	1000	-141	-158	
KFCTS1000-100-5	1000	-141	-158	
KFSA1000-100	1000	-145	-160	
KFXLNS-1000	1000	-149	-154	
FCTS2000-10-5	2000	-135	-158	
FCTS2000-100-5	2000	-135	-158	
KFCTS2000-100-5	2000	-135	-158	
KSFLOD12800-12-1280	12800	-122	-123	
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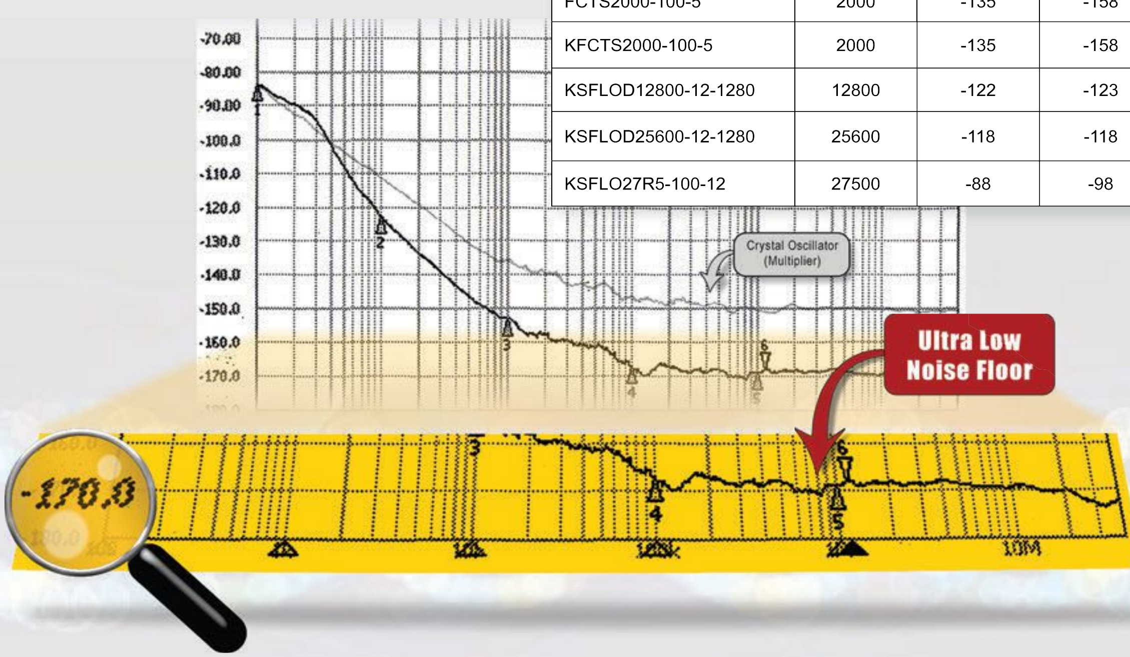

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Around the **Circuit**

Morse Micro announced the official opening of its new Taiwan branch. This strategic move demonstrates the company's commitment to operations in Taiwan and marks a significant milestone in its Asia-Pacific expansion efforts. Operating in Taiwan for several years, Morse Micro has existing relationships with Taiwan Semiconductor Manufacturing Company for its manufacturing and Weikeng, ASEC and Alltek for the distribution of its Wi-Fi certified HaLow chips in Greater China. With a strong focus on customer-centricity, the move reinforces Morse Micro's commitment to bringing Wi-Fi HaLow solutions to market, working with Wi-Fi HaLow module and ODM customers to deliver long-range, low-power connectivity to IoT devices.

KYOCERA AVX recently hosted a groundbreaking ceremony for KYOCERA AVX Components Corporation (Erie)'s new manufacturing and design center for high-quality, low-noise quartz crystal frequency control products. The new facility will be part of the Knowledge Park at Penn State Erie research and development hub for forward-thinking, knowledge-driven businesses, which is located on the Penn State Behrend campus in Erie, Pa. Work began on the new 49,000-square-foot facility on February 17, 2024; the official groundbreaking ceremony took place on April 12, 2024.

ACHIEVEMENTS

A medical device that can help determine if you have cancer but can fit on the pad of a fingertip. Miniaturized RF devices to enable 5G technology and beyond. Wearable sensors and implantable technology. Quantum computing. These are just some of the futures made possible by nanotechnology — technology measured on the scale of a nanometer, one-billionth of a meter. Now, **Northeastern University** is launching the first-of-its-kind Institute for NanoSystems Innovation (NanoSI), straddling both coasts of the U.S. NanoSI is co-directed by David Horsley and Matteo Rinaldi, both professors of electrical and computer engineering (and recipients of the 2024 Global Network Accelerator Award).

CAES, a leading provider of mission-critical advanced technology, announced that it has been recognized by Northrop Grumman Corporation as a top supplier in Performance Excellence for 2023 with a Supplier Excellence Award. The award was given by three Northrop Grumman Sectors — Mission Systems, Defense Systems and Space Systems — for excellent performance at CAES Defense Systems. CAES was honored as one of more than 70 top suppliers from Northrop Grumman's network of partners. Northrop Grumman's Supplier Excellence Awards recognize top supplier partners across their supply chain. The Supplier Performance Excellence Award acknowledges suppliers who maintained exceptional management, cost, schedule, engineering for sustainment and performance as well as proposals and overall customer satisfaction statuses.

New Jersey Institute of Technology's (NJIT) Newark College of Engineering (NCE) celebrated its 26th Annual Salute to Engineering Excellence with its continuing commitment to engineering education advancement. The celebration event took place Thursday, April 18, 2024, with the proceeds going to support NCE Dean's Fund. In 2021-2022, NJIT alumni and friends made gifts and pledges to the university totaling more than $14 million, supporting a variety of campus priorities including student scholarships, classroom renovations and faculty research. These gifts have had a profound impact on the campus community, inspiring others to give with equal generosity and serving as a vote of confidence in the mission of the university.

Junkosha has concluded its second year of the Technology Innovator of the Year Award. The ceremony took place in a YouTube livestream event in April where Afon Technology was presented with the award and a $25,000 prize. The prize-winning product, Glucowear, is a significant step forward in the development of non-invasive glucose monitoring. The award, which was designed to spotlight the achievements of pioneers in advanced technologies from across the globe, recognized this year's winners as shining a light into the blind spot of today's blood glucose monitoring technologies. In recent years there has been widespread discussion surrounding the integration of optical sensors into smartwatches for glucose monitoring purposes.

CONTRACTS

Raytheon, an RTX business, has been awarded a $344 million contract for the development of two missile variants — the SM-2 Block IIICU and SM-6 Block IU — which will be based on a common guidance section, where the electronics and software that guide a missile to its target are housed. The updated variants will share a newly designed guidance section, target detection device, independent flight termination system and electronics unit. This commonality will allow Raytheon to manufacture both missiles on a common production line, providing flexibility, scalability and cost reductions. The development program is largely funded by **Foreign Military Sales**. The first users of these updated missiles will be the U.S., Australia, Canada, Japan and Korea.

Elbit Systems announced it was awarded a contract in an amount of approximately $50 million for its new air defense system, "Red Sky,"™ by an international customer. The contract will be executed over a period of two years. The Red Sky is a tactical very short-range air defense system designed to provide protection against low-altitude aerial threats. As part of the contract, Elbit Systems will supply two Red Sky batteries, offering a comprehensive solution that integrates both soft-kill and hard-kill defense capabilities. This solution includes Elbit Systems' Redrone, an electronic warfare solution designed for detecting, identifying, locating and neutralizing unmanned aerial systems.

The Australian Government has awarded $18.4 million to the **University of Sydney** to establish Quantum Australia to help grow the quantum industry and eco-


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Around the **Circuit**

system in Australia. Australia consistently ranks within the world's top five countries for high impact quantum research and quantum computing patents. With one of the largest quantum workforces in the world, Australia is now the home of world-leading companies in quantum software, cybersecurity, sensing technologies and quantum computing. Quantum computing promises to radically change technology through the development of machines that can calculate in completely new ways.

PEOPLE

▲ *Stephany Kearney*

Stephany Kearney has been promoted to VP, general manager of **Quantic™ Evans**, an aerospace and defense capacitor manufacturer based in East Providence, R.I. Kearney joined Quantic™ Evans in 2021 as division controller for the company's entire capacitor portfolio comprised of Quantic Evans, Quantic Eulex, Quantic Paktron and Quantic UTC. In 2023, she was promoted to vice president of finance and operations. With her proven track record in finance, operations and people management, Kearney is well-equipped to lead Quantic™ Evans through its next phase of expansion and success, driving sustainable growth and solidifying the company's position as a key player in the aerospace and defense capacitor manufacturing industry.

REP APPOINTMENTS

3H Communication Systems announced **RF Sales** as the newest sales representatives. 3H Communication Systems is an industry leading RF and microwave company that provides high value, cost effective solutions to military and commercial markets. The team specializes in the design and manufacturing of filter products including lumped component, ceramic, cavity, high power, multiplexers, multi-function assemblies, SMT, connectorized, pins and leadless filter products from DC to 50 GHz. The high degree of engineering and technical capability focused on innovation with decades of expertise for high value and high-quality RF products allows 3H to provide its customers with custom, high performing filter solutions.

Electro-Photonics LLC, a leading provider of passive RF and microwave components and solutions, announced the appointment of **Component Distributors Inc.** as its authorized distributor for the Americas region. This strategic partnership aims to enhance accessibility to Electro-Photonics' innovative products and bolster support for customers across North and South America. Component Distributors Inc., renowned for its commitment to quality and extensive distribution network, will now offer Electro-Photonics' comprehensive range of RF and microwave components, including but not limited to, SMT hybrid and directional couplers, resistors, power dividers, test fixtures, isolators and circulators.

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Key Features of the PRM2136X Module:

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- 8 active RF chains
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- Automatic polarization switching
- BPSK to 16 QAM modulations
- Total user data capacity > 3.5 Gbps
- Multi-user support up to 32 STA
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Using Metamaterials in mmWave 5G Antennas

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High gain and panel-mountable antennas are essential to enable future mmWave-based portable devices to establish a feasible cellular communication link. Conventional antenna design techniques might be inadequate to meet these design and physical footprint criteria. To address these challenges, metamaterials (MTMs) might provide a useful tool to improve the gain and other performance metrics of high gain antennas specifically designed for mmWave 5G portable devices. This article delves into the application of the sub-wavelength MTM structures for compact, high gain antennas. The end-fire gain enhancement technique is initially explored, followed by broadside gain enhancement. Case studies of the two antennas are also presented. Mutual coupling reduction techniques using electrically small MTM structures are also discussed.

With the explosion of data usage among smartphone users, researchers and pundits across the globe have been contemplating feasible solutions to accommodate this growth.[1] As the number of users grows, so too does the bandwidth required by these users. To fulfill these technical requirements, the spectral efficiency of the current communication channels could be exploited. The critical problem with this approach is that the achievable upper limit of spectral efficiency is finite and communication theoreticians believe that the current protocols in place are already approaching this theoretical limit.

The primary challenge for the communication link at mmWave frequencies is the relatively high free space path loss compared to its microwave counterparts. Among the strategies to overcome this issue is to design and deploy numerous low-power base station towers. Even if the radiated powers of base station towers are increased within a given geographical radius, the received power at the mobile device would still be well below the receiver's sensitivity. Thus, the only viable option for a successful implementation of the mmWave link is to integrate high gain antennas within the mobile terminal and base stations.[2] This compromises the angular coverage,

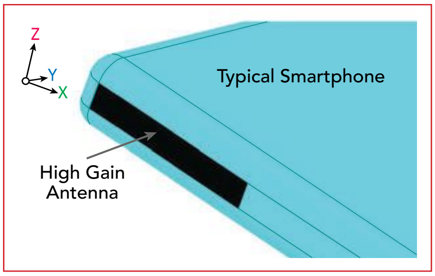

Fig. 1 **Typical layout of a commercial 5G portable device.**

so alternate strategies to optimize coverage need to be explored for a real-world deployment. The design of high gain compact antennas in the context of portable devices is the theme of this article.

It must also be noted that the preexisting infrastructure and industrial processes used to manufacture sub-6 GHz antennas could be tweaked to manufacture antennas operating in and around the 28 GHz band. A typical smartphone case is depicted in ***Figure 1*** with the dimensions adopted from a successful, widely-used commercial smartphone model. The available footprint to integrate high gain antennas or antenna systems is very limited. A typical dimensional requirement would be 7 mm (panel height) × 10 mm (tentative width) x 3 mm (expected depth). If these dimensions are expressed electrically, it translates to 0.65 λ × 0.93 λ × 0.28 λ, with λ computed at 28 GHz. These values indicate that the electrical footprint for antenna integration is minimal. Hence, compact antennas with maximum gain for the available effective radiating aperture are necessary for 5G portable devices.

Numerous techniques have been reported in literature to enhance the gain of planar antennas. For instance, metal strip parasitics can be loaded in the radiating aperture for gain enhancement or a dielectric lens could be integrated with a broadside radiator for a narrower unidirectional beam. Both strategies deliver lower gain for the occupied radiating volume. The other popular strategy is to minimize the losses within the substrate to boost gain in the forward direction but the quantum of gain enhancement would be in the vicinity of 1 dB. A printed ridge gap waveguide method can also be used for dielectric loss reduction.[3]

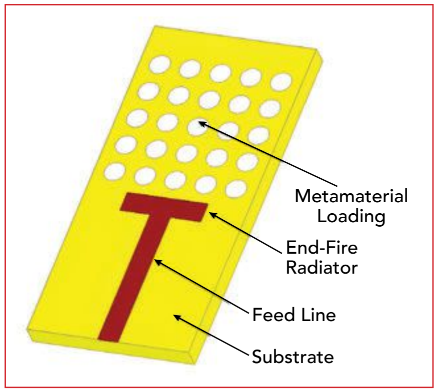

Fig. 2 **Generic layout of a typical end-fire metamaterial loading.**

Another strategy is to implement phased arrays within the smartphone panel.[4] This strategy increases the complexity of the antenna system. Also, beam locking between the transmitter and receiver has to be programmed and dynamically updated. Thus, to implement high gain antennas with minimal electrical and physical footprint, MTM integration seems to be an optimal solution.

MTM are periodic sub-wavelength geometries. When they are integrated with an antenna, the performance metrics of the antenna will be altered.[5] As these are primarily sub-wavelength geometries, the same could be explored for gain enhancement with an electrically small protrusion of the dielectric suitable for 5G portable devices.

The rest of the article addresses the benefits of MTMs for a variety of applications. The end-fire or planar gain enhancement using MTM loading is discussed in the next section, followed by an explanation of the role of MTMs in the context of broadside radiators. This will be followed by a discussion of mutual coupling reduction in phased arrays with the application of periodic structures. Even though MTMs have been exhaustively illustrated for the miniaturization[6] of microwave antennas, the same might not be relevant in the mmWave domain. The primary reason for this thesis is that the physical size of the mmWave antennas is typically less than 10 mm (or in the vicinity of 1 λ at 28 GHz), alleviating the requirement for further miniaturization to make antennas compatible with portable devices.

END-FIRE GAIN ENHANCEMENT

End-fire antennas radiate in the same plane as that of the antenna's orientation. Two primary types of end-fire radiators are resonant, like printed dipole and printed Yagi-Uda antennas and traveling wave, like printed antipodal and Vivaldi antennas. End-fire antennas are important for portable 5G devices. The primary reason for this is that end-fire antennas radiate away from the user when integrated with portable devices. MTMs could be loaded onto an end-fire antenna for gain enhancement without significantly altering the physical footprint of the element. For these applications, MTM unit cells could yield high gain and be electrically compact.

A generic schematic of an end-fire antenna integrated with MTMs is shown in ***Figure 2***. This architecture incorporates a PCB-based radiator fed by a microstrip line. The antenna is printed on an electrically-thin substrate to avoid surface wave modes.[2] The radiating aperture must be placed at least a wavelength away from the feed plane to avoid pattern contamination due to the connector.[4] This could be neglected in the commercial deployment of the antennas. The radiator could be either resonant or traveling wave type. Hence, the anticipated unidirectional pattern would be away from the radiator, traversing through the dielectric integrated with the sub-wavelength unit cells as shown. These unit cells aid in the phase correction of the E-fields emanating from the aperture, resulting in higher antenna gain. The length and width of the MTM spread would be electrically small, typically 0.5 to 1 λ, saving significant RF real estate. Most of the reported designs in the literature are based on the generic layout shown in Figure 2.

A tapered slot antenna (TSA) integrated with zero-index metamaterial (ZIM) unit cells is illustrated in ***Figure 3a***. The unit cells aid in the phase correction of the electric field emanating from the microstrip to slot line transition. The proposed antenna is designed on a low-cost FR4 substrate with a thickness of 0.5 mm. Since the substrate is electrically thin, the dielectric losses en-

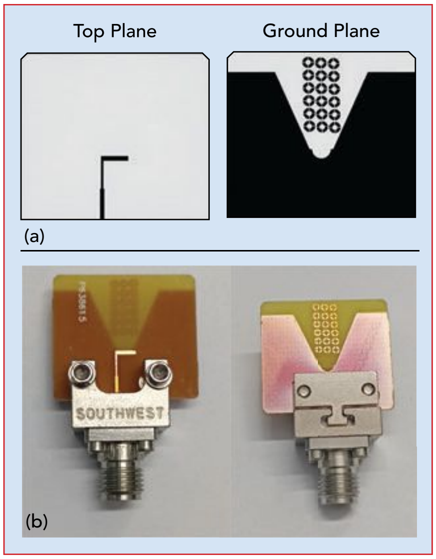

Fig. 3 (a) Schematic of the proposed TSA integrated with ZIM. (b) Fabricated TSA integrated with ZIM prototype.

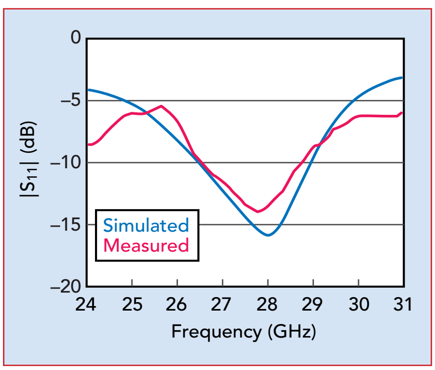

Fig. 4 $|S_{11}|$ of the proposed TSA integrated with ZIM.

countered within the substrate are negligible even in Ka-Band. The gap within the ZIM was maintained at 100 μm, due to the limitation of the photolithography technique. The fabricated antenna is displayed in ***Figure 3b***.

The simulated and measured input reflection coefficients are shown in ***Figure 4***. The -10 dB bandwidth is from 26.45 to 28.94 GHz, translating to 9 percent. The narrow bandwidth is attributed to the electrical thickness of the substrate and the design of the transition from the standard 50 Ω feed line to the slot line.

The E-plane radiation patterns are illustrated in ***Figure 5***. The front-to-back ratio is greater than 10 dB across the operational bandwidth. It must also be noted that the patterns have minimal variation across the bandwidth. The pattern integrity is high due to the layout of the ZIM unit cells in the radiating aperture of the proposed antenna.

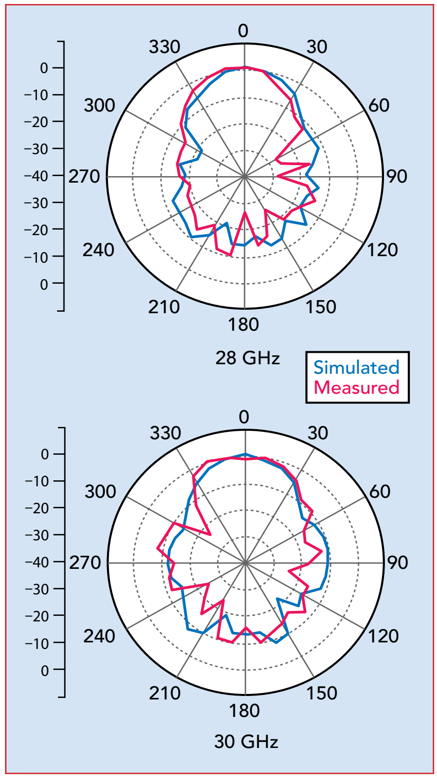

Fig. 5 E-plane patterns of the proposed TSA integrated with ZIM.

The gain enhancement of the antenna is close to 1 dB across the entire spectrum, as evident from ***Figure 6***. The quantum of gain enhancement is not high due to the number of unit cells available in the physical aperture of the proposed antenna. Gain enhancement up to 3 dB could be achieved with this technique by integrating unit cells in the H-plane.

Another strategy involves integrating the ZIM unit cells with resonant structures such as a printed dipole, is illustrated in the circuit layouts of ***Figure 7a***. The proposed antenna is designed on a low-cost FR4 substrate with a thickness of 0.5 mm. The ZIM unit cells integrated within the extended dielectric of the printed dipole help increase the antenna gain.

Conventional half-wavelength parasitics also yield a similar gain with a compromise in the real estate and the operating bandwidth. The proposed element is only 4.9 mm wide, which could be easily integrated with 5G smartphones that typically have a panel height of 8 mm. The fabricated prototype is shown in ***Figure 7b***. The dimensions of the unit cells are maintained to be within the fabrication limits.

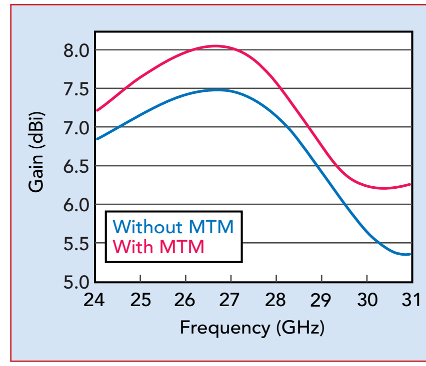

Fig. 6 Forward on-axis gain of the proposed TSA integrated with ZIM.

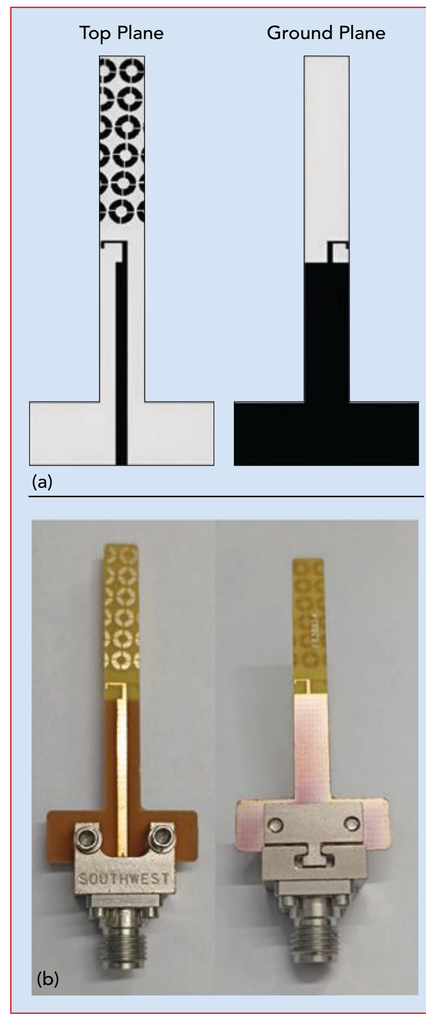

Fig. 7 (a) Schematic of proposed printed dipole integrated with ZIM. (b) Fabricated TSA integrated with ZIM prototype.

The simulated and measured input reflection coefficients are illustrated in ***Figure 8***. The proposed antenna offers an impedance bandwidth of 5.3 GHz, translating to

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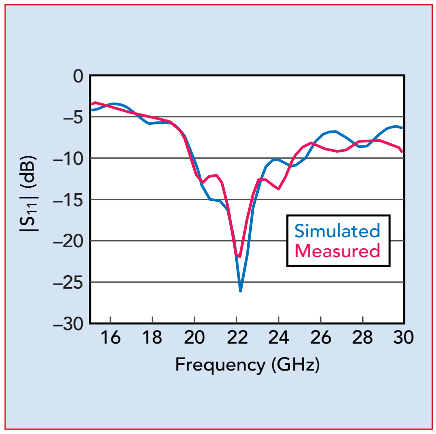

Fig. 8 $|S_{11}|$ of the proposed printed dipole integrated with ZIM.

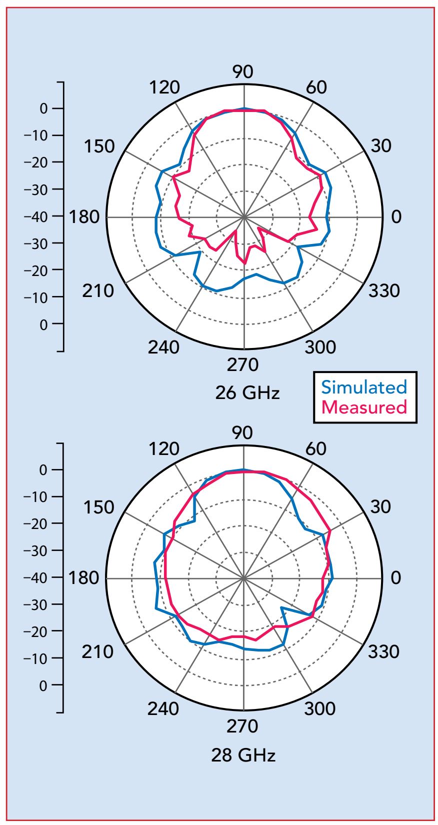

Fig. 9 H-plane patterns of the proposed printed dipole integrated with ZIM.

23.7 percent. The wide bandwidth can be attributed to the impedance-matched feed structure and the wideband behavior of the ZIM unit cells. The bandwidth is relatively high even with the use of an electrically-thin substrate. The design could be scaled to any band by varying the dimensions of the dipole arms and the slot size within the ZIM unit cells.

The normalized H-plane radiation patterns are displayed in ***Figure 9***. The patterns indicate a high front-to-back ratio, greater than 10 dB, throughout the operating bandwidth. The beamwidth and gain are adequate to meet the specifications of commercial devices. The proposed antenna would be vertically integrated within the commercial 5G device.

Forward gain with and without the MTM unit cells is illustrated in ***Figure 10***. Gain enhancement of close to 2 dB is observed across the operating band. The achieved gain is relatively high for the available aperture of the antenna. It must also be noted that the high dielectric loss

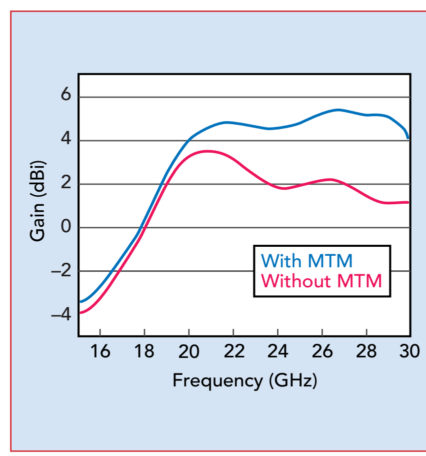

Fig. 10 Forward gain of the proposed printed dipole.

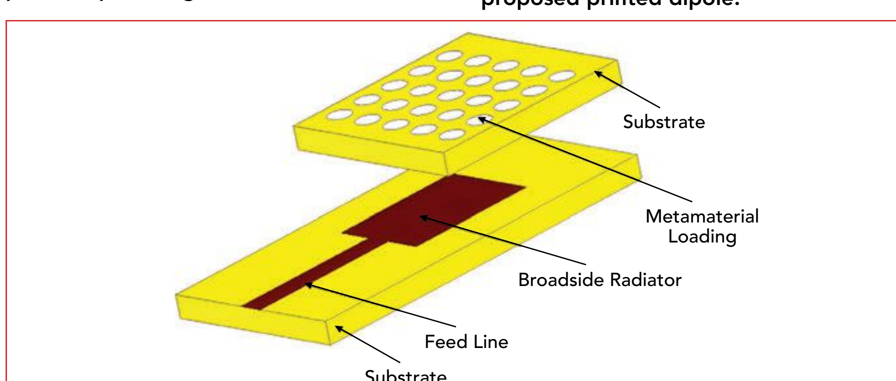

Fig. 11 Generic layout of a broadside antenna with MTM unit cells.


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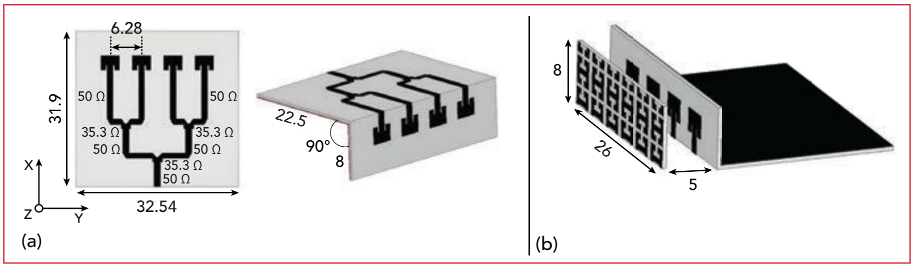

Fig. 12 **(a) 28 GHz broadside antenna. (b) Realization of the quasi-PRS integrated broadside antenna.**

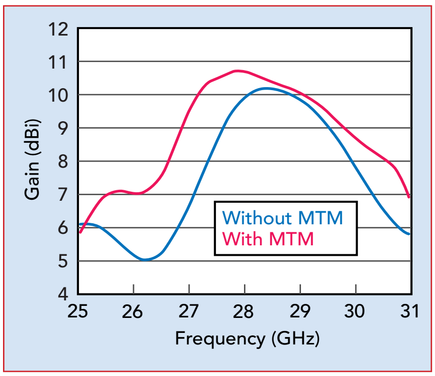

Fig. 13 **Boresight gain of the quasi-PRS integrated broadside antenna.**

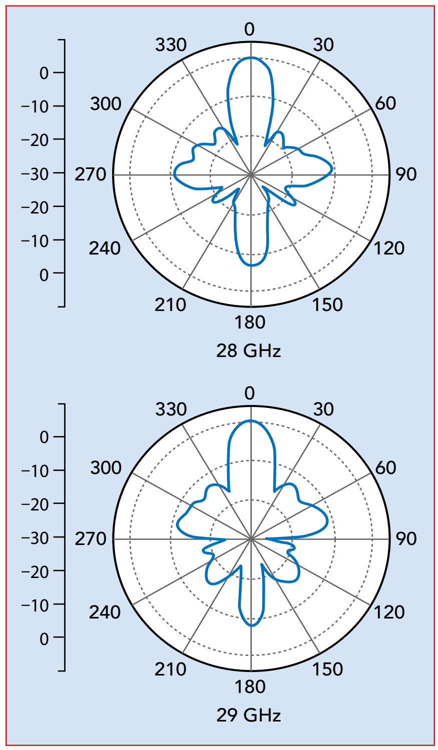

Fig. 14 **Normalized radiation patterns of the broadside antenna with MTM cells.**

tangent of the low-cost substrate does not affect the on-axis gain.

BROADSIDE GAIN ENHANCEMENT

Broadside antennas with unidirectional patterns are equally important for 5G portable devices. These broadside antennas are compact and they can be panel-mounted on a smartphone or wireless dongle. Techniques to enhance gain in broadside antennas include increasing the number of array elements in the phased array, integrating a parasitic superstrate and integrating a dielectric lens with the antenna. Most of these techniques succeed in enhancing the gain of the broadside radiator but they sacrifice the electrical footprint and impedance bandwidth as the compromise. This section explores using MTM unit cells as partially reflecting surfaces (PRS).

A generic layout of the MTM-loaded broadside antenna is illustrated in ***Figure 11***. Like the earlier case, only planar antennas are considered. The antenna is a microstrip-fed element on an electrically-thin substrate. The feeding mechanism is not very important in the broadside radiation case. However, the antenna must have a ground that is electrically large, which means that the standalone antenna will have a low gain unidirectional pattern in the absence of MTM loading. The concept of PRS will not work with bidirectional or omnidirectional antenna elements. The broadside radiator would invariably be a resonant structure; this is because a traveling wave radiator would require an electrically large radiating aperture along the direction of propagation.

A quasi-PRS integrated with a broadside antenna operating in the 28 GHz band is shown in ***Figure 12a***. It is a corporate-fed array, composed of four elements of inset-fed microstrip patch antennas with half-wavelength spacing. The antenna array is realized on Rogers 5880 substrate, which offers minimal dielectric loss. The feed network is optimized for wide bandwidth centered at 28 GHz.

The radiating aperture is bent, as illustrated in ***Figure 12b***, to align the radiators with the panel of the target use case device. This method of corner bending prevents radiation toward the user. To enhance the boresight gain of this antenna array, a quasi-PRS structure is integrated with the array, as illustrated in Figure 12b.

The boresight gain characteristic of the antenna, with and without the integrated PRS from 25 to 31 GHz is shown in ***Figure 13***. The quantum of gain enhancement is quite low due to the available aperture. Higher gain enhancement could be achieved by extending the PRS cells in the lateral dimension. However, this approach would make the design unsuitable for commercial devices.

The unidirectional narrow beam patterns of the proposed antenna are illustrated in ***Figure 14***. Even though this topology offers natural isolation with the back-end electronics, the effective radiating volume is higher compared to conventional end-fire antennas. Therefore, this approach might not be a viable option for commercial deployment.

REDUCING MUTUAL COUPLING

Mutual coupling is an important phenomenon in multiple radiator antenna systems designed for 5G portable devices. As mentioned earlier, one of the common techniques for gain enhancement in the mmWave domain is to implement phased arrays. Typically, the radiating elements within the phased array would be placed and operated electrically close together. For instance, for maximum gain enhancement, the antennas might be placed at a half-wavelength distance at the resonant frequency. Ideally, the antennas should contribute to beamforming alone, but due to the electrical proximity of the elements, part of the input power will be wasted in mutual coupling with other ports. Two primary consequences result from this topology: the overall forward gain of the antenna system decreases due to the partial loss of energy within the ports and there may be detuning and deterioration of

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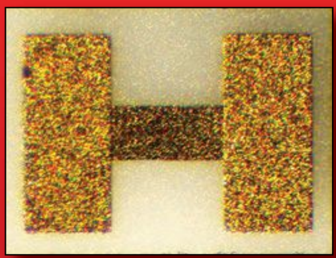

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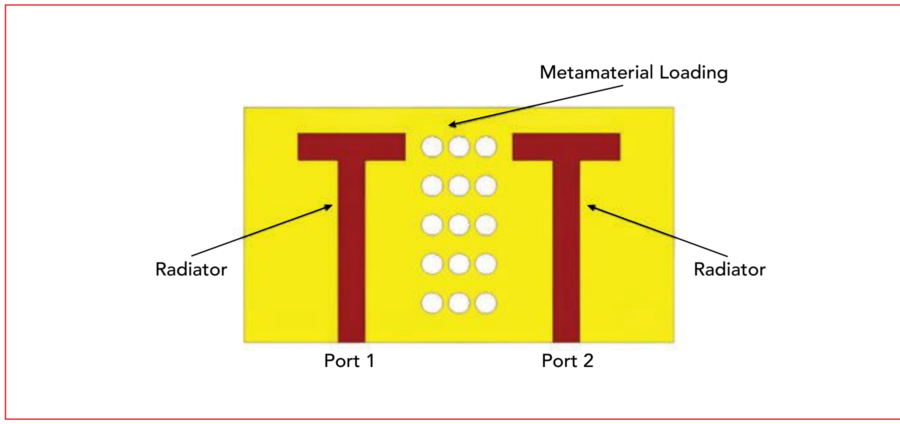

Fig. 15 Layout of an MTM-based antenna to reduce mutual coupling.

the input impedance characteristics of the individual ports, potentially leading to an impedance mismatch with the back-end electronics.

The other consequence of the mutual coupling effect is most impactful for MIMO antenna systems. More mutual coupling means less diversity gain and this affects the overall throughput of the antenna system. Reducing mutual coupling by even 5 dB among the ports might improve the forward gain by up to 1 dB. A generic layout of a two-port antenna system integrated with MTM for mutual coupling reduction is illustrated in ***Figure 15***.

In Figure 15, both antennas are identical and similar to most commercial implementations. The radiators can be either broadside or end-fire. Both the elements would be typically spaced at a fraction of a wavelength, computed at the center of the operating frequency. The sub-wavelength MTM unit cells must not be the reflective type because this will severely detune both constituent antennas. The performance or characteristics of the unit cell cannot be used to predict the post-integrated mutual coupling reduction phenomenon.

There are some simple and effective ways to reduce mutual coupling. These include placing the antennas electrically far away from each other or placing the radiators in an orthogonal orientation. Unfortunately, neither of these techniques would enable mmWave 5G antenna communications because distant antenna placement prevents beamforming and orthogonal antenna placement will severely degrade the beam integrity.

CONCLUSION

This article discusses the feasibility of metamaterials in the design of high gain compact antennas for mmWave 5G devices. Gain enhancement using MTM unit cells for both end-fire and broadside radiators has been explained with case studies. Finally, the concept of mutual coupling reduction using MTM unit cells for mmWave bands has been illustrated. ■

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- Gain & Loss Equalizers
- Integrated MIC/MMIC Assemblies (IMAs)
- Miscellaneous Products
- Monopulse Comparators
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A 71.5 to 81 GHz Active Phase Shifter in 40 nm CMOS Technology

Shangyao Huang, Yanjie Wang and Xianfeng Que
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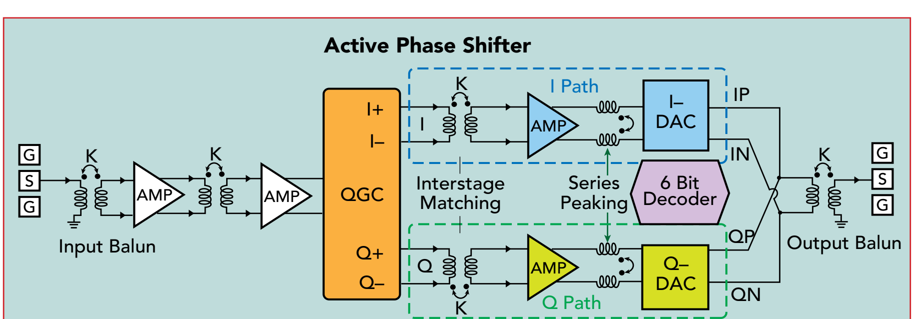
A 71.5 to 81 GHz 6-bit phase shifter in 40 nm CMOS incorporates a compact differential capacitor-free quadrature generator circuit (QGC) based on a folded transformer for I/Q generation and size reduction. A transformer-based series peaking technique is also used for bandwidth extension. The phase shifter demonstrates a 3 dB bandwidth from 71.5 to 81 GHz. Its RMS phase error is 3.2 to 3.6 degrees and its RMS gain error is 0.85 to 0.90 dB. The phase shifter's core area is 250 × 720 µm.

To improve signal-to-noise ratio and reduce interference, beamforming techniques based on phased array systems have been widely applied in mmWave communication.[1,2] In phased array systems, the phase shifter is a key component. Its phase resolution and phase shifting range determine the array system's beamforming and beam steering capabilities.[3,4] Phase shifters can generally be classified as passive[5,6] and active.[7,8] Switched,[9] reflection[10] and load transmission line phase shifters are all passive. They generally occupy large physical areas and have high insertion loss, while active phase shifters offer better phase resolution, lower insertion loss and smaller size.

A conventional active phase shifter typically contains several inductors and this consumes a large area.[11] In addition, the performance of the variable gain amplifier (VGA) limits the phase resolution. There are typically two methods to implement the VGA: tail current-controlled Gilbert cell[11] and current steering.[12] Regardless of the approach, phase resolution is poor because the VGA is difficult to adjust. At mmWave frequencies, this is more pronounced due to limited transistor performance and parasitic effects in CMOS design.

To address these issues, this article presents a 6-bit active phase shifter employing a compact QGC and a proportional digital-to-analog converter (DAC) array with a 6-bit decoder. It demonstrates an RMS phase error of 3.2 to 3.6 degrees and an RMS gain error of 0.85 to 0.90 dB from 71.5 to 81 GHz. This performance is achieved without digital calibration.



▲ **Fig. 1** Active phase shifter block diagram.

PHASE SHIFTER DESIGN

The phase shifter comprises a compact capacitor-free QGC, a three-stage amplifier and an I/Q DAC array for phase synthesis with a 6-bit decoder. Input and output baluns are added to enable measurements. After two stages of amplification, fully differential I/Q signals are created by the QGC. Interstage matching in the I/Q path between the QGC and the amplifier is employed for maximum power transmission. The binary-weighted I/Q DAC and 6-bit decoder are co-designed for vector synthesis. Series peaking between the amplifier and DAC is used for bandwidth extension. The phase shifter block diagram is shown in ***Figure 1***.

QGC Design

The QGC plays a critical role because it generates the orthogonal I/Q signals and directly affects phase shifter performance. Many traditional transformer-based QGCs employ a planar structure with horizontal coupling, but this wastes area. To solve this problem, the design described by Li et al.[13] is a vertically stacked structure with vertical coupling. However, this approach increases design complexity due to considerations regarding capacitor design and placement when adding additional capacitors.

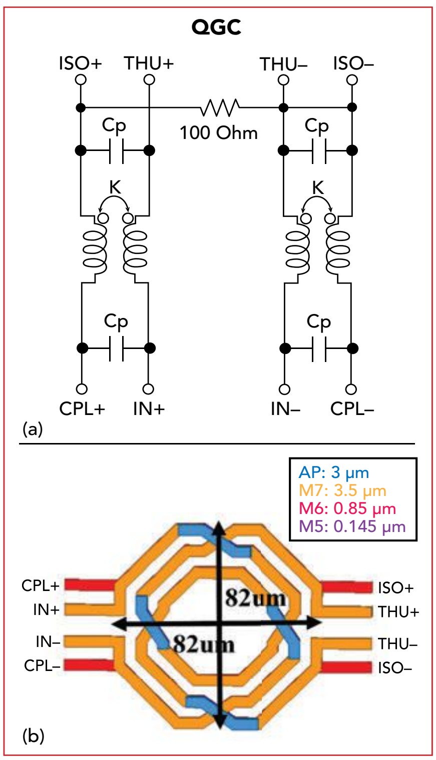


Fig. 2 (a) QGC schematic. (b) QGC layout.

In the phase shifter design described in this article, parasitic capacitors are used between metal layers. The equivalent circuit and layout of the QGC are shown in ***Figure 2a*** and ***Figure 2b***, respectively. A differential input signal is applied to the input ports (IN+, IN-) and then split into two quadrature signals at the through (THU+, THU-) and coupled (CPL+, CPL-) ports.[14] A 100 Ω resistor is connected between two isolation ports (ISO+, ISO-). Cp is the parasitic capacitance at different physical layers. In 40 nm CMOS technology, the thickness of the upper layer metal is thicker and its resistivity is lower. This is beneficial for reducing insertion losses. Therefore, the top four metal layers are used for the QGC layout.

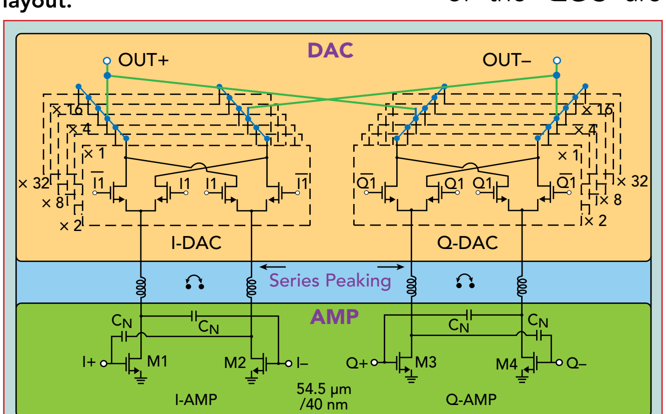


Fig. 3 Schematic of the amplifier, series peaking and I/Q DAC.

TABLE 1

BANDWIDTH AND GAIN COMPARISON

Peaking Method	3 dB Bandwidth (GHz)	Peak Gain (dB)
Baseline	7.6	-12.3
Series Peaking	10.0	-11.0
Parallel Peaking	11.4	-12.0

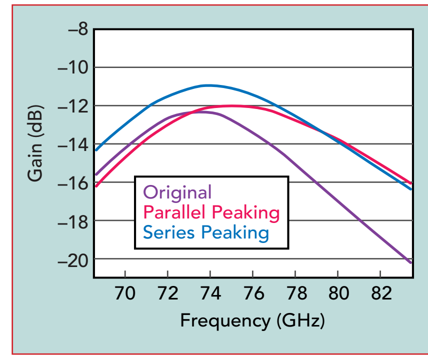


Fig. 4 Simulated phase shifter bandwidth and peak gain.

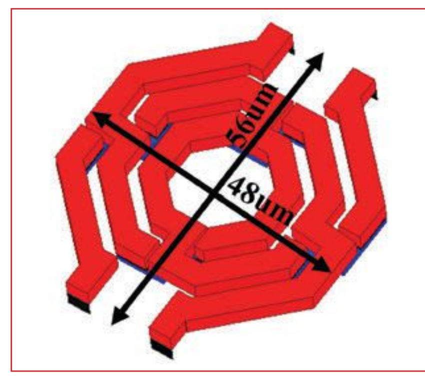


Fig. 5 Transformer-based series peaking inductor layout.

Amplifier and I/Q DAC Design

The amplifier and DAC schematic in the I/Q path is shown in ***Figure 3***. In the amplifier section, a capacitor, CN, neutralizes the gate-to-drain capacitance. Series peaking is used between the amplifier and DAC for bandwidth extension. In the DAC section, all transistors are controlled by a 6-bit decoder. To achieve phase accuracy, transistor size ratios in the DAC are optimized to be 1:2:4:8:16:32.

Series Peaking Technique

Parasitic capacitance from the amplifiers and DACs narrows the phase shifter bandwidth. There are at least two techniques to mitigate this: series peaking and parallel peaking. These techniques apply the principles of LC series resonance and LC parallel resonance, respectively. The inductance for both series and parallel resonance is shown in ***Equation 1***:

$$L = \frac{1}{(2\pi f_o)^2 C} \tag{1}$$

Simulation results for the phase shifter, along with the peaking results are plotted in ***Figure 4*** and listed in ***Table 1***. The results show the improvement in bandwidth and peak gain using the two peaking methods. The baseline is with no resonant inductor. Both series peaking and parallel peaking improve the 3 dB bandwidth. Without the resonant inductor, the 3 dB bandwidth is 7.6 GHz. With series and parallel peaking, the bandwidth is 10 GHz and 11.4 GHz, respectively. Although the bandwidth is slightly reduced, series peaking is chosen for this design due to its higher peak gain.

The layout of the added series peaking inductor is shown in ***Figure 5***. The inductor is rotationally arranged to reduce size. Therefore, transformer-based series peaking is adopted to improve bandwidth and gain and also to reduce chip size.

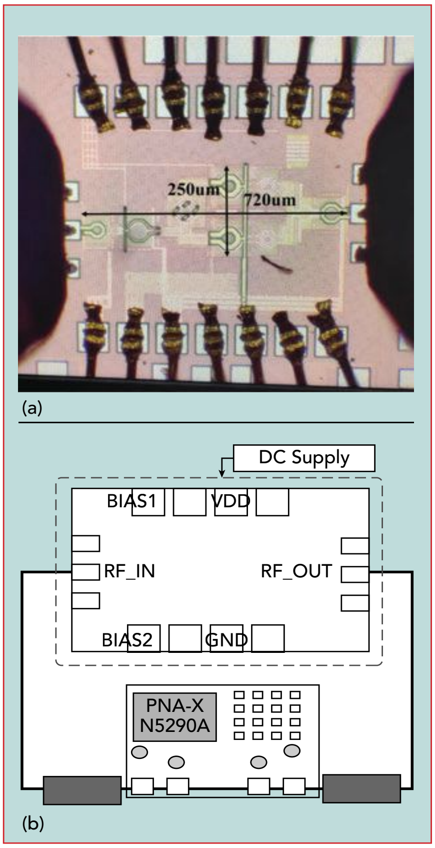


Fig. 6 **(a) 6-bit phase shifter die. (b) Measurement setup block diagram.**

MEASUREMENTS

The phase shifter chip shown in ***Figure 6a*** is implemented in 40 nm CMOS technology with a core area of 250 × 720 µm². ***Figure 6b*** is the measurement setup block diagram. Measurements reveal a 3 dB bandwidth of 71.5 to 81 GHz and an insertion loss of 6 to 9 dB for one basic stage. The entire phase shift range is 360 degrees with a minimum phase

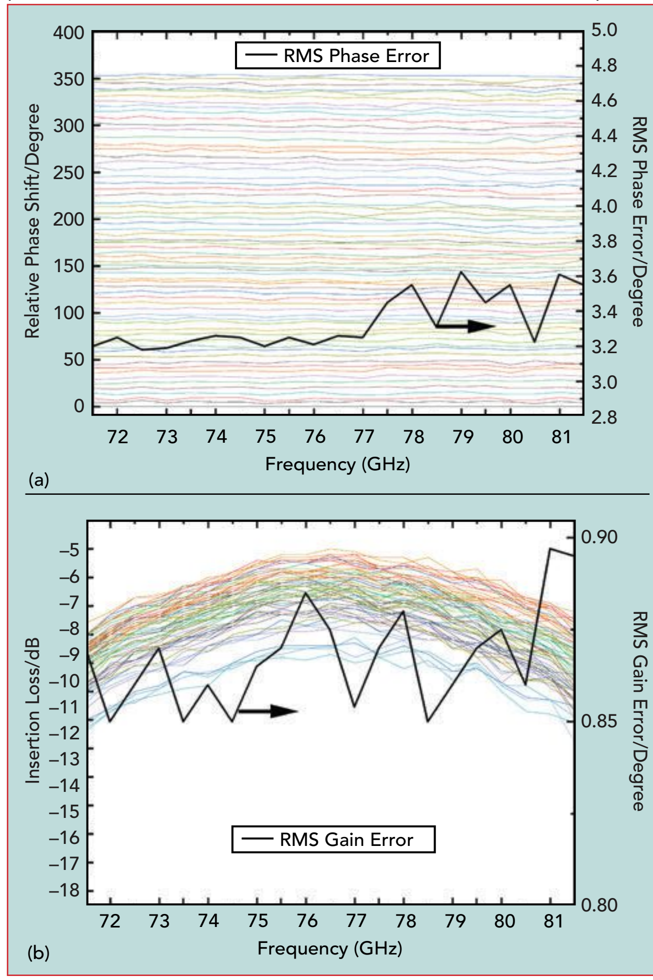


Fig. 7 **(a) Relative phase shift performance. (b) Insertion loss performance.**

TABLE 2

PERFORMANCE SUMMARY AND COMPARISON

Reference	Technology	Frequency (GHz)	Resolution (bits)	RMS Phase Error (degrees)	RMS Gain Error (dB)	Peak Gain (dB)	DC Power (mW)	Core Area (mm²)	FoM (dB)
15	28 nm CMOS	78.8 to 92.8	4	11.9	2	2.3	21.6	0.17	63.8
16	65 nm CMOS	79*	5	6.74	1.89	-11.4	24.7	0.14	35.5*
17	65 nm CMOS	51 to 66.3	5	7	0.72	-1.8	5	0.3	67.6
18	28 nm CMOS	55 to 64	5	3.3	0.47	-3.02	15.4	0.41	64.4
11	40 nm CMOS	52 to 57	6	2.8 to 3.76	2.07 to 2.23	-9	14.3	0.15	56.5
12	40 nm CMOS	56 to 65	7	1.4 to 7	0.13 to 0.3	-0.4	38	>0.5	69.7
19	0.18 µm SiGe	8 to 12	5	4.5 to 4.6	0.50 to 0.60	-1.25	73.92	0.60	60.7
20	28 nm CMOS	67 to 79	6	0.38 to 0.69	0.49 to 0.83	-11.8	28.5	0.078	99.4
21	22 nm CMOS FDSOI	24 to 36	5	2.6@ to 4	0.60	-5	7.2	0.60	42.2
This work	40 nm CMOS	71.5 to 81	6	3.2 to 3.6	0.85 to 0.90	-6	39	0.18	72.9

** Does not provide the entire bandwidth.*
@ Rough estimate obtained from the figure.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resolution of 5.625 degrees. ***Figure 7a*** is the measured relative phase shift and ***Figure 7b*** is the insertion loss of the 64 states. The RMS phase error is below 3.6 degrees and the RMS gain error is less than 0.9 dB from 71.5 to 81 GHz. Performance characteristics and comparisons with other work are summarized in ***Table 2***. The derivation of the FoM in Table 2 is shown in ***Equation 2***:

$$\text{FoM} = 20\log\frac{fo(\text{GHz}) * \text{Gain}(\text{linear})\text{BW}_{3\text{ dB}}(\text{GHz}) * n(\text{bits})}{\text{RMS Phase Error}(\text{deg}) * \text{RMS Gain Error}(\text{dB}) * \text{Core Area}(\text{mm}^2)} \quad (2)$$

CONCLUSION

A wideband 6-bit active phase shifter with three-stage amplification employs a compact and capacitor-free QGC with series peaking for quadrature signal generation and bandwidth extension. The phase shifter chip is implemented using TSMC's 40 nm CMOS with a core area of 250 × 720 µm. A peak gain of -6 dB at 76.5 GHz and a 3 dB bandwidth from 71.5 to 81 GHz are achieved. Within the 3 dB bandwidth, the RMS phase error is 3.2 to 3.6 degrees and the RMS gain error is 0.85 to 0.90 dB. Its compact size and low phase error make this phase shifter suitable for application in mmWave phased array systems. ■

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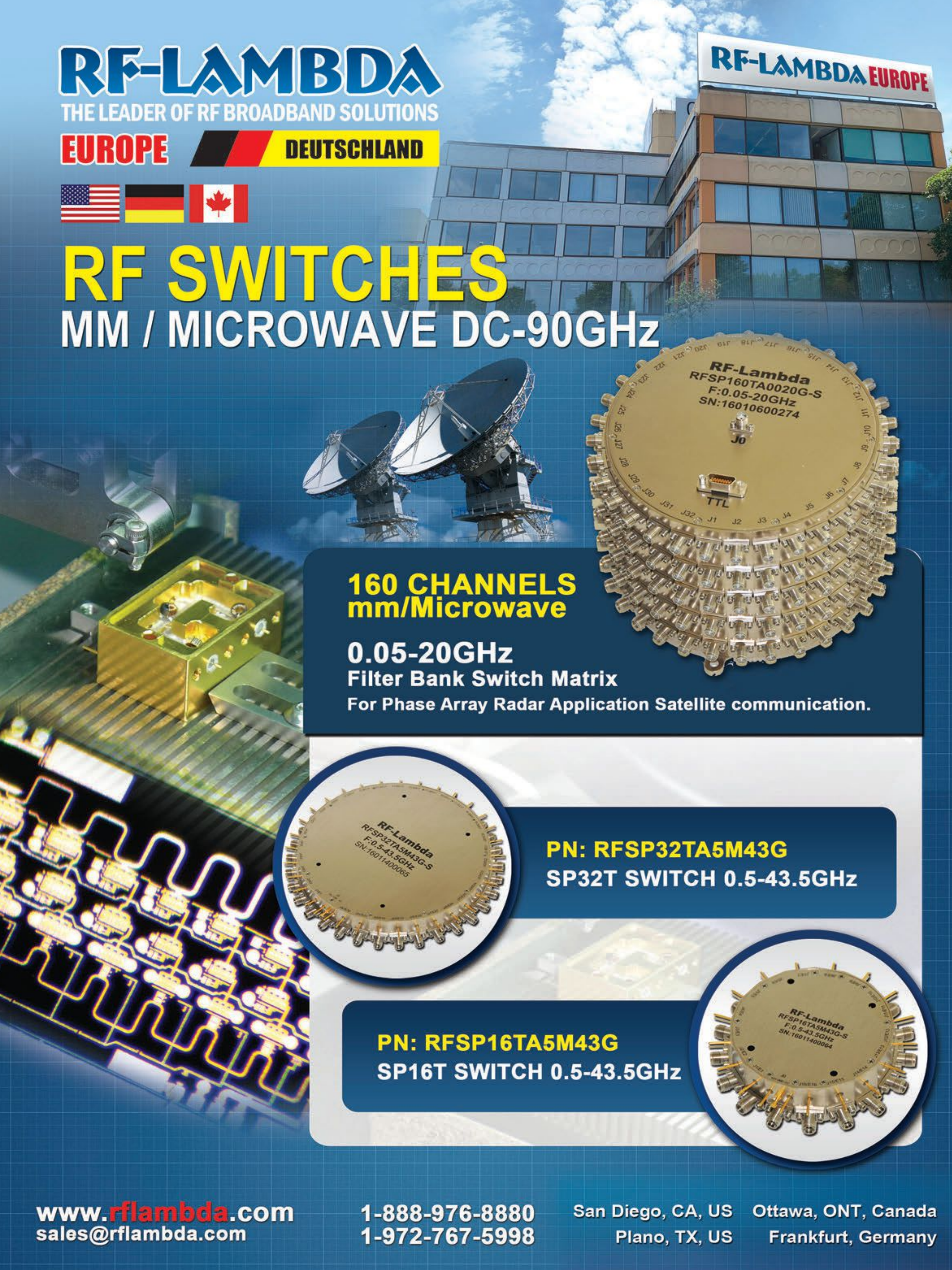
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The industry uses electromagnetic compatibility (EMC) testing to measure the levels and effects of this interference. These tests measure radiated emissions, which is unintentional electric, magnetic or electromagnetic field energy that escapes the equipment. The tests will also measure conducted emissions that are unintentional energy emitted from the equipment on power or signal cables. In addition to measuring emissions, EMC testing will determine how well a device continues to function as intended in the presence of several electromagnetic phenomena.

▲ Fig. 1 **REMC18G40GC2 EMC benchtop power amplifier.**

The purpose of EMC immunity testing is to verify whether the equipment can function properly when exposed to high levels of RF energy. Typically, EMC immunity tests require field strengths in the range of 3 to 200 V/m. EMC power amplifiers (PAs) generate the RF power required to create the necessary field strengths required for EMC testing. A signal generator creates the test signal that is amplified by the PA and sent to an E-field generator. The magnitude of this E-field will be determined by the field strength required at a given distance from the antenna.

To meet these requirements, RF-Lambda has expanded its family of solid-state benchtop EMC RF system amplifiers with the REMC18G40GC2 that operates from 18 to 40 GHz. The performance of the device eliminates the need for multiple amplifiers and this conserves rack space, along with reducing costs. The PA's input connector is a 2.92 mm male and the output connector is a WRD180C24. This product also has a calibration feature that enables customers to compensate for time and temperature changes. It also provides over-temperature and over-current protection, along with an autocalibration feature. The REMC18G40GC2 is shown in ***Figure 1***.

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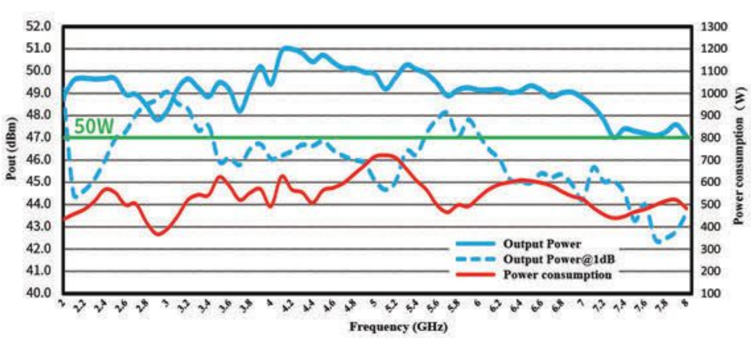

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TABLE 1
ELECTRICAL SPECIFICATIONS (TA =+25°C)

Parameter	Minimum	Typical	Max.	Units
Frequency range	18		40	GHz
Small-signal gain	55	60		dB
Gain flatness		±6		dB
Gain variation over temperature (0°C to +50°C)		±3		dB
Input return loss		10		dB
Output P1dB		36.8		dBm
Saturated output power (P_{sat})		45		dBm
Supply current (110/220 V AC)		5	8.1	A
IM3		-28		dBc
PAE		20		%
Weight			90	lbs.
Impedance		50		Ω
Input/output connectors	2.92 mm male (input)/WRD180C24 (output)			
Supply voltage	110/220 VAC			
RF input power	= P_{sat} – large-signal gain			

for EMC immunity testing, the GaN-based amplifier provides a typical saturated power of 44 dBm over the frequency range. To reach these saturated output powers, the REMC18G40GC2 provides a typical small-signal gain of 60 dB. This gain level allows the user to reach the saturated power output using a standard input signal source. The precision of the output signal power is enhanced with the built-in 15 dB attenuator. Users can adjust the output power in 0.5 dB increments. The REMC18G40GC2 switches seamlessly between 110 and 220 VAC power inputs and there is a remote-control feature for added convenience. The full set of electrical performance parameters for the REMC18G-40GC2 are shown in ***Table 1***.

Figure 2 shows the room temperature gain from 17 to 41 GHz, with markers set at the 18 to 40 GHz band edges. Despite the wide bandwidth of the unit, it easily meets the ±8 dB gain flatness specification. ***Figure 3*** shows the saturation power versus frequency.

The REMC18G40GC2 is a versatile tool for EMC testing. With the wide frequency range and its performance characteristics, this benchtop EMC PA can be used in a variety of applications. These include wireless infrastructure, defense, aerospace, research and development and test applications.

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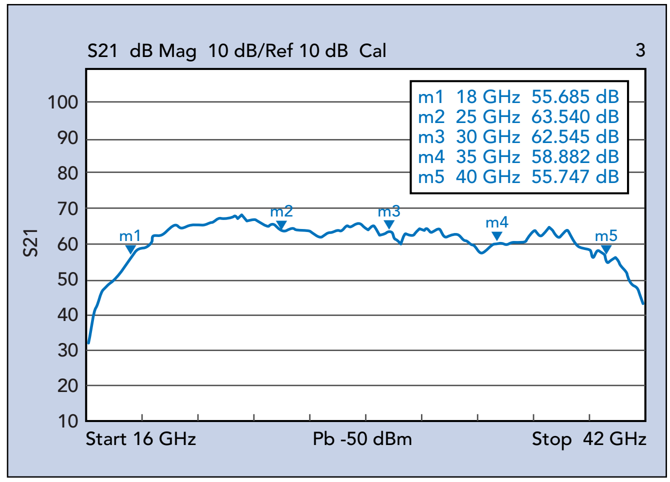

Fig. 2 Gain at +25°C.

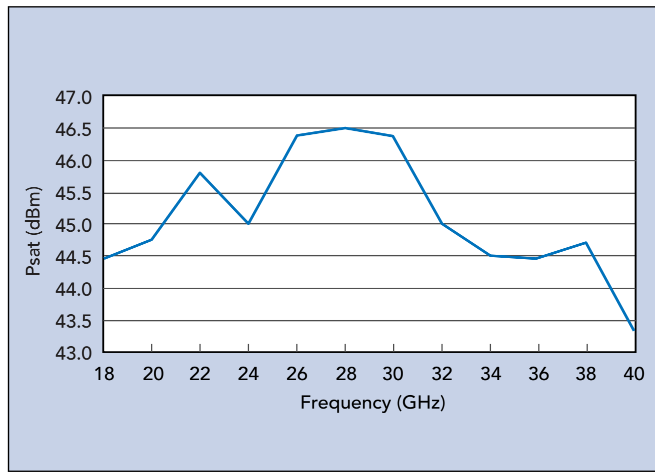

Fig. 3 Pulsed saturation power with 5 dB attenuation.

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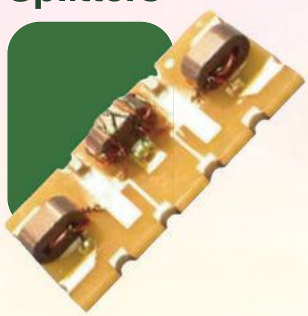

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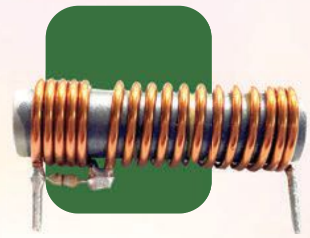

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The satcom industry has seen tremendous growth in recent years due to a combination of lower launch costs combined with reduced satellite manufacturing costs. It is expected that 50,000 satellites will be launched over the next decade. The number of ground terminals needed to support these satellites is estimated in the millions and these terminals vary from large gateway terminals to small portable user terminals. The fastest-growing segment of the satellite market is Ka-Band, which uses the 17.3 to 21.2 GHz frequency band for downlink and the 27.5 to 31.0 GHz frequency band for uplink. It is this uplink frequency band and the ground terminal market that Nxbeam supports with its line of high-power Ka-Band MMIC products.

TABLE 1

NXBEAM KA-BAND SATELLITE GROUND TERMINAL MMIC PRODUCTS

MMIC	Frequency (GHz)	Power (dBm)	Gain (dB)	PAE (%)	Form
NPA2003	27.5 - 31.0	45.3	25.0	31	Die
NPA2030		43.0	25.0	35	Die
NPA2040		40.0	24.5	31	Die
NPA2050		38.5	23.0	25	QFN
NPA2001	26.5 - 29.5	45.5	25.0	31	Die
NPA2002	27.0 - 30.0	45.3	25.0	31	Die
NPA2004	25.0 - 27.5	46.0	24.0	34	Die

KA-BAND GAN POWER AMPLIFIER PRODUCTS

To support the Ka-Band ground terminal market, Nxbeam offers a full suite of high fidelity power amplifier (PA) MMICs focused on increasing data throughput. As shown in ***Table 1***, the Ka-Band PA MMIC products range from 7 to 40 W of output power, making them suitable for a wide range of ground terminals. Nxbeam entered this market and focused first on the higher-power products to support the gateway market. Building on that success, Nxbeam moved down in power to support smaller ground terminals.

The company's latest product offering is the NPA2050-QF, which is a 7 W Ka-Band PA in a QFN package. This product was designed specifically for the high volume, low-cost Ka-Band ground terminal market. The challenge with this specific market has been the need for a very low-cost PA. Until now,

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MODEL	FREQ. RANGE	MAX. VSWR	MAXIMUM FLATNESS (± dB)	LOW LEVEL SENSITIVITY (mV / µW)
DZR50024A	10 MHz-50 GHz	1.3:1 (to 18 GHz) 1.6:1 (to 26 GHz): 1.8:1 (to 40 GHz) 2 :1 (to 50 GHz)	± 0.3 (to 18 GHz) ± 0.6 (to 26 GHz) ± 0.8 (to 40 GHz) ± 1.0 (to 50 GHz)	0.5
DZR50024B	10 MHz-50 GHz			0.5
DZR50024C	10 MHz-50 GHz			0.5

*All models have 2.4 mm (M) input connector
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it has been a challenge for GaN to achieve the necessary price point, but by implementing a new innovative design approach, Nxbeam has been able to significantly reduce the cost for this power level.

The cost of a GaN PA is directly proportional to the GaN semiconductor area of the MMIC. By decreasing this area, more chips can be fabricated from one wafer, which decreases the overall product cost. Nxbeam has used an innovative design approach to reduce the GaN semiconductor area of the NPA2050-QF by more than 50 percent. This dramatic decrease in the semiconductor area has enabled the design to achieve the desired price points.

PA DESIGN AND PERFORMANCE

Like all of Nxbeam's Ka-Band PA products, the NPA2050-QF offers the same high performance with high reliability. As with other Nxbeam MMIC amplifiers, it is a three-stage design with the capability to control the quiescent current of each stage independently. This has proven to be essential to many customers as they use this feature to tailor the linear power performance to their specific needs through bias control.

The NPA2050-QF operates from 27.5 to 31.0 GHz and provides 7 W of saturated output power, 23 dB of linear gain and 25 percent power-added efficiency. ***Figure 1*** shows the output power versus input power curves. The bias for all measurement results shown was 26 V and 525 mA quiescent current with all gates at the same voltage. For ground terminal use, the fidelity of the PA is critical, so its linear power capability is more important than pure saturated output power.

Figure 2 shows the measured IM3 curves for this specific bias with a frequency spacing of 10 MHz. As seen in this figure, an output power of 4 W can be achieved at an IM3 level of -20 dBc. This is just one set of IM3 curves and by adjusting the bias for each stage, linear power performance can be tailored for specific use cases. ***Figure 3*** shows the linear power performance in terms of spectral regrowth for a QPSK modulation at 10 MSPS and alpha = 0.2.

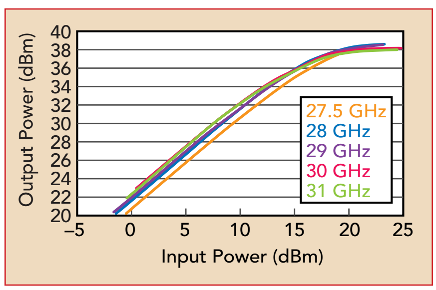

Fig. 1 NPA2050-QF measured output power versus input power.

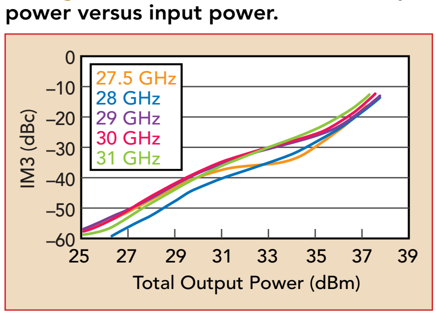

Fig. 2 NPA2050-QF measured IM3 versus total output power.

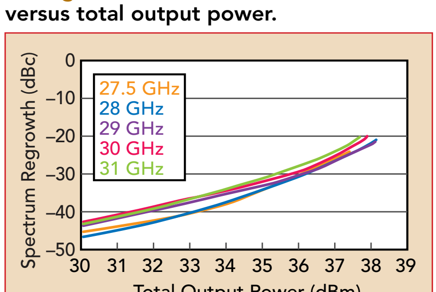

Fig. 3 NPA2050-QF measured spectral regrowth versus total output power.

FUTURE WIRELESS SYSTEMS

As the world advances toward a more AI-driven automated society, access to wireless data from anywhere at any time will require wireless infrastructure capable of higher data rates and satellites along with their supporting ground terminals, will play a key role. There is already work at higher frequencies beyond Ka-Band, like V-Band and E-Band, to support future wireless data needs. While Nxbeam is currently supporting the Ka-Band ground terminal market, the company also supports these future bands and will be continuously releasing new products to support them.

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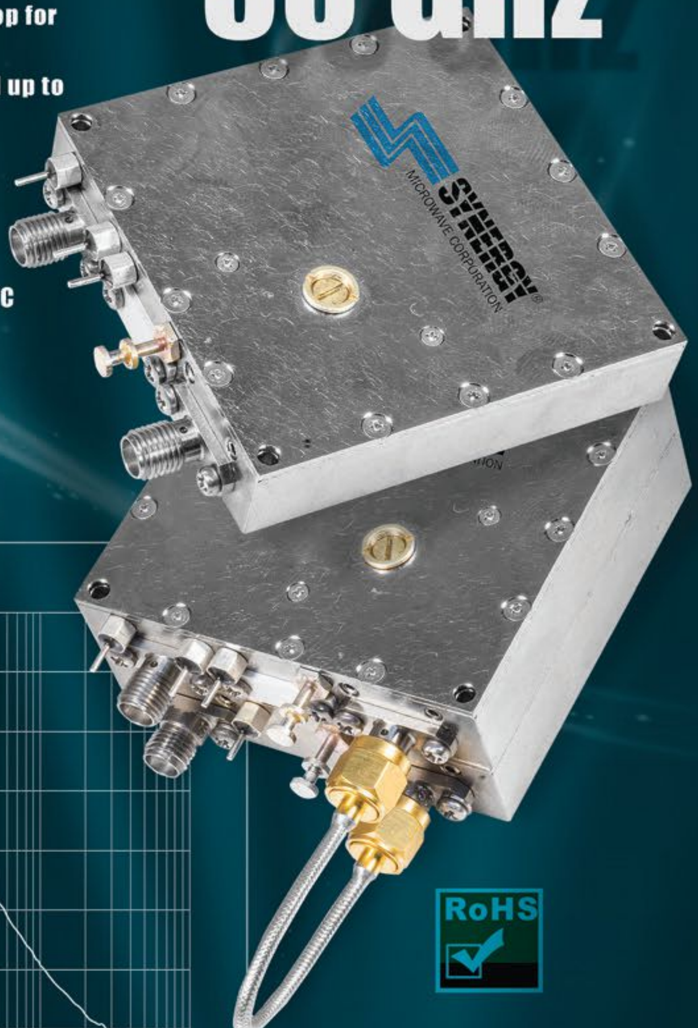
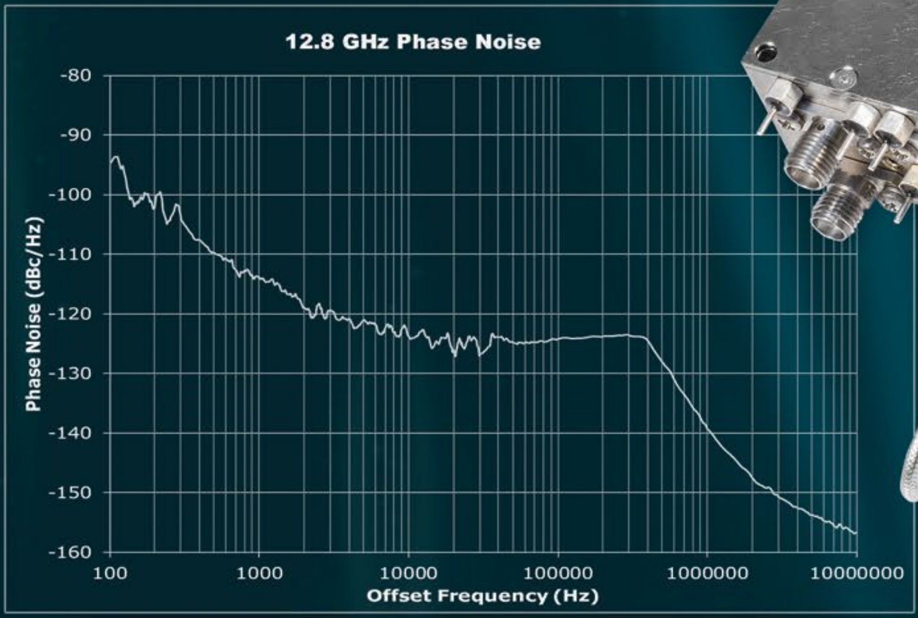


Applications:

- SATCOM, RADAR, MICROWAVE RADIO

* *16 - 30 GHz with added x2 module < 1" in height.*



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mmWave Tactical Communications Platform

Peraso, Inc.
San Jose, Calif.

Peraso announced a new wireless platform utilizing the company's proven mmWave product line for secure tactical communications. This new solution creates an opportunity for Peraso to expand into new markets while also highlighting the practical application benefits of 60 GHz mmWave within the defense sector. Peraso's PRM2136 is a member of the Pro series of modules that are compliant with IEEE 802.11ad specifications. It offers support for high bandwidth, low latency applications using unlicensed mmWave spectrum and it enables high bandwidth throughput connection rates of more than 3 Gbps between the users. The PRM2136 operating frequency range is in the unlicensed band from 57 to 63 GHz and because it operates in the 60 GHz band, interference from traditional Wi-Fi devices operating in the 2.4 GHz and 5 GHz bands is minimized. The use of directional beamforming technology, the propagation characteristics of 60 GHz signals and advanced software features from Peraso help mitigate interference from other IEEE 802.11ad devices.

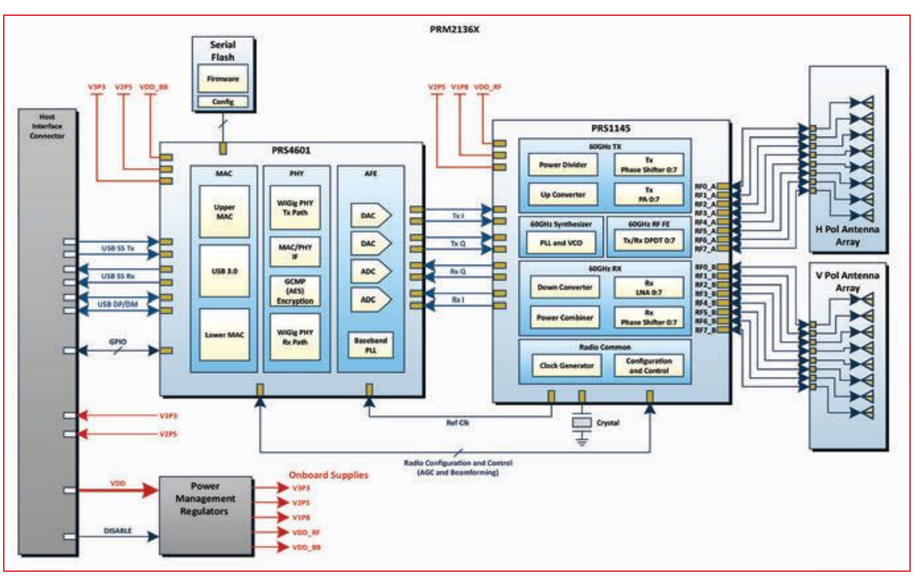
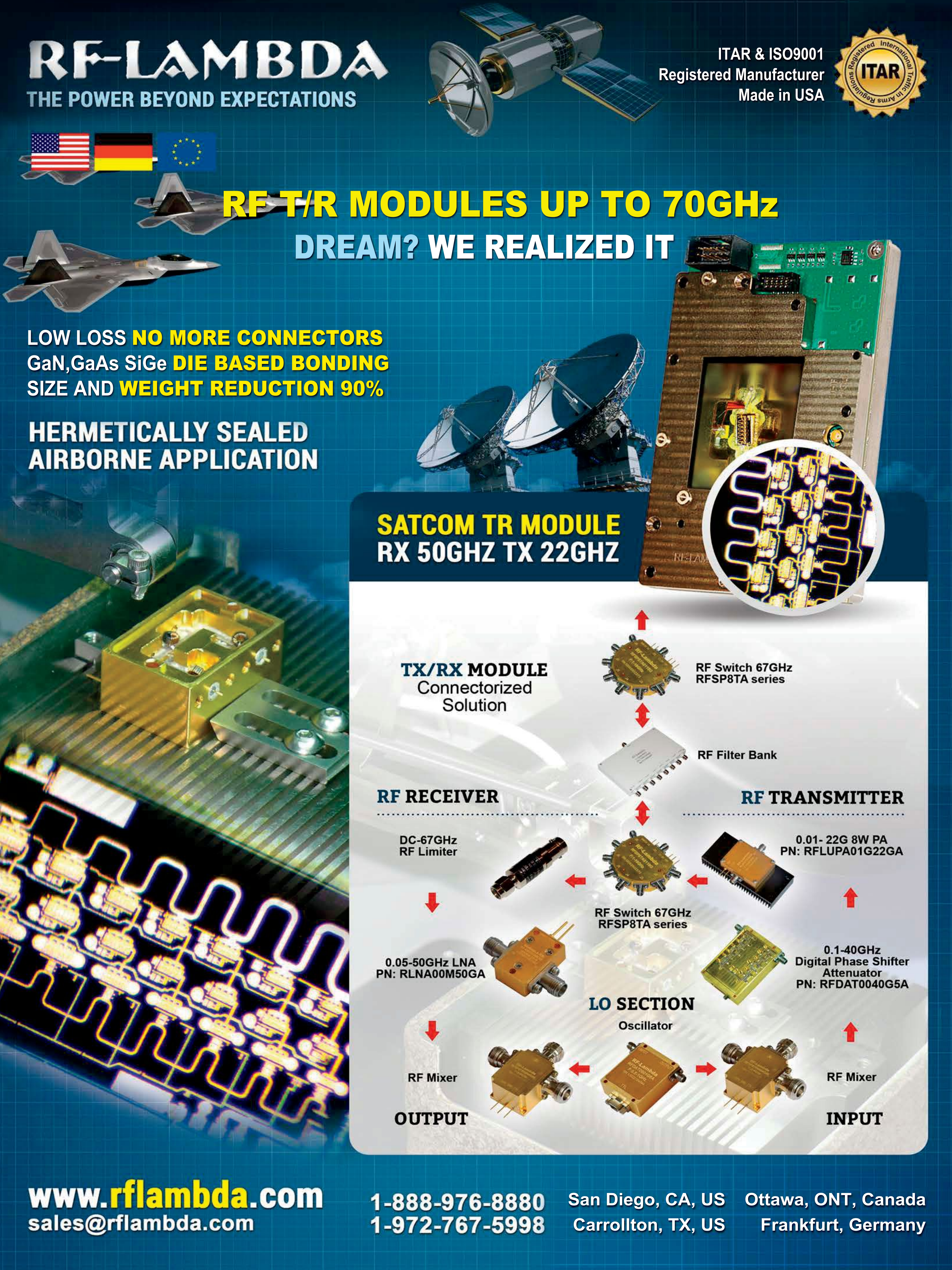


Fig. 1 **PRM2136 block diagram.**

Peraso's 60 GHz modules enable multi-gigabit data transfer rates, which can be especially important in military operations where sharing real-time data is essential. One key advantage of the company's technology is the ability to create small, lightweight and power-efficient solutions that are ideally suited for tactical, standalone military applications. Additionally, the PRM2136 delivers adaptive beamforming and narrow "pencil" beams that enable highly directional communications, which are inherently stealthy with a low probability of interception, low probability of detection and less susceptible to conventional jamming techniques. The block diagram for the PRM2136 module is shown in ***Figure 1***.

As shown in the block diagram, the module relies on Peraso's PRS1145 and PRS4601 ICs that, collectively, comprise the X720



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chipset. The PRS1145 is a 60 GHz radio IC that contains 16 RF chains to support 16 Tx/Rx antenna ports. The RF chains have a transmit power of up to 24 dBm with a receive noise figure of 7 dB. The IC contains an integrated crystal oscillator and the PLL tunes to channels 1 to 6 in half-channel steps. The PRS1165 supports BPSK, QPSK and 16-QAM single carrier modulation. It also contains the baseband I/Q interface to the PRS4601 IC.

The PRS4601 is an 802.11ad baseband IC chip. It has an 802.11ad-compliant PHY that can provide maximum data throughput of up to 4.62 Gbps and it supports single carrier MCS0 to MCS12 (16-QAM). It offers a variable rate LDPC FEC and has full support for beamforming and beam tracking. The PRS4601 also has a USB 2.0/3.0 device controller with an integrated PHY supporting up to 5 Gbps communications. It also has an 802.11ad-compliant MAC with two integrated RISC CPUs. In addition, the chip has on-chip memory for all packet buffering, control and management functions. The PRS4601 has 128-bit AES security with support for 32 clients and two connected radios. It has 24 configurable, multi-function GPIOS and it offers Windows, Linux and Android support. All this functionality comes in a 7 mm × 7 mm BGA package.

TABLE 1

PRM2136 MMWAVE MODULE PERFORMANCE

Parameter	Value		
Data Interface	USB 3.0		
Air Protocol	802.11ad		
Modulation Schemes	MCS0-12 (pi/2-BPSK, pi/2-QPSK, pi/2-16-QAM)		
Multiple Access Modes	CBAP, proprietary long-range CBAP and controlled access protocols		
Security Modes	128-bit AES WPA3		
Networking Support	Infrastructure, peer-to-peer, standard WLAN, point-to-multipoint		
	Conditions	**Value (Typ.)**	**Units**
RF Frequency		57 to 66	GHz
Channel Bandwidth	802.11ad Channels 1-4	2.16	GHz
Module Size	Length x Width	45 x 20	mm
Operating Temperature Range		-40 to 85	°C
TX Parameters			
EIRP	T_{amb}=25°C, Channel 4, MCS9	29	dBm
RX Parameters			
Sensitivity	T_{amb}=25°C, Channel 4, MCS1	-84	dBm
Beamforming Parameters			
Azimuth Scan Range	-3 dB edge H-pol V-pol	±40 ±45	degrees
Elevation Scan Range	-3 dB edge H-pol V-pol	±40 ±30	degrees
DC Power Consumption			
Tx DC Power	MCS9 Operation. 100% Duty Cycle	3.2	W
Rx DC Power		2.9	W

The PRM2136 module leverages the X720 chipset and the other peripherals shown in Figure 1 to implement a low-cost, low-power, high performance SuperSpeed USB 3.0 to IEEE 802.11ad 60 GHz mmWave systems. The PRM2136 also provides multi-gigabit throughput with the ability to power applications such as secure tactical networking, wireless AR/VR, wireless displays, wireless docking and wireless access to the cloud. These applications can now be much more effective and efficient using 60 GHz technology. The performance specifications of the PRM2136 module are shown in ***Table 1***.

Figure 2a shows the component side of the PRM2136 module. From the layout, it is easy to see the smaller PRS1145 60 GHz radio IC at the top of the module and the larger PRS4601 802.11ad baseband IC in the lower half of the module. ***Figure 2b*** shows the top side of the PRM2136 module.

Peraso is a pioneer in high performance 60 GHz license-free and 5G mmWave wireless technology, offering chipsets, modules, software and IP. Peraso supports a variety of applications, including fixed wireless access, immersive video and factory automation. In addition, Peraso's solutions for data and telecom networks focus on accelerating data intelligence and multi-access edge computing, providing end-to-end solutions from the edge to the centralized core and into the cloud.

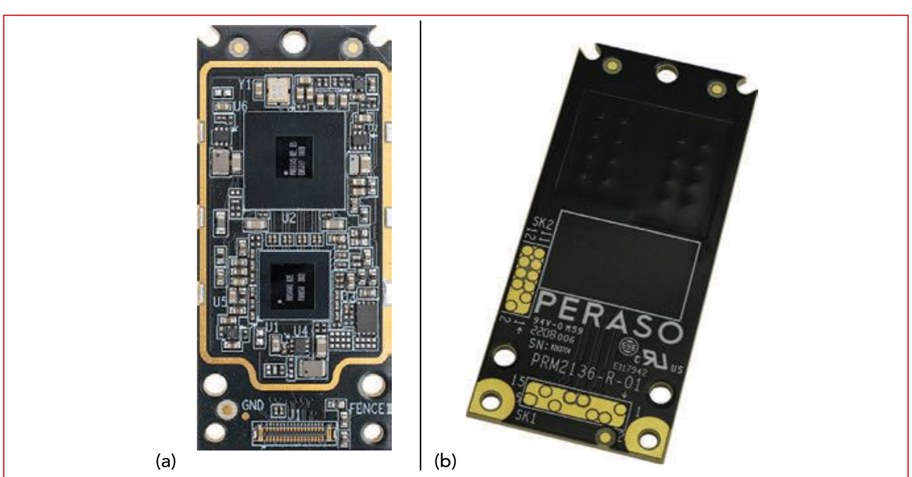

Fig. 2 **(a) PRM2136 module circuitry. (b) Top view of PRM2136 module.**

Peraso, Inc.
San Jose, Calif.
www.perasoinc.com

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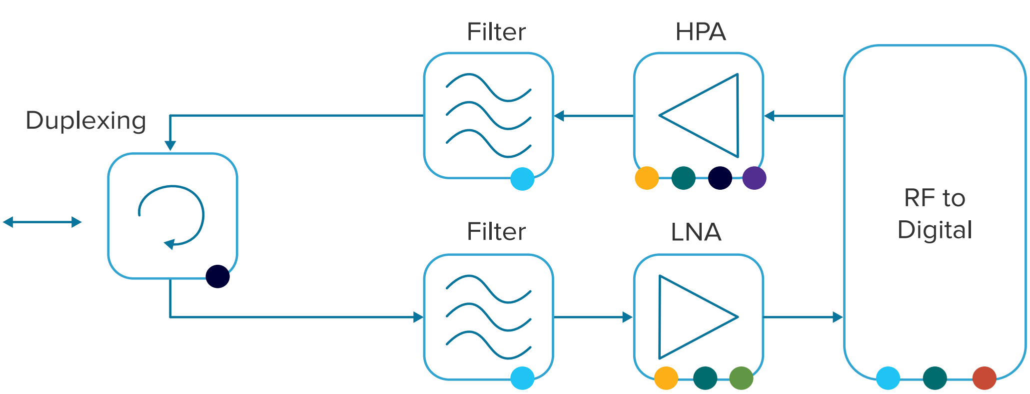

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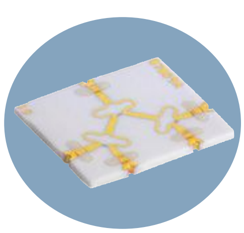

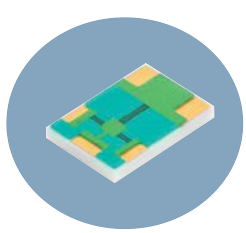

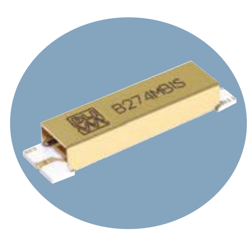

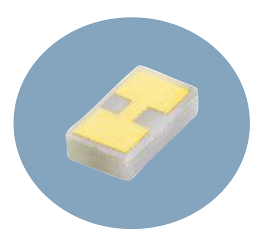

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SPDT Toggle Switches Operate to 26 GHz

Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has announced its latest innovation, SPDT toggle switches with SMA connectors. Tailored for a multitude of applications spanning telecommunications, aerospace and defense industries, these switches provide signal routing and connectivity solutions. These switches are designed to meet the demands of high frequency RF connectivity in applications up to 26 GHz.

Built with reliability in mind, the SPDT toggle switches give users flexibility and ease of operation through a switching configuration of SPDT and a toggle-switch mechanism. An operating frequency range of up to 26 GHz ensures compatibility with various high frequency applications. The SMA connectors provide reliable and secure connections, maintaining signal integrity. With a VSWR of 1.5:1, these switches offer excellent impedance matching for optimal signal transmission. They also achieve isolation performance of up to 80 dB, minimizing signal interference and ensuring reliable signal switching.

Pasternack's new SPDT toggle switches with SMA connectors are in stock and available for same-day shipping.

Pasternack has been supplying RF products since 1972. The company is an ISO 9001:2015-certified manufacturer and supplier offering the industry's largest selection of active and passive RF, microwave and mmWave products available for same-day shipping. Pasternack is an Infinite Electronics brand.

Infinite Electronics has a global portfolio of in-stock connectivity solution brands. The brands help propel the world's innovators forward by working to provide products, solutions and real-time support for their customers. Backed by Warburg Pincus, Infinite's brands serve customers across a wide range of industries with a broad inventory selection, same-day shipping and 24/7 customer service.

VENDORVIEW

Pasternack, an Infinite Electronics brand
Irvine, Calif.
www.pasternack.com
+1 (949) 261-1920 for inquiries

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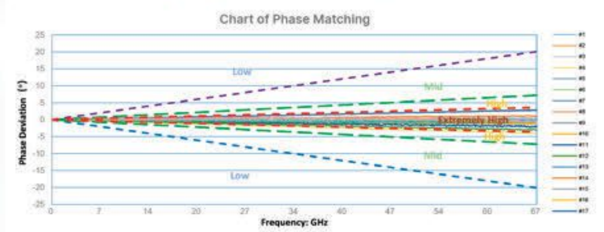
PHASE TRACK	Keep phase matched over the working temperature range
ABSOLUTE PHASE MATCH (optional)	Phase matched per requested electrical/phase length
PHASE & AMPLITUDE MATCH (optional)	Both phase and amplitude matched on requests
CUSTOM PHASE MATCH	Phase matched among multiple channels with several different length segments
SELECTABLE PHASE MATCH LEVEL	Available for phase match level selecting per application requirements so as to achieve high cost-effectiveness

67GHz Extremely High Phase Matching Chart (Cable Length 0.2m)



Level of Phase Matching

Level	Low	Mid	High	Extremely High (Bottom Line)
Criteria Length within 0.5 m	>±0.3°/GHz or>±0.83ps	≤±0.3°/GHz or≤±0.83ps	≤±0.108°/GHz or≤±0.3ps	≤±0.054°/GHz or≤±0.15ps
	>±1.8°@6GHz >±5.4°@18GHz >±12°@40GHz >±20°@67GHz	≤±1.8°@6GHz ≤±5.4°@18GHz ≤±12°@40GHz ≤±20°@67GHz	≤±0.7°@6GHz ≤±2°@18GHz ≤±4.5°@40GHz ≤±7.5°@67GHz	≤±0.4°@6GHz ≤±1°@18GHz ≤±2°@40GHz ≤±3.5°@67GHz

* For length over 0.5 meters, the criteria will be converted by corresponding multiples

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GaN MMIC PA Operates 6 to 18 GHz

Wavepia announced the latest addition to its GaN-on-SiC MMIC power amplifier (PA) family. The WPGM0618020M is a PA that operates from 6 to 18 GHz. The device has a saturated output power of 43.1 dBm, small-signal gain of 26.5 dB, power gain of 12.3 dB and PAE of 19.4 percent with all these typical values measured at 10 GHz and 28 V bias voltage. The amplifier can be operated with VDD values from 28 to 32 V.

The WPGM0618020M is available in an MPKG 10-lead bolt-down package measuring 16.94 x 7.35 x 1.4 mm. A companion part, the WPGM0618020C, comes in a leadless bolt-down package measuring 20 x 10 x 1.27 mm. The WPGM0618020C operates over the same frequency range with slightly better performance than the WPGM0618020M. Both devices target applications in a wide range of radar, electronic warfare, satellite and communication systems.

Established in 2014, WAVEPIA is an RFIC/MMIC design house based in South Korea. They design and develop a broad range of RF GaN HEMT bare die, MMICs and packaged RF GaN transistors that operate up to 40 GHz and up to 300 W. WAVEPIA also design solid-state RF generators using their GaN transistors that generate up to several kW of saturated output power for the RF energy market. They have a broad range of standard products, but all WAVEPIA devices are customizable upon request. In addition to defense, communications and RF energy applications, WAVEPIA devices find opportunities in general purpose, ISM, test and measurement, satellite and 5G/6G markets.

Wavepia
Hwaseong, South Korea
www.wavepia.com

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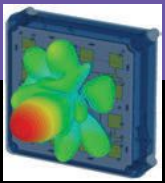


LadyBug Technologies Celebrates 20 Years

LadyBug Technologies announced they are celebrating their 20th year anniversary serving the industry. Founded in Santa Rosa, Calif., in 2004 and based in Boise, Idaho, LadyBug Technologies was created by microwave engineers with a passion for quality test instrumentation.

LadyBug Technologies
www.ladybug-tech.com

New Website Launch

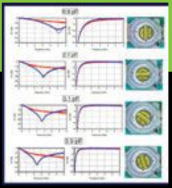
Microwave Techniques LLC has launched a new corporate website. The new site hosts hundreds of new 3D CAD models, product data and STEP files with unified branding for Microwave Techniques standard product portfolio. The latest updates offer visitors fresh content with the latest product line information and give users the ability to download CAD files to streamline their RF and microwave designs.

Microwave Techniques LLC
www.microwavetechniques.com

Trim Circuit Performance with Model-Based Design

Trimmer capacitors are useful components that may find homes in circuits that require frequency tuning, such as a crystal oscillator, tunable filter or amplifier matching network. To aid designers that may need to use these components, Modelithics recently developed a model for a trimmer capacitor from Knowles Corporation. In this blog post, you can learn more about this model and see its usefulness through a practical tunable filter example.

Modelithics
https://bit.ly/4aZvK0A



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Avoid Missing RF Signals: Discover the BB60C's Power

This video, featuring Signal Hound's senior engineer Justin Crooks, delves into the technical nuances and innovative engineering behind the BB60C. From its roots replacing the BB60A to its advanced double conversion superheterodyne architecture, learn how the BB60C sets new standards in the field.

Signal Hound
www.youtube.com/watch?v=JwRW0OhEiaE

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5G Mitigation Filter for C-Band

A1 Microwave expanded their range of C-Band receive filters for satellite ground installations to include off-the-shelf components that are fully compliant to the RED and BLUE spectrum masks. In addition to the close-in 5G rejection, they also feature transmit band rejection as well as X-Band radar for use in naval applications. This includes a recent trial for the U.K. Royal Navy, as well as hundreds of installations on cruise ships and terrestrial news-gathering equipment.

A1 Microwave
www.a1microwave.com

Waveguide Power Dividers

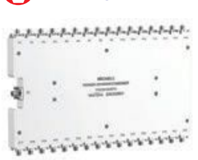
VENDORVIEW

Fairview Microwave, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has announced the release of its waveguide power dividers. These advanced components, featuring single-pole, double-throw (SPDT) toggle switches with SMA connectors, are a milestone in RF component availability, offering customers unmatched convenience and performance. Fairview's waveguide power dividers cater to the dynamic requirements of RF applications. They feature a robust SPDT switching configuration with a toggle switch, enabling precise signal control and routing.

Fairview Microwave
www.fairviewmicrowave.com

18 to 67 GHz Ultra-Wideband 32-Way Power Divider/Combiner

VENDORVIEW



MIcable 18 to 67 GHz ultra-wideband 2-way power divider/combine P32N180670 can accept a 18 to 67 GHz signal and deliver 32 output signals with extremely good amplitude unbalance (typically ±0.4 dB) and phase unbalance (typically ±8 degrees). Due to wide bandwidth, excellent VSWR (typically < 1.5:1), insertion loss (typically < 8.8 dB) and isolation (typically > 18 dB), it can be widely applied in 5G, test and measurement, instruments, antenna feed network and signal distribution system etc.

MIcable
www.micable.cn

Non-Blocking Solid-State Switch Matrix

Mu-Del Electronics, an Ironwave Technologies company, introduces non-blocking solid-state switch matrix, working in L-, S- and C-Bands. In the second half of 2024, an L-, S-, C- and X-Band non-blocking solid-state switch matrix will be introduced. Designed for top performance and versatility, this solid-state switch matrix offers outstanding features and benefits for a wide range of applications and environments. Offering touchscreen and remote interfacing with an option of frequency range down to 20 MHz. These units can be delivered with additional options such as programmable attenuation, bias tees, blocking and combining options.

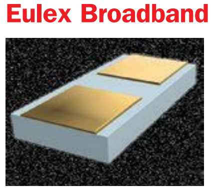
Mu-Del Electronics,
an Ironwave Technologies Company
www.mu-del.com

Ku-Band Low-Profile LC Filter

NIC has extended its LC filter capabilities until Ku-Band and successfully built an LC filter at 16,500 MHz in a low-profile (0.44 × 0.39 × 0.14 in.) surface-mount package. This filter offers low passband insertion loss (< 2.5 dB) and high selectivity (> 40 dB) in a compact package size which makes it a good alternative to a thin film filter. The LC design approach allows for quick turn prototypes, higher yields and more tuning flexibility as compared to a thin film approach. The filter is built with high temperature (Sn95Sb05) solder and is capable of meeting standard reflow temperatures of 215°C. Custom designs are available from 1 MHz to 18 GHz.

NIC
www.nickc.com

Eulex Broadband Gap Capacitor



The Eulex Gap Capacitor offers ultra-low loss performance in a surface-mount package for broadband microwave/ mmWave, test equipment and optical applications. The Eulex Gap Capacitor utilizes a novel patented internal electrode design allowing for significant leverage in capacitance for a given dielectric. These gains mean that Quantic™ Eulex can offer devices manufactured from ultra-stable materials with high Q and extremely high self-resonance with capacitance values far exceeding those offered by other manufacturers.

Quantic Electronics
www.quanticnow.com

Wideband Bias Tee

Sigatek introduced a new 2.92 mm connectorized bias tee offering high performance over the ultra-broadband frequency range of 30 khz to 40 GHz. This bias tee offers a flat loss response of 2.2 dB across the frequency band and current rating is 750 mA with 50 Vdc. Isolation is greater than 30 dB typically and return loss is greater than 12 dB. Applications are for emerging designs, test and measurement, 5G, 6G, radar, mmWave and more.

Sigatek LLC
www.sigatek.com

DC to 67 GHz SPDT Coaxial Switches

Teledyne Relays announced the release of its latest innovation, the CCR-67V series. This advanced range of DC to 67 GHz SPDT coaxial switches is specifically designed to meet the rigorous demands of 5G telecommunications, high frequency automated test equipment and mmWave communication systems. The CCR-67V series represents a significant advancement in electromechanical switch technology with both failsafe and latching models available. The CCR-67V series is now available for purchase through Teledyne Relays or an authorized distributor.

Teledyne Relays
www.teledynedefenseelectronics.com

CABLES & CONNECTORS

Multi-Channel SMPM Cable Assemblies (WMCM Series)

Withwave's multi-channel SMPM cable assemblies (WMCM Series) provide a wide range of multiple coax connectors and flexible cable assemblies with a choice of 26.5, 40 and 50 GHz configurations based on precision array design and superior high frequency cabling solutions. These products consist of high performance flexible assemblies which can be bundled in housings (four and eight channels) and the interface to board is compression type which provides lower total cost of testing by avoiding costly soldering components.

withwave
www.with-wave.com

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NewProducts

AMPLIFIERS

Exodus AMP2025A 0.8 to 2.5 GHz, 300 W, 150 W P1

VENDORVIEW

Exodus AMP2025A, ideal for broadband EMI-Lab, communication and EW applications. Class A/AB linear design for all modulations and industry standards. Covers 0.8 to 2.5 GHz, producing 300 W minimum, 150 W P1dB and 55 dB minimum gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability and ruggedness. Integrated in our compact 4U chassis weighing approximately 30 kg.

Exodus Advanced Communications
www.exoduscomm.com

MMIC LNA Boosts 0.4 to 8.0 GHz

VENDORVIEW

Mini-Circuits' model TSY-83LN+is a surface-mount MMIC low noise amplifier (LNA) for a wide range of applications from 0.4 to 8.0 GHz. Typical gain is 22.3 dB at 6.0 GHz and 20.6 dB at 8.0 GHz. The noise figure is typically 1.5 dB at 2.0 GHz and 2.4 dB at 8.0 GHz. The GaAs pHEMT amplifier includes a bypass mode for input signal levels as high as +29 dBm compared to maximum input levels of +22 dBm for amplified signals.

Mini-Circuits
www.minicircuits.com

Ultra-Broadband Low Noise Amplifier

VENDORVIEW

Quantic PMI Model PEC-30-0R5G50G-22-12-24FF is an ultra-broadband low noise amplifier that operates over the 0.5 to 50 GHz, provides a typical gain of 30 dB while maintaining a ±2.5 dB flatness with a noise figure of 9 dB maximum. This model offers a small 1.37 × 1.00 × 0.60 in. package with 2.4 mm female connectors.

Quantic PMI
www.quanticpmi.com

SYSTEMS

Inertial System

VENDORVIEW

The ADIS16545/ADIS16547 are a complete inertial system that includes a triaxis gyroscope and a triaxis accelerometer. The ADIS16545 and ADIS16547 offer a technological leap that elevates the SWAP-C value of MEMS-based gyroscopes into the fiber-optic gyroscope performance space. The newest six DoF fully calibrated IMUs to join ADI's portfolio offer gyroscope performance of 0.07 degrees/hr angular random walk, and all-condition bias repeatability as low as 65 degrees/hr. ADIS16545 and ADIS16547 enable applications such as navigation, platform stabilization, precision instrumentation and more.

Analog Devices
www.analog.com

SOURCES

Single- and Multi-Channel Signal Generator

VENDORVIEW

The APLCXX(-X) is an agile ultra-low phase noise signal generator from 10 MHz to 12.75 GHz (APLC12), 20 GHz (APLC20), 40 GHz (APLC40) or 54 GHz (APLC50). The multi-channel version is available in 1, 2, 3 or 4 channel configurations in a 2HU 19 in. enclosure. The single-channel version is available in a portable/benchtop enclosure with color touch display and front panel control or as a rack-mountable module. For high phase coherence, RF channels are locked to a single reference source.

AnaPico AG
www.anapico.com

PACKAGING

Low Loss SMD Package for up to 95 GHz

VENDORVIEW

Cubic Nuvotronics presents a new state-of-the-art low loss MMIC package, the PSP1028108. This PolyStrata® package complements integrated MMIC performance, with less than 0.5 dB insertion loss up to 95 GHz and 20 dB return loss. The package can be surface-mounted to a PCB using standard SMT processes. This increases the ease of manufacturing while maintaining superior performance in a smaller size compared to other packaging substrates. Available at RFMW.

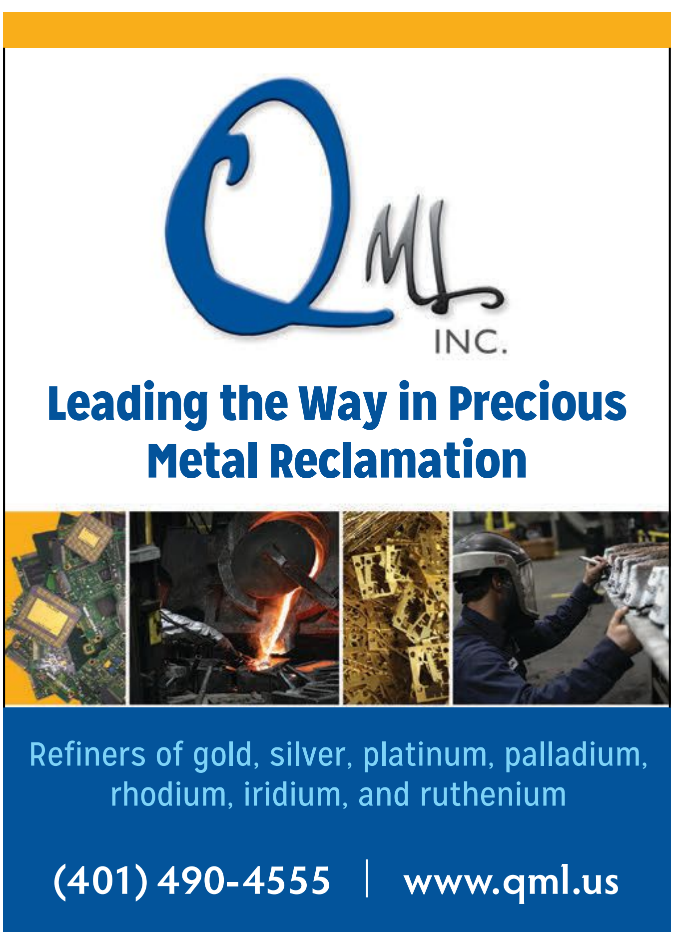
RFMW
www.rfmw.com

ANTENNAS

Ultra-Wideband Antennas

Amphenol RF announced the expansion of their emerging antenna portfolio with a variety of ultra-wideband (UWB) antenna options. UWB antennas can cover frequencies from 3.1 to 10.6 GHz. These antennas offer extremely high accuracy in location tracking, often within centimeters. They operate with low power consumption and provide high data transfer rates while having the ability to penetrate walls and other obstacles. UWB antennas are resistant to interference which makes them ideal for IoT and high speed wireless applications such as smart home, smart agriculture, automotive, healthcare and telematics.

Amphenol RF
www.amphenolrf.com



NewProducts

L-Type Mounts for Standard Gain Horn Antennas

VENDORVIEW

Pasternack, an Infinite Electronics brand, announced its latest breakthrough: L-type mounts for standard gain horn antennas. This groundbreaking mounting solution optimizes testing and measurement setups by combining convenience and precision in a single package. The antenna mounts simplify antenna installations and enhance testing capabilities for professionals across various industries. They offer a versatile and efficient solution for mounting standard gain horn antennas.

Pasternack
www.pasternack.com

Flexible LTE Antenna from Taoglas

VENDORVIEW

Richardson RFPD, Inc., an Arrow Electronics company, announced the availability and full design support capabilities for a new LTE antenna from Taoglas. The FXUB63 is an extremely efficient, wideband, flexible LTE antenna with a small footprint. This easy-to-install, durable, flexible polymer antenna operates on greater than 45 percent efficiency on LTE bands from 698 to 3000 MHz. It is suitable for a wide array of applications that need LTE connectivity, including home automation, emergency services, automotive, healthcare, HD video, vending machines, digital signage, IoT gateways, smart grid and agriculture.

Richardson RFPD
www.richardsonrfpd.com

VALOR™ ESA Product Line

Reticulate Micro Inc., a commercial and defense technology company dedicated to delivering trusted and resilient communications over any transport and in any environment, announced its disruptive flat panel antenna product family. VALOR™, the second product debuting from Reticulate Space, is a flexible line of electronically steerable antennas (ESAs) featuring standard core components purpose fit for users across land mobile, airborne, maritime and mobile/manpack applications. The product family is designed for scalability and multi-orbit connectivity. It comes following Reticulate's debut of its VESPER™ terminal management capability.

Reticulate Micro Inc.
www.reticulate.io

TEST & MEASUREMENT

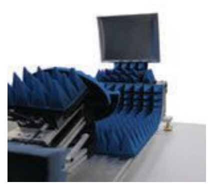
Inline Power Sensor

Anritsu Company introduces its inline power sensor MA24103A designed to measure accurate peak and true-RMS average power measurements from 25 MHz to 1 GHz and 2 mW to 150 W power range. Several applications demand accurate peak and average power measurements well below the frequency range of 1 GHz. Agencies in public safety, avionics (air traffic control and repair stations) and railroads must maintain critical communications between the control centers and the vehicles.

Anritsu Company
www.anritsu.com

Antenna Measurement Services

VENDORVIEW



Introducing Eravant's cost-effective antenna measurement services – from gain and 2D/3D radiation pattern measurements to customized test parameters. Eravant now offers comprehensive antenna measurement services for microwave to mmWave and terahertz frequency antennas. State-of-the-art facilities include far-field anechoic chambers and an Eravant-developed benchtop compact antenna range. Measurement capabilities cover a combined frequency range from 0.7 to 330 GHz.

Eravant
www.eravant.com

Microwave Signal Generator

VENDORVIEW

The new R&S SMB100B analog microwave signal generator from Rohde & Schwarz offers outstanding, market-leading performance for analog signal generation up to 40 GHz in the midrange class. Thanks to its easy operation and comprehensive functionality, the versatile R&S SMB100B is now the first choice for all applications requiring clean analog signals or high output power from 8 kHz to 40 GHz. Typical applications include testing radar receivers, semiconductor components, up-converters, down-converters or amplifiers.

Rohde & Schwarz
www.rohde-schwarz.com

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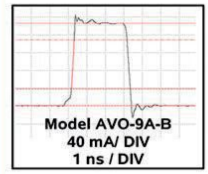
MICRO-ADS

Laser Diode Drivers with Butterfly Sockets



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.

Avtech Electrosystems Ltd.
http://www.avtechpulse.com/

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Review by: Katerina Galitskaya

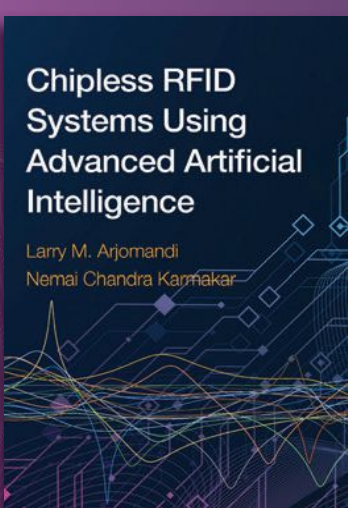
Bookend

Motion and Gesture Sensing with Radar

By Jian Wang and Jaime Lien

As a senior antenna engineer with a keen interest in radar technology, *Motion and Gesture Sensing with Radar* by Jian Wang and Jaime Lien presents a refreshing perspective on a technology that many consider mature. This book steps into the exciting topic of radar integration into consumer devices. It offers a valuable resource for engineers and students, emphasizing clarity and practicality. The authors begin with a fundamental premise: radar, long associated with defense and aerospace, is now making its way into everyday consumer applications. It is an exciting shift that calls for a fresh look at radar theory and design, specifically tailored to the requirements and challenges of consumer technology. One of the book's standout features is its clear and comprehensive coverage. Several chapters are dedicated to radar hardware, waveforms/modulations, signal processing and detection. This approach ensures that the reader not only understands the theory but also gains insight into practical design procedures, analysis tools and real-world examples. This is particularly helpful for engineering students looking to apply radar technology to motion sensing, gesture controls and more. Furthermore, the book acknowledges the growing role of machine learning in enhancing the capabilities of consumer radar, which is a widely discussed topic on its own. In summary, this book offers a comprehensive view of radar systems tailored for consumer applications, emphasizing clarity and practicality for engineering students and professionals. It provides an exciting glimpse into the future of radar sensing. *Motion and Gesture Sensing with Radar* is a valuable resource for anyone interested in the promising intersection of radar technology and consumer devices.

ISBN 13: 9781630818234
Pages: 288
Digital download: $123
To order this book, contact:
Artech House
us.artechhouse.com



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- Includes practical examples of design, and a QA section to answer the possible doubts in simpler phrases.

Chipless RFID Systems using Advanced Artificial Intelligence
Larry M. Arjomandi,
Nemai Chandra Karmakar
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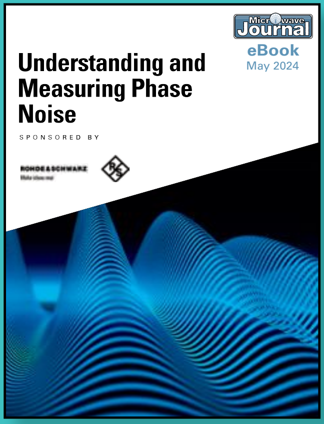

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- High Q

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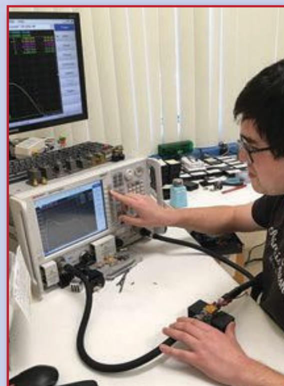
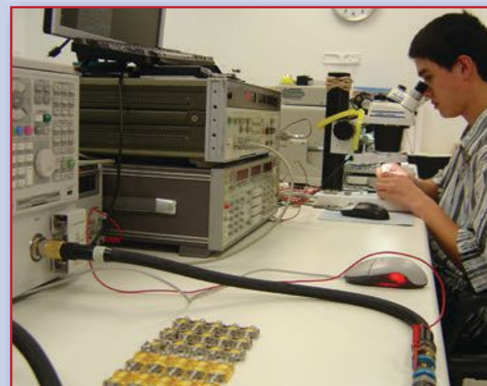
FABS and LABS

B&Z Technologies: Innovating to Excel





B&Z Technologies, Inc., located on Long Island, N. Y., has been designing and manufacturing low noise amplifiers and medium power amplifiers for more than 20 years. The engineers at B&Z Technologies have been pioneers in the design of state-of-the-art microwave and mmWave amplifiers for the past 40 years.

B&Z has earned a reputation in the electronics industry as a leading and reliable supplier of state-of-the-art, high-performance amplifiers. These include low noise, wideband, medium power, high dynamic range microwave and mmWave amplifiers. The performance of B&Z amplifiers is made possible by screening and selecting commercially available transistors for high transconductance and incorporating these transistors into circuit designs with negative feedback, traveling wave concepts and proprietary lowpass/highpass network topologies. Using discrete transistors, miniature-sized lumped elements and airline technology enables B&Z Technologies amplifiers to meet stringent performance, mechanical and environmental requirements.

B&Z Technologies' product offering is extremely broad with the B&Z website currently offering more than 6100 products in 16 different amplifier categories. These amplifiers cover a frequency range from 300 KHz to 50 GHz. Several wideband amplifier products can operate at cryogenic temperatures with extremely low noise figures. These devices can be optimized over a specified bandwidth to achieve lower noise figures.

A major advantage offered by B&Z is that over 80 percent of its amplifiers are available in a single, standard connectorized or drop-in package. This increases the efficiency of the design and manufacturing process. The standard packaging also reduces production costs and this helps reduce delivery lead times. This single-package approach gives the system designer the flexibility to support their evolving system requirements without changing the amplifier footprint in the system. The standard housing has a modular design, offering the flexibility of removing the connector fixture, which allows the amplifier to be used in a surface-mount or drop-in configuration with a small footprint. Many of the B&Z amplifiers are available with waveguide input and with weatherproof housings.

The B&Z advantage is its commitment to offer designs based on specific customer specifications. The company supports this commitment by encouraging direct contact between its customers and the B&Z design engineering team. B&Z Technologies believes that this approach minimizes the time it takes to arrive at a mutually agreed upon cost-effective solution, which minimizes the time required to deliver a product.

B&Z has relied upon these processes and advantages to become a reliable supplier of state-of-the-art amplifiers for applications at defense satcom and research organizations worldwide.

www.bnztech.com

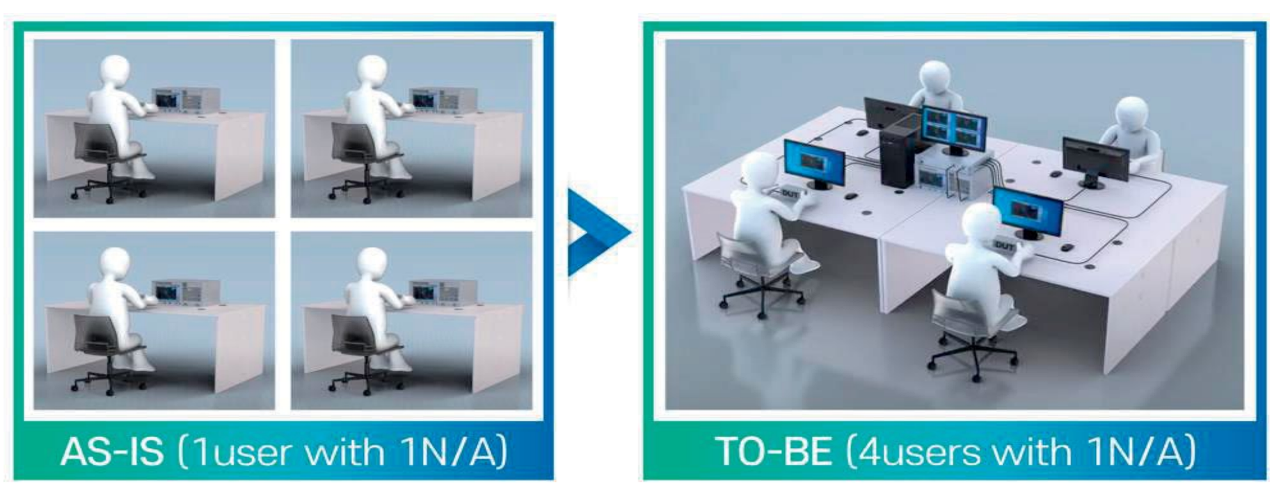
Network Analyzer Smart Sharing

Feature

- 4 users can use with one network analyzer.
- Each user can measure under different test conditions.
  ▷ different frequency, different band-width
- Compact size & Simple GUI.
- Product type : NAS 8.5G / NAS 20G / NAS 40G

Applicable models

- All type network analyzers based on Windows OS.



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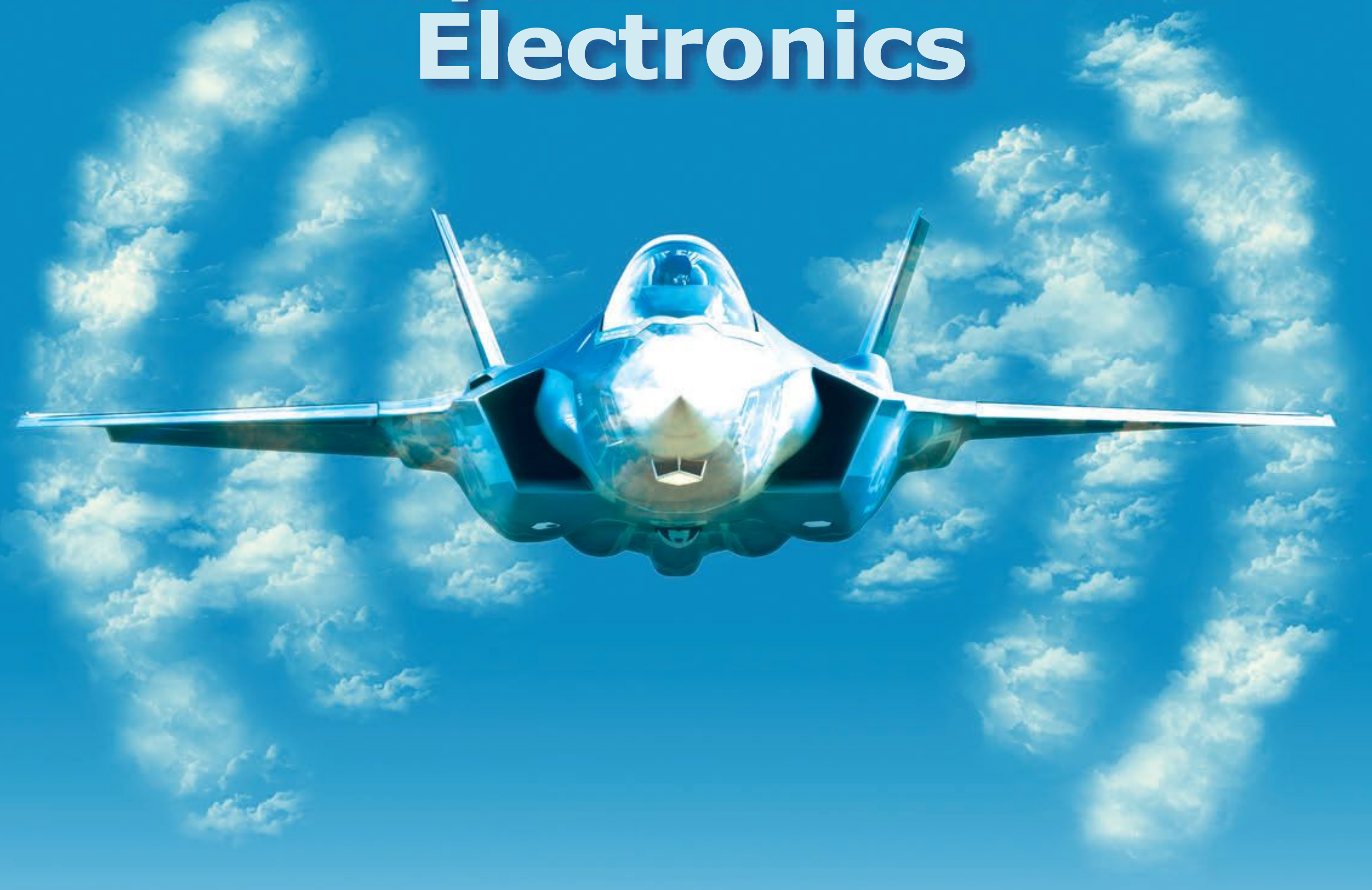

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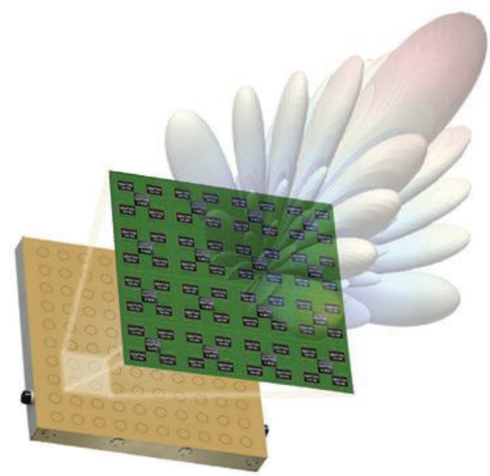

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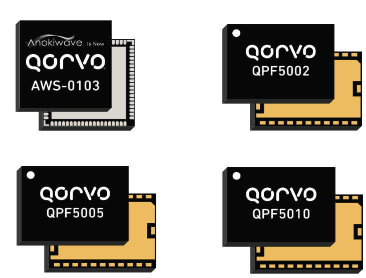

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Improving C-SWaP with Multifunction GRIN Antennas

Nicolas Garcia and Nicholas Estes, *Cheshir Industries, Albuquerque, N.M.*
Philip Lambert, Jeff Von Loesecke and Henrik Ramberg, *Fortify, Boston, Mass.*
Charles Dietlein, *Spectragem LLC, Bethesda, Md.*
Jonathan Chisum, *University of Notre Dame, Notre Dame, Ind.*

Wireless technology is essential for defense, enabling everything from radar and radio communications to drones and navigation. With these requirements growing, more capabilities must be integrated into less hardware and antennas are becoming a bottleneck. Specialization in antenna subsystems results in multifunction wireless systems requiring multiple conventional antenna systems. This is not feasible for platforms with stringent cost, size, weight and power (C-SWaP) constraints. This article proposes gradient index (GRIN) lenses as an antenna solution that integrates multiple features into a single aperture, dramatically reducing C-SWaP.

The sheer variety of defense wireless applications and the breadth of operating frequencies have spurred the adoption of dedicated antenna systems. Large naval vessels are studded with reflectors and arrays with each system performing unique sensing duties. Other craft are likewise dotted with myriad dipoles, slots and reflectors that serve different purposes in different bands. This approach has to evolve as the nature of battlefield electromagnetic superiority is rapidly changing. The core of wireless spectrum dominance is moving from aircraft, ships and bases to the frontline. At the tactical edge, small platforms reign. Ground vehicles, small UAVs and personnel are increasingly involved in wireless operations. One-way drones and active decoys, which protect higher value assets, are increasingly common. These small platforms have stringent C-SWaP constraints so they cannot carry heavy, conspicuous antenna systems. Their deployment scale makes it economically infeasible to encumber these units with active electronically scanned arrays (AESAs).

Developing low C-SWaP multifunction apertures is complicated because the antenna must support three advanced radio features: low probability of detection (LPD), spatial selectivity and multi-band operation.

LPD refers to specific waveforms and modulation schemes that obfuscate the actual signal. While these signal-level features are essential, an additional layer of LPD can be achieved with high directivity antennas since a narrow beamwidth lowers the risk of unintended detection. High directivity also improves jamming resilience because signals outside the beam are attenuated.

High antenna directivity enables spatial selectivity and increases range. From a sensing perspective, these features provide more detailed spectrum reconnaissance, along with enhanced survivability in the presence of hostile radar. Given the highly mobile nature of small platforms, the antenna system must electronically control beam direction over some field of view (FoV). This can be achieved with an AESA.

Classical AESAs are generally neither cost-effective nor power-efficient, particularly when operating over an extremely wide bandwidth. For wideband operation, an AESA generally requires extremely wideband beamforming chipsets and antenna elements, components that are expensive and difficult to procure. Complex AESAs are typically developed in-house for specific applications and wideband variants and this is not an ideal cost basis for widescale adoption on small platforms.

GRIN lens technology is well-suited to these requirements. GRIN lens antennas have shown directivity greater than 30 dBi,[1] which aids in LPD. They also achieve high FoV beam scanning without beam squint for spatial selectivity.[2] Most GRIN devices are true time delay, enabling extremely wide instantaneous operating bandwidths for multifunction apertures.[3] Having these features available in a single aperture makes GRIN extremely attractive for small platforms. GRIN system versatility appeals to applications like fixed wireless access, 5G/6G and satcom. With appropriate materials, GRIN systems are also suitable for high temperature applications like high-power microwaves (HPMs) counter-UAS and even hypersonic radomes.

WHAT IS GRIN?

Microwave lenses are conceptually identical to "conventional" optical lenses. ***Figure 1a*** illustrates a lens constructed from a homogeneous dielectric of constant index of refraction (n). The lens, assumed electrically large, collimates rays produced by a low directivity feed antenna, forming a high directivity beam. Rays incident on the

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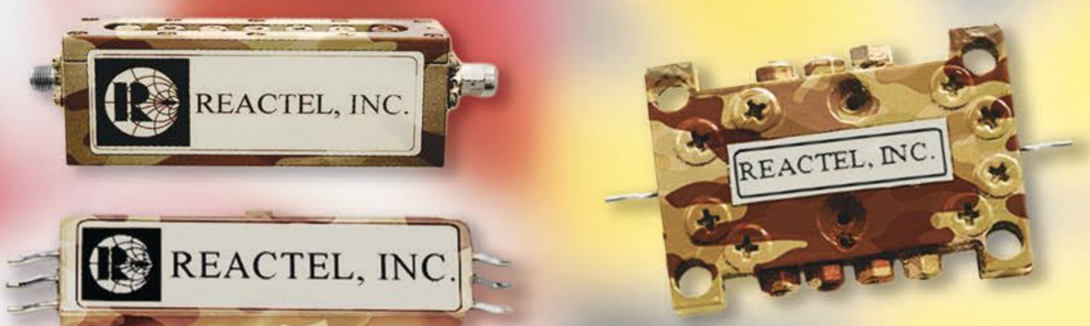

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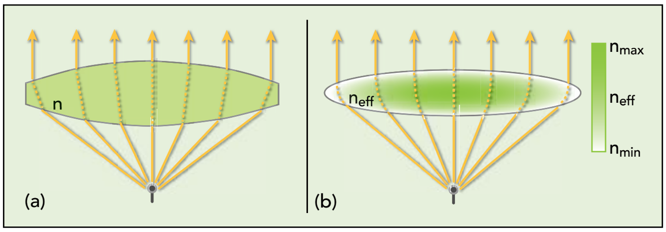

Fig. 1 (a) Homogeneous lens antenna. (b) GRIN lens.

lens surface are bent upon entering and exiting the lens according to Snell's law. Within the lens, rays travel in straight lines. The shape of the lens surface dictates its behavior and the geometry of a homogeneous dielectric lens is constrained by its application.

A more general approach proposed in 1853 and widely attributed to Maxwell, allows the lens material and its index of refraction to vary spatially.[4] ***Figure 1b*** illustrates this GRIN concept. In a GRIN lens, rays refract throughout the lens, not just at its surface.

This creates important advantages. The shape of a GRIN lens is not constrained by its application. Flat or conformal GRIN designs are possible, as shown in ***Figure 2a***. A GRIN lens can correct aberrations at the focal plane, enabling wide FoV beam scan as shown in ***Figure 2b***.[2] GRIN lenses can be more compact and lightweight as shown in ***Figure 2c***.[5] Finally, unlike homogeneous lenses, which have an impedance discontinuity at the surfaces, GRIN lenses provide a smooth transition from air to lens dielectrics, maintaining high transmission efficiency over a wide operating bandwidth.

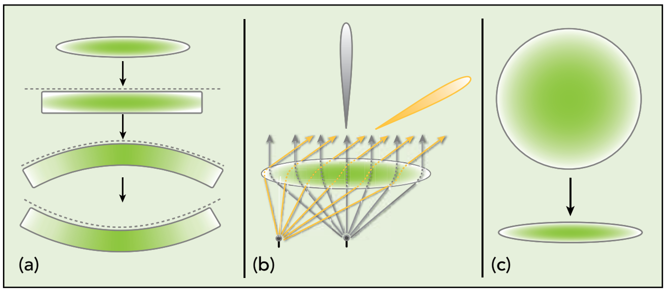

Fig. 2 (a) Arbitrary geometry GRIN lenses. (b) Wide-angle beam-scanning GRIN lens. (c) Thin, lightweight GRIN lenses.

The canonical Luneburg lens, shown in ***Figure 3a*** and derived from geometric optics, is the most common GRIN lens. It is spherically symmetrical with an index of refraction varying radially between n=1 at its surface and $n=\sqrt{2}$ at its center.[6] A Luneburg lens has the attractive property that rays emanating from a source on the lens surface are perfectly collimated on the other side. In essence, the Luneburg lens produces a high gain beam for a low directivity feed placed anywhere on its surface. This allows for a theoretically perfect beam scan across an approximately hemispherical aperture by mounting a feed array on its surface. However, Luneburg lenses are bulky and heavy, causing integration issues. The radiating aperture is hemispherical, making it unsuitable for constrained form factor applications, especially where a flush fit to a flat or conformal surface is necessary. The feed array must also follow the lens' spherical surface, so conventional planar arrays cannot be used.

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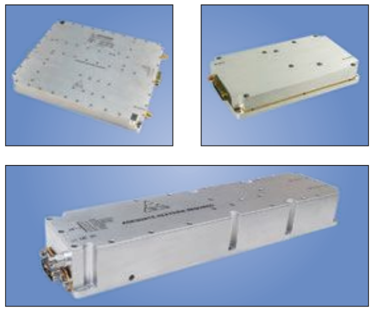

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Alternatively, a flat lens, shown in ***Figure 3b***, can be designed for flat or conformal radiating apertures and focal surfaces. This enhanced design freedom allows for small form factors and integration with planar arrays. However, this freedom comes with two primary challenges that hinder the widespread adoption of flat GRIN components: economically producing high-quality GRIN materials and designing high performance flat GRIN lenses. These are considered in the next section.

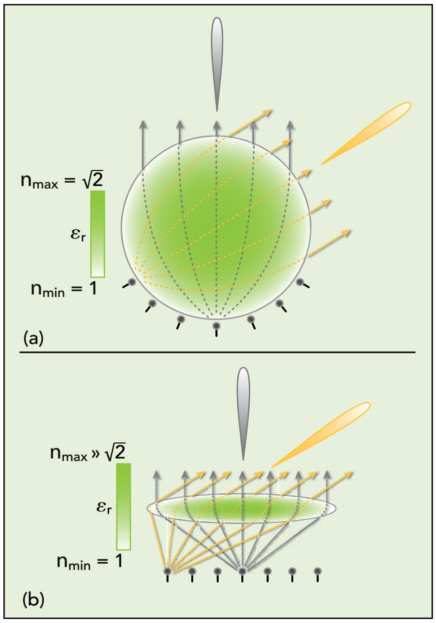


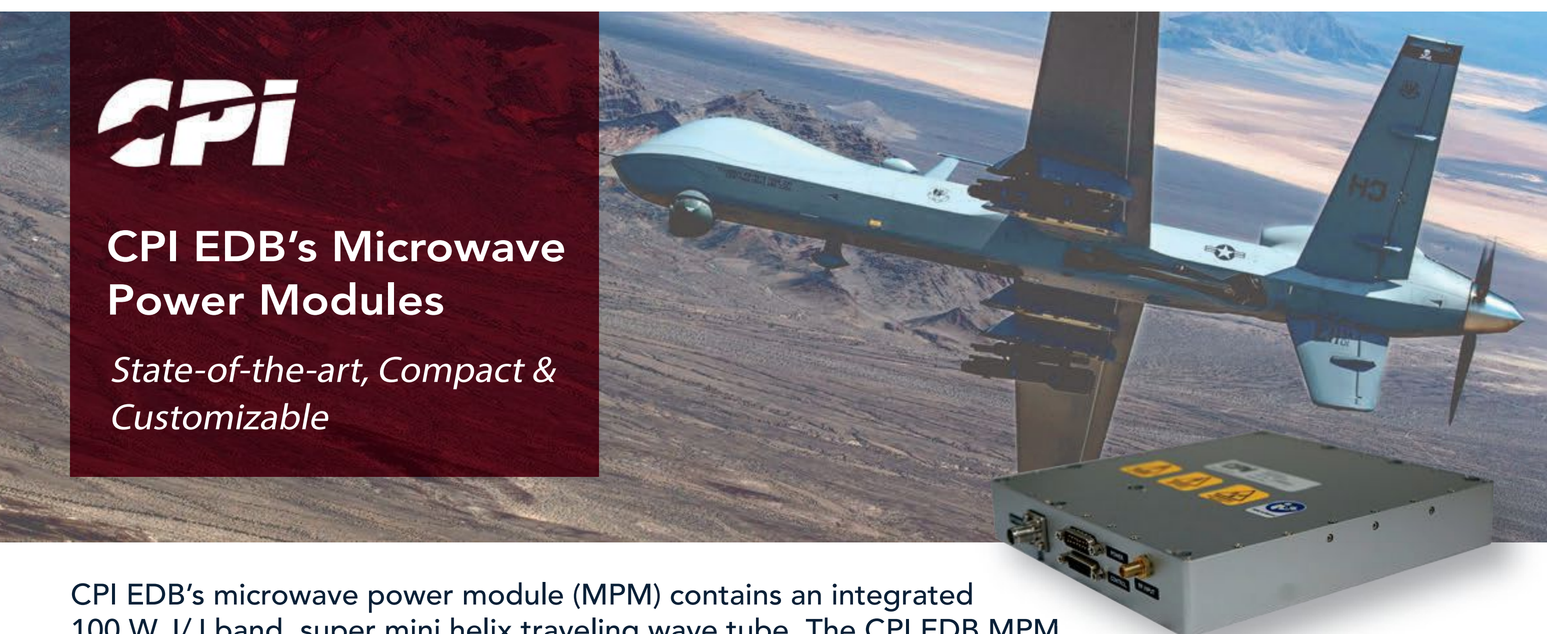
Fig. 3 **(a) Luneburg lens. (b) Flat GRIN lens.**

ADVANCEMENTS IN GRIN

Understanding why fabrication has been a barrier to flat GRIN lens adoption requires understanding GRIN material manufacturing. Though multiple methods of constructing GRIN exist, the most common approach embeds air structures in a low loss "host material" dielectric. This alters its effective dielectric constant (Dk) and corresponding refractive index.[1,2,5] The effective Dk is controlled approximately by the volumetric ratio of air to host material. Dk is lower in regions with more air than host material and vice versa. Achieving the necessary volumetric ratios to produce aggressive Dk gradients is not mechanically straightforward because the air structures must be subwavelength. Tooling and tool path capabilities limit machining technologies, making GRIN manufacturing an extensive and expensive process. Standard PCB foundry operations work but these are serial processes with high material costs. Historically, GRIN manufacturing, particularly for high gradient flat lenses, has been prohibitively expensive and time-consuming. However, recent advances in additive manufacturing provide geometric freedom for scalable manufacturing of complicated structures producing GRIN media.

Fortify has developed technology enabling low-cost, high performance GRIN structures. ***Figure 4a*** shows a Fortify gyroid unit cell. This cell enables optimized GRIN devices with smooth dielectric gradients.

Fortify's digital light processing combines parallel manufacturing with high throughput material processing technology to unlock scale production of GRIN media. While competing manufacturing methods like deposition printing, molding or machining are limited to single-unit production, Fortify's digital manufacturing process duplicates parts at the same manufacturing speed as a single unit. ***Figure 4b*** shows 28 RF lenses produced in a single run. Thanks



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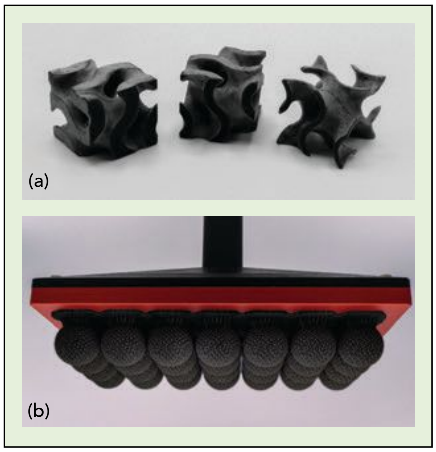

Fig. 4 (a) Gyroid unit cell. (b) RF lenses from Fortify Flux Core 3D printer.

to the flexibility of this process, GRIN media can be produced and optimized without the extra time and setup costs associated with creating tooling and fixtures. These advantages are crucial for integrating GRIN materials into conventional wireless applications and accelerating adoption.

The second challenge for widespread GRIN adoption is the development of sophisticated design techniques for high performance flat lenses. The design freedom associated with flat lenses is immense and no single design heuristic simultaneously guarantees all the multifunction antenna requirements. Only recently have flat lens design techniques advanced to make this possible. Designs proceed iteratively, drawing inspiration from both canonical optics principles and classical microwave circuit techniques.[1,2,5]

Cheshir Industries' flat lens design paradigms employ multiple design heuristics simultaneously to achieve wideband, wide FoV, beam scanning flat lenses. GRIN lenses exploit extremely high index gradients to minimize system depth and weight without reducing performance. These designs rely on greater material availability and scalable additive manufacturing to provide superior performance in low C-SWaP applications. Recent improvements in manufacturing and design are making flat GRIN antenna systems economical.

COMPARISONS

Figure 5a shows a conventional AESA antenna. ***Figure 5b*** shows a switched-beam GRIN lens system that routs Rx/Tx signals with a single feed and a switch matrix. Switched-beam GRIN lenses are the simplest beam steering architecture and demonstrate three key advantages over conventional AESA systems: they are extremely power-efficient, particularly on receive;

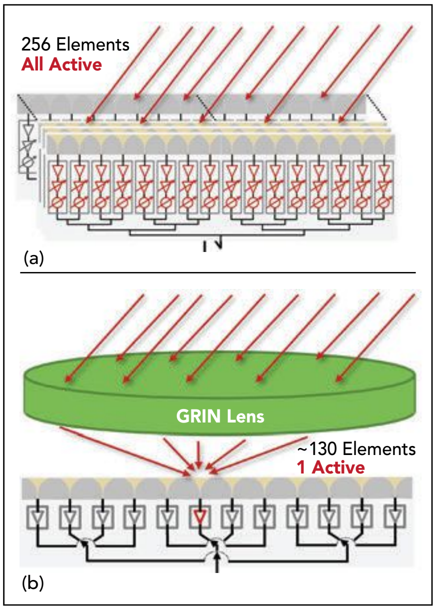

Fig. 5 (a) AESA antenna. (b) GRIN lens antenna.

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beamforming is intrinsically wideband and switched-beam GRIN systems require few electronic components, making them cost-effective.

In a switched-beam system, one element generates or receives a beam. A conventional AESA requires every element to be active. A switched-beam GRIN system receiver requires <1/N the total power consumption of a comparable AESA with N elements as shown in ***Table 1***, resulting in tremendous power savings.[7]

The Tx case is complicated by the EIRP requirements. With a single element transmitting per beam, the switched-beam power amplifier (PA) requires higher saturated power. As a result, a switched-beam system may need GaN or GaAs Tx PAs, whereas the AESA might use a silicon PA. However, this may also be an advantage. The Tx PA dominates the total power of the switched-beam GRIN system and GaN/GaAs PAs can achieve better power-added efficiency values than silicon beamformers.

Multiband/wideband systems increase these power savings since a single GRIN aperture may replace multiple AESAs. GRIN lenses have demonstrated instantaneous bandwidths of 5:1 and bandwidths greater than 10:1 are possible.[1,2,5] Conversely, AESAs typically do not exceed 1.2:1 bandwidth, meaning a wideband system may require multiple AESAs.[8]

Cost is an important differentiator. Switched-beam GRIN systems produce a comparable FoV with half the elements of AESAs. Switched-beam systems do not exhibit grating lobes and they are not constrained to λ/2 element spacing. Because a single feed element has a 1:1 correspondence with a beam, the system requires only as many feeds as beams necessary to cover a specified footprint. Switched-

TABLE 1

POWER CONSUMPTION COMPARISON

	AESA			GRIN Lens Antenna		
Directivity (dBi)	Number of elements	Rx DC Power* (W)	Tx DC Power* (W)	Number of elements**	Rx DC Power (W)	Tx DC Power*** (W)
11	4	**0.6**	**0.8**	**< 4**	**< 0.2**	**< 0.4**
14	8	**1.2**	**1.6**	**< 6**	**< 0.2**	**< 0.7**
17	16	**2.4**	**3.2**	**< 8**	**< 0.2**	**< 1.4**
23	64	**9.6**	**12.8**	**< 32**	**< 0.3**	**< 5.7**
29	256	**38.4**	**51.2**	**< 128**	**< 0.3**	**< 22.7**
35	1024	**153.6**	**204.8**	**< 512**	**< 0.5**	**< 90.4**

* Assumes DC power consumption of 150 mW and 200 mW for Rx and Tx BFICs, respectively. Assumes Tx PAE is 15 percent (Si BFIC).[9]

** GRIN lens element-spacing is typically 0.7λ - 0.75λ, requiring less than half the total elements. Total elements can be reduced with a reduced beam-scanning range (assumes ±60 degree Az-/El- scanning).

*** GRIN lens Tx DC power consumption maintains AESA EIRP and assumes 35 percent PAE (corresponding to GaN PA).[10]


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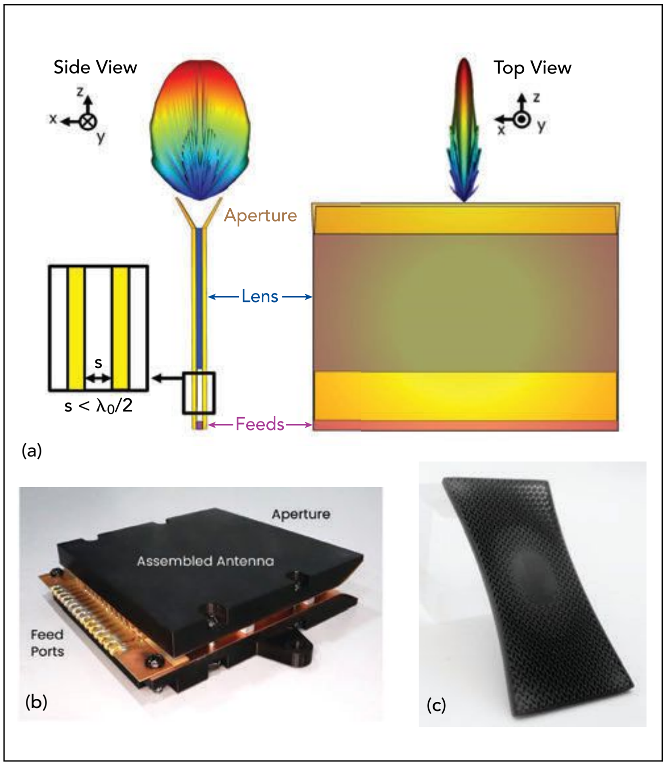

▲ Fig. 6 **(a) PPWG antenna fan-beam. (b) PPWG GRIN lens demonstrator. (c) PPWG GRIN lens.**

beam systems do not require VGAs or phase shifters, reducing component count by more than 75 percent.

SWITCHED-BEAM DEMONSTRATOR

Figure 6a shows a 20 to 40 GHz switched-beam flat GRIN lens conceptual prototype system with a 2:1 instantaneous bandwidth. This device comprises a GRIN lens and feed antennas mounted inside two conductive plates that form a parallel plate waveguide (PPWG). Waves collimated by the lens radiate from the flared aperture in a distinctive "fan-beam" pattern.[2] Each feed antenna corresponds to a different azimuth beam.

The fully assembled prototype shown in ***Figure 6b*** weighs 180 g. The lens is low loss Rogers Radix™ Printable Dielectric material printed with Fortify's DLP process. ***Figure 6c*** shows a sample.

Figure 7a, ***Figure 7b*** and ***Figure 7c*** show radiation patterns for a 13-beam prototype demonstrating a ±52 degrees FoV. The beams exhibit < 3 dB crossover for 20 to 35 GHz and < 4 dB crossover for 35 to 40 GHz. At 40 GHz, scan loss is below 2 dB for the farthest beam, corresponding roughly to a scan loss envelope of $\cos^{0.6}(\theta)$. An "ideal" scan loss envelope of $\cos^{1.0}(\theta)$ is shown for comparison.

DEMONSTRATORS AND PRODUCTS

GRIN lenses can operate from C- to V-Bands. These lenses range from traditional spherical Luneburg to optimized cylindrical, radially symmetric geometries that increase existing antenna system gain. ***Figure 8*** shows a cylindrical lens mounted to a Ka-Band horn antenna. The lens increases gain by 6 dB.

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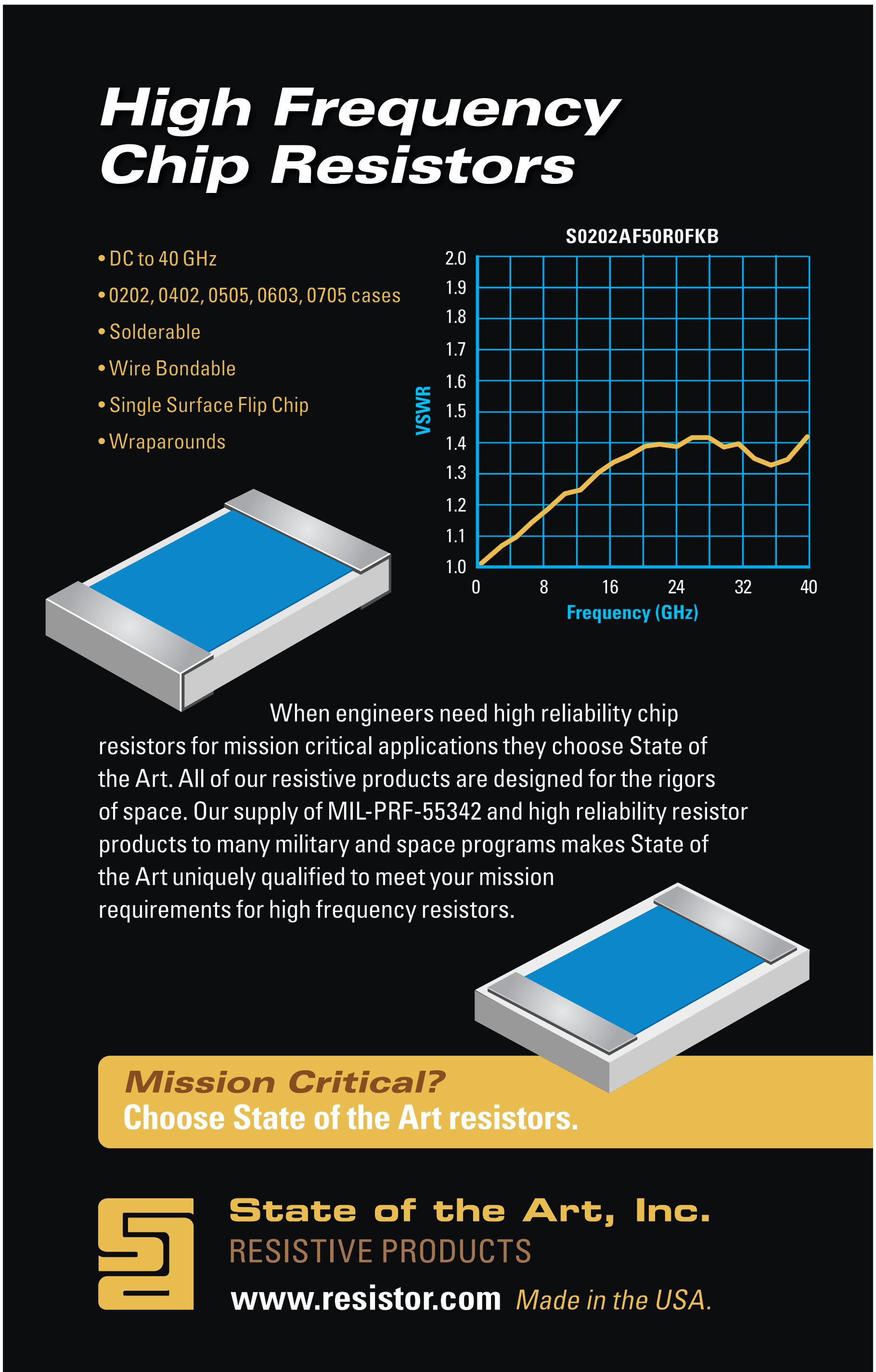
and flexibility, along with a broader FoV and lower scan loss, Fortify and Rogers designed and fabricated a lens capable of increasing phased array FoV from ±60 to ±90 degrees. Reducing antennas is attractive in FWA and satcom-on-the-move applications. Defense organizations are exploring FoV-enhancing lenses for AESAs used in radar, electronic warfare and wireless tactical communications.

GRIN lensing is a convenient and powerful way to simultaneously increase antenna performance and reduce mass. Lenses have been produced with competitive performance and approximately 50 percent weight savings. The increased antenna power-to-weight ratio offers advantages in radar cross-section augmentation on UAVs or live-fire target vehicle applications where C-SWaP requirements are stringent. ***Figure 9*** shows a Luneburg lens-enhanced retroreflector mounted to a quadcopter drone.



ADDITIONAL APPLICATIONS

A host of applications can use GRIN capabilities. HPM devices use high-power RF pulses and narrow beams to

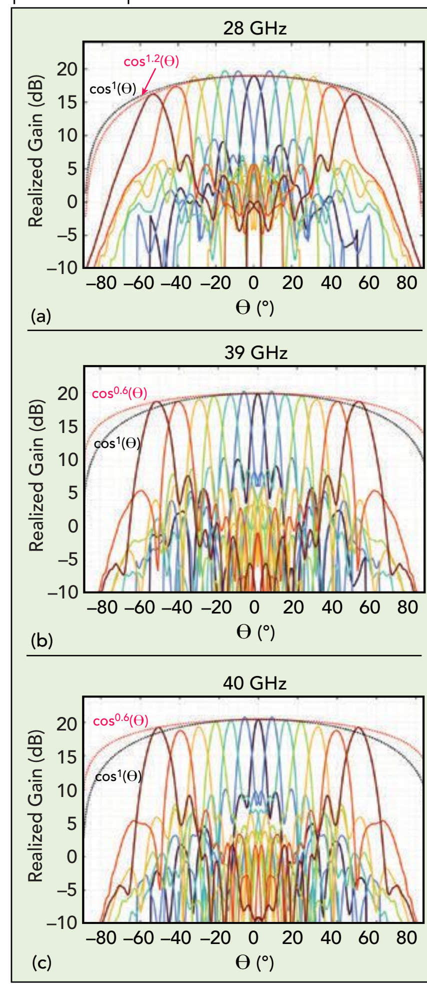


Fig. 7 (a) 28 GHz (5G-NR N261). (b) 39 GHz (5G-NR N260). (c) 40 GHz (maximum frequency).

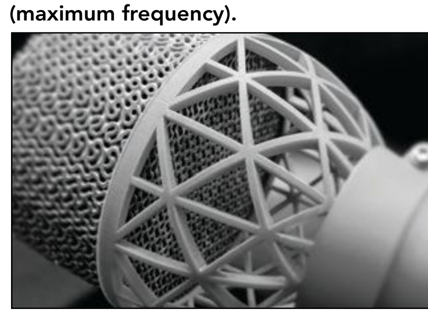


Fig. 8 Cylindrical GRIN lens.

Fig. 9 Drone-mounted retroreflector.

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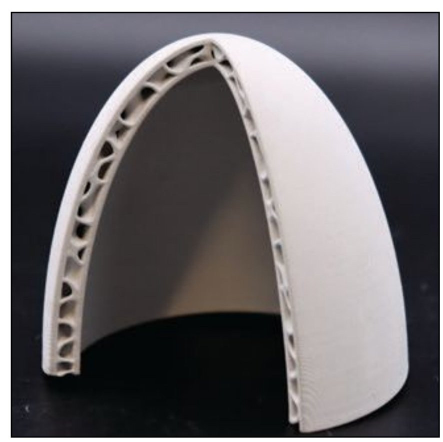
disable sensitive electronics, often on UAVs. A GRIN lens HPM solution can be substantially more compact than a reflector and the architecture is more amenable to integration with a feed array for beam scanning. Low loss, high power handling 3D-printable ceramics like alumina are also attractive options for this application.[11]

Ceramic GRIN is suitable for heat-resistant radomes on hypersonic vehicles. Hypersonic vehicles experience very high surface temperatures, making ceramic and ceramic composites compelling materials for vehicle surfaces.[12] GRIN radomes can be designed to tune the radiation patterns or enhance the bandwidth of antennas while satisfying thermal requirements. Fortify has designed and manufactured nose cone devices with unique composite sandwich architectures that enable efficient broadband transmittance for high temperature radomes. ***Figure 10*** shows an example.

GRIN lens antennas are a power-efficient alternative to beamforming arrays in 5G FR2 and upcoming 6G FR3 (7 to 20 GHz) bands. The wide instantaneous bandwidth of GRIN apertures could also provide RAN-sharing benefits by addressing multiple frequency bands, simultaneously.[13] This configuration could reduce the hardware and cost of high capacity 5G/6G deployments.[2] Similarly, GRIN lens antennas could provide a solution for wideband PtP/PtMP FWA. A switched-beam GRIN system forms multiple beams without reducing EIRP, allowing a single access point to address multiple nodes without performance degradation.

GRIN lens antennas offer advantages for satcom systems. For ground applications, a single GRIN system can cover Ku- and Ka-Band. A switched-beam system with multi-beam operation enables make-before-break operation. For the satellite, these features enable high capacity communications to the gateway terminals and users. ***Figure 11*** shows a 13 in. diameter switched-beam satcom lens antenna designed and manufactured by Fortify.

AESA applications provide another opportunity for GRIN lenses. A lens placed over an AESA provides FoV, bandwidth and pattern enhancements and serves as a radome. The system may be designed so the lens is fed



▲ Fig. 10 **Ceramic radome.**

▲ Fig. 11 **13" diameter Ku-Band GRIN lens.**

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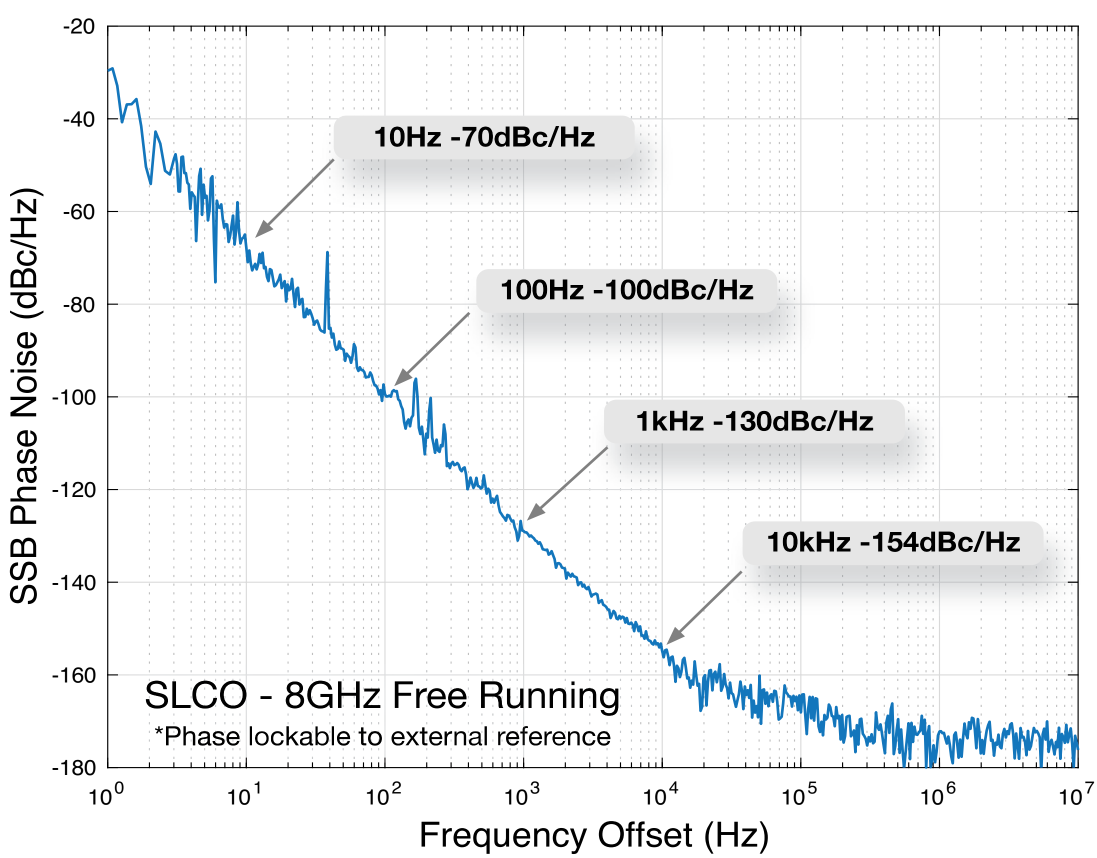

only by a subset of the AESA feeds.[7] This phased array-fed lens (PAFL) architecture lies somewhere between a phased array and a switched-beam system. Because multiple elements are excited, the per-element power requirements for a PAFL are reduced from a switched-beam system for a given EIRP. However, a beam only uses some AESA elements, making the PAFL approach more power-efficient than the phased array. The PAFL technique exhibits the benefits of both beamforming approaches while mitigating their respective drawbacks.

CONCLUSION

This article presented an overview of the untapped utility of GRIN lenses with a focus on switched-beam antenna systems. Using quasi-optical approaches and sophisticated design techniques, these antennas are capable of wide-angle, high directivity beam scanning over a wide instantaneous bandwidth. These features make the GRIN lens antenna ideal for multifunction operations onboard small platforms. A prototype antenna system having more than ±52 degrees beam scanning capability over a 2:1 bandwidth and less than 2 dB of scan loss was discussed. GRIN technology is scalable and economical and it can provide myriad performance enhancements in additional applications. While GRIN technology is still nascent, it represents a dramatic shift from conventional antenna paradigms that will usher in a new generation of multifunctional antenna systems. ■

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RF Signal Chain and Components for Space-Based Satcom Applications

Baljit Chandhoke
Microchip Technology, Chandler, Ariz.

This article addresses the requirements of satellite communications (satcom) and space applications. It describes RF transmitters and receivers, along with their block diagrams, which form the basis for many RF systems. It discusses RF components and the attributes of these components in the RF signal chain. Finally, the article explores some of the details of space-based satellite networks and how these requirements influence the trade-offs in the RF components selection process.

THE RF TRANSMITTER AND RECEIVER

A communications network is a sophisticated system that performs many digital and analog functions. Even though most communications networks are now classified as "digital," signal transmission from the point of origin to the intended target uses analog RF signals. The RF portion of this network contains transmitter and receiver circuitry. In the transmitter, a digital signal carrying the information to be transmitted is converted to an analog signal using a digital-to-analog converter (DAC). This intermediate frequency (IF) signal is conditioned with amplification and filtering before it is converted to a higher RF frequency for transmission. The upconversion process involves a mixer and a local oscillator (LO) signal from some type of source. A mixer is a non-linear three-port device that produces output signals that are harmonically related to the input signals, along with the sum and difference of these inputs. Proper selection of the input IF and LO signals will produce the desired RF output signal frequency. Once the desired RF frequency range is attained, the signal may undergo several stages of filtering and amplification to remove unwanted products from the mixing process and increase the RF signal power to the appropriate level for transmission from the antenna. This architecture is known as superheterodyne and some of the key RF components in the transmit RF signal chain are the power amplifier (PA), distributed amplifier, filters, voltage-controlled oscillator (VCO) or voltage-controlled SAW oscillator (VCSO), phase-frequency detectors and pre-scalers. An example of this transmitter architecture is shown in ***Figure 1***.

The superheterodyne receiver has a similar architecture, but it serves a much different purpose. At the receiver antenna, the signal level is likely to be very low. The first order of business is to retrieve the incoming information. This typically involves filtering to remove any unwanted fre-

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quency components and then amplify the remaining frequency components to useful signal levels. The first amplification stage is known as a low noise amplifier (LNA) and as the name implies, the purpose of this amplification stage is to add as little additional noise to the input signal as possible. From here, the amplified signal reaches the mixer in the superheterodyne receiver. In this case, the mixer products are chosen to down-convert the input signal to a lower IF frequency for processing. The down-converted signal is filtered to remove unwanted mixing products and then amplified to the appropriate level for processing. An analog-to-digital converter (ADC) converts the analog signal to a digital signal to be processed by a field programmable gate array (FPGA) or a digital signal processor (DSP) in the digital section of the communications network. An example of this receiver architecture is shown in ***Figure 2***.

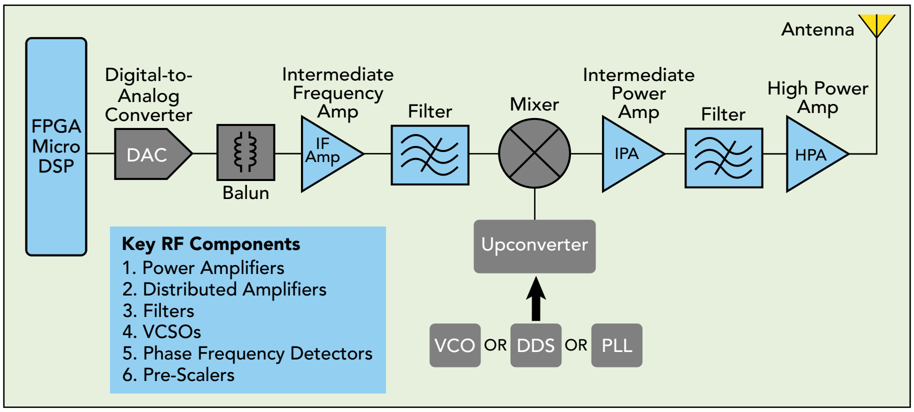

Fig. 1 **RF superheterodyne transmitter.**

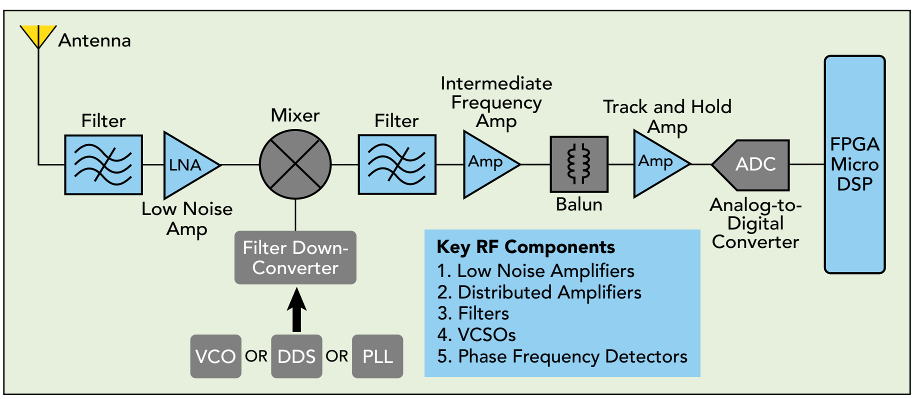

Fig. 2 **RF superheterodyne receiver.**

RF COMPONENTS CONSIDERATIONS

Designing an RF transmitter and receiver chain involves evaluating component trade-offs to find the solution that best satisfies the system requirements. ***Table 1*** shows some of the most important elements of the transmitter and receiver. The PA in the transmitter amplifies the input signal to the appropriate RF output power level for transmission. This signal must also meet linearity requirements, which have gotten more stringent as data traffic increases. The linearity performance is characterized by output third order intercept point (OIP3) and 1 dB compression point (P1dB). Higher OIP3 and P1dB values imply higher PA linearity, which increases spectral efficiency and the ability to keep pace with increasing data traffic requirements. PAs dominate the overall power consumption of the RF signal chain. In addition to creating heat dissipation challenges for designers, this power dissipation translates into operating expenses for providers and general environmental concerns. Power-added efficiency (PAE) is the metric for how efficient a PA is at generating the required output power and amplifier designers are working hard to incorporate new amplifier designs and device technologies to increase PAE.

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AMP2111A	6.0-18.0 GHz	60	48
AMP2033-LC	6.0-18.0 GHz	100	50
AMP2065A-LC	6.0-18.0 GHz	200	53
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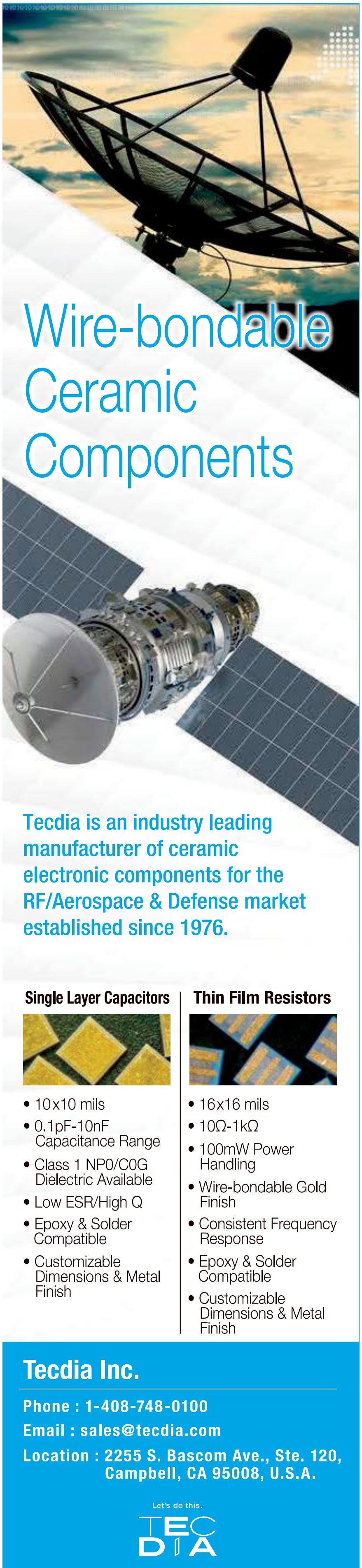

TABLE 1

RF COMPONENT CONSIDERATIONS

Product	Important Parameters	Benefits
LNA	Noise figure (dB)	Improved detection range and signal sensitivity
PA	OIP3 (dBm), P1dB (dBm), PAE (%), gain (dB)	Linear efficient power – low distortion
Mixer	Conversion loss (dB), frequency range (GHz)	Frequency conversion with as little added loss and distortion
Filters	Loss (dB), rejection (dB/dBc), passband (GHz), return loss (dB)	Reduce unwanted signals, improve distortion

In the receiver, the noise figure of the LNA determines the sensitivity of the receiver. Lower noise figures imply better signal sensitivity and improved detection range. In both the transmit and receive chains, the mixer function converts the RF signal. The conversion loss during this process is an important consideration because more loss in the mixer requires more gain in the amplifier chain to reach the desired RF output power and this may increase cost and power consumption. This is a non-linear device, so minimizing the out-of-band mixing products reduces the requirements on the filters and improves system linearity. The transmit and receive chains both rely heavily on filters of several types and configurations to remove the unwanted signals that all the active elements will generate. Some attributes of important components are shown in Table 1.

For all applications, component reliability is of paramount importance. Reliability is viewed as a "must-have" for the commercial supply chain. The defense supply chain institutes specifications like MIL-HDBK-217 and MIL-STF-883 and space applications may fall under specifications like NASA EEE-INST-002 that address mission length and mission criticality.

Packaging is also a consideration for components. For cost considerations, most low-power components are packaged in plastic. As power dissipation or performance requirements increase, packaging shifts toward ceramics, metal inserts and finally to metal. Space-based applications also must address radiation requirements as designers consider component and packaging design.

SATCOM

Space has become a dynamic market opportunity. Geosynchronous orbit (GEO) satellites orbit 35,800 km away from the Earth with the advantage that these satellites appear stationary to an observer on the ground. High throughput satellites (HTS) in this orbit use phased array techniques with superheterodyne transceivers to provide high-capacity spot beam coverage to users on the ground, along with providing connectivity to airborne and maritime applications.

In what is being referred to as "New Space," satellites in low earth orbit (LEO) are positioned less than 2000 km above the Earth's surface. The satellites move with respect to an observer on the ground, so beam tracking and handover on the ground and in space have become important, but satellite constellations launched into LEO orbit are seeing fast growth. These satellites are smaller and less sophisticated than GEO satellites, but as an example of this dramatic growth, Starlink is reported to have 4800 operational satellites in LEO orbit with regulatory approval for a total of 12,000 satellites. These LEO satellites provide connectivity to underserved areas.

The space segment with GEO and LEO, along with a variety of other orbits, has become an essential piece of the global connectivity and national sovereignty puzzle. Data gateways on the ground connect commercial and defense users to the satellite constellation. An emerging segment in the satellite market is "direct-to-device" applications that allow user terminals and handsets to connect directly to a satellite. While these are still low data rate connections, this is a new opportunity. All of these applications and opportunities rely on RF chains similar to those shown in Figure 1 and Figure 2. A conceptual representation of the satellite network is shown in ***Figure 3***.

SATCOM FREQUENCY BANDS

Satcom frequency bands are shown in ***Table 2***. Earth stations transmit the uplink signals to a satellite at a higher operating frequency, while satellites

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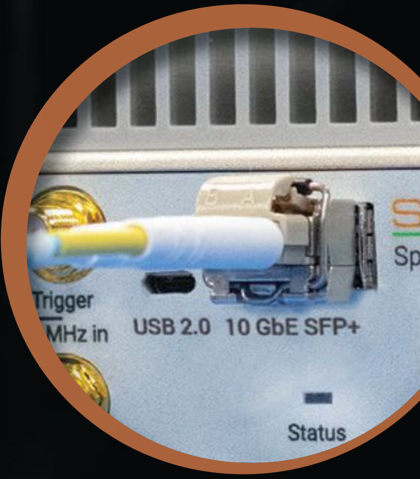

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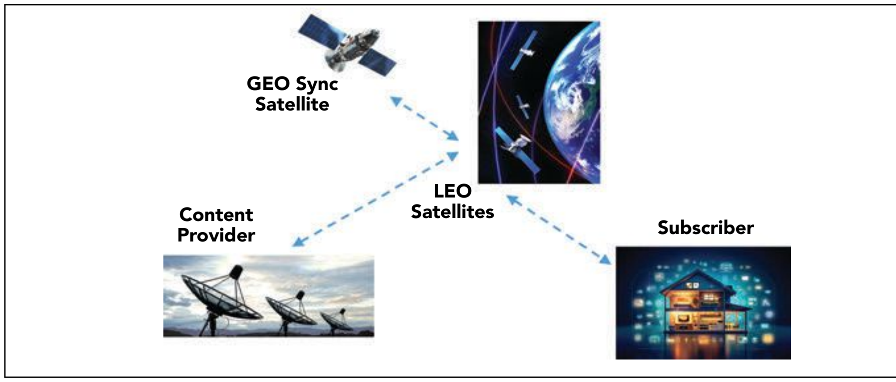

Fig. 3 Satellite communication network.

transmit at a lower operating frequency to be cost-effective. As we go to higher frequency bands, such as Ku- and Ka-Bands, there is more bandwidth available resulting in higher data rates. There are challenges with these 12 to 40 GHz frequencies; there is attenuation due to rain and the signal propagation characteristics of mmWave transmission. In addition, higher frequencies mean the equipment needed to transmit and receive the signals becomes more expensive equipment.

SATELLITE ORBITS

In addition to LEO and GEO orbits, medium earth orbit (MEO) is another popular orbit for satellite constellations. This orbit, ranging from 2000 to 35,800 km, fills the gap between LEO and GEO. All these orbital planes offer advantages and disadvantages.

Satellites in GEO have high latency because of the distance from the Earth, but each satellite can cover a very large footprint. Three GEO satellites have sufficiently large footprints to cover es-

TABLE 2
SATCOM FREQUENCY BANDS

Band	Downlink Frequency (GHz)	Uplink Frequency (GHz)	Typical Bandwidth (MHz)	Comments
L-	0.9 to 1.6	0.9 to 1.6	15	Terrestrial – shared
S-	1.61 to 1.63	2.48 to 2.5	70	ISM-Band – shared
C-	3.7 to 4.2	5.925 to 6.425	500	Terrestrial – shared
X-	7.25 to 7.75	7.9 to 8.4	500	Mil/Government
Ku-	11.7 to 12.2	14.0 to 14.5	500	Rain attenuation
Ka-	17.7 to 21.2	27.5 to 31.0	3500	Rain attenuation, expensive equipment
	20.2 to 21.2	30.0 to 31.0	1000	

TABLE 3
SATCOM ORBITS

	GEO	MEO	LEO
Altitude latency	High	Low	Very low
Earth coverage	Very large	Large	Small
Satellites required	Three	Six	100s+
Data gateways	Few fixed	Regional flexible	Local numerous
Antenna speed	Stationary	1-hour slow-tracking	10-minute fast-tracking
Advantages	Basic broadband Three satellites cover the Earth	Fiber equivalent Few satellites	High bandwidth/high speed Smaller, low-power satellite constellation
Disadvantages	High latency	Dual tracking antennas	Complex phased array tracking antennas


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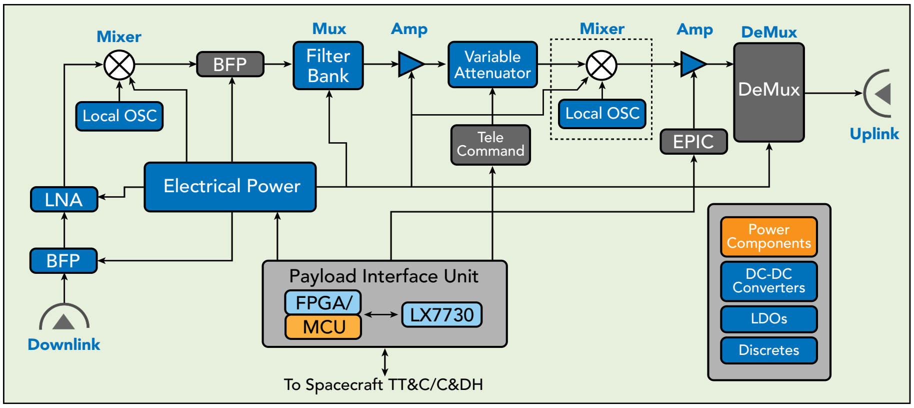

Fig. 4 **Satcom RF signal chain.**

sentially the entire globe, missing only the polar regions. Since MEO satellites are closer to the Earth, they have less latency. However, six MEO satellites are typically required for coverage like GEO satellites. As mentioned, GEO satellites appear stationary to a point on Earth. As orbit gets closer to Earth, satellites begin to move with respect to that point. MEO satellites require a slow-tracking antenna. LEO satellites are closest to Earth and have the lowest latency but each satellite only covers a small area. LEO constellations require hundreds or thousands of satellites to provide coverage and they require a fast-tracking phased array antenna. LEO satellites have become attractive because they are smaller, less sophisticated and lower power, making them less expensive to manufacture and launch. A summary of these attributes is shown in ***Table 3***.

SATCOM RF SIGNAL CHAIN

Table 2 shows that satcom links use frequency-division duplex (FDD), meaning uplink and downlink communication happens in different frequency bands. This is done to enable bidirectional data transfer and minimize channel interference. The uplink (Earth station to satellite) band is higher in frequency than the downlink from the satellite to minimize the cost of the satellite electronics. ***Figure 4*** shows a more detailed block diagram of a representative satellite RF signal chain. The receive and transmit architectures, along with the functionality, are like what was described earlier.

There are some differences. The satellite downlink signal received at the ground terminal first encounters a bandpass filter or a diplexer. In this application, the incoming signal is so low, it is best to filter out any unwanted components before amplification. The block diagram in Figure 4 shows filter banks that would contain switches, along with multiplex (Mux) and demultiplex (Demux) functions that reflect channelization in the satellite signal. An important point is that while architectures for communication applications may have different realizations, the principles are the same.

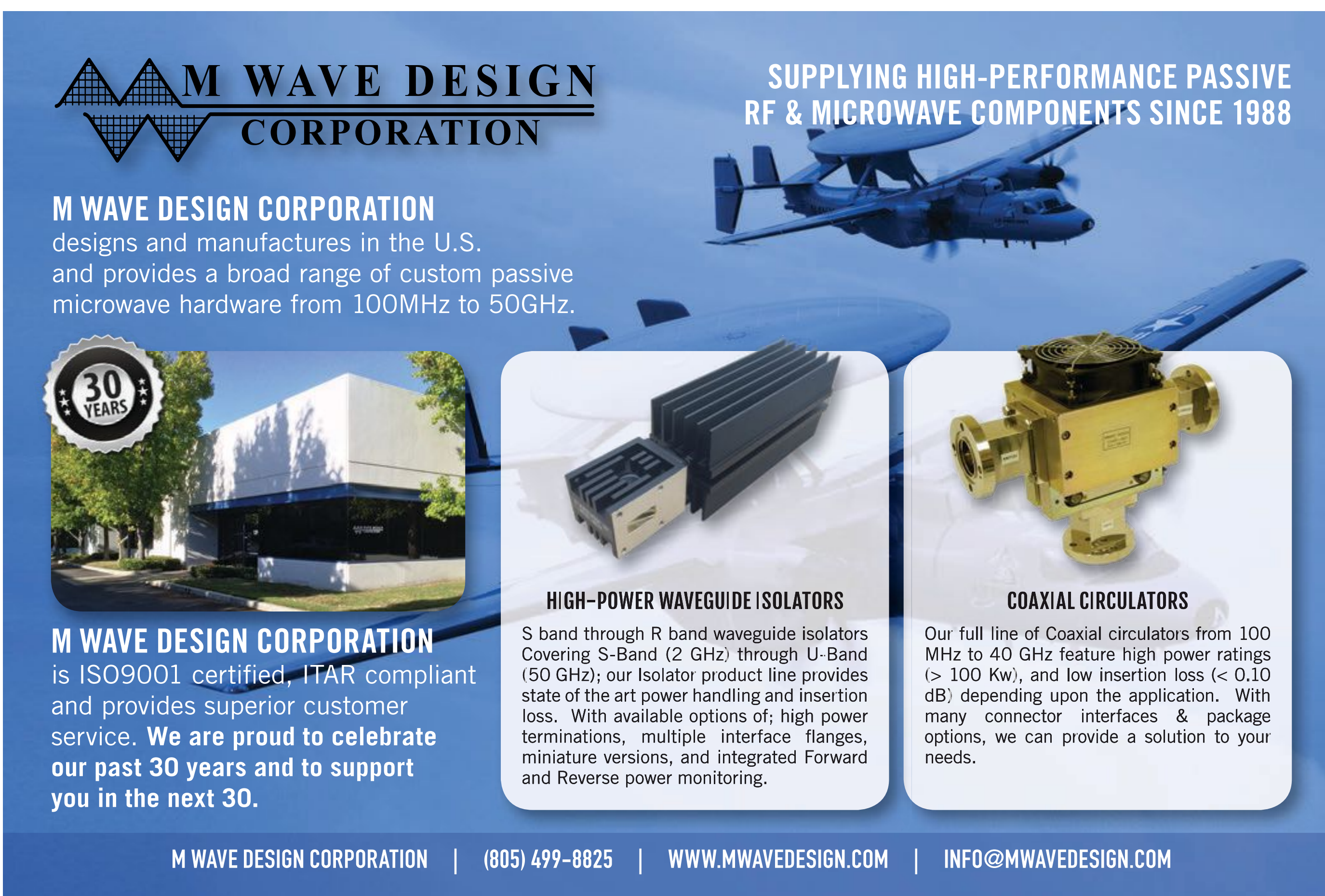

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TABLE 4 CHARACTERISTICS OF COMPONENT CLASSIFICATIONS			
Parameter	***COTS***	***Rad-Tolerant***	***Rad-Hardened***
Radiation tolerance	≤ 1 krad (Si)	15 to 50 krad (Si)	≥ 100 krad (Si)
Qualification	Industrial temperature range (-40°C to +85°C)	Characterized for radiation tolerance levels	NASA EEE-INST-002 component qualification
Mission duration	Short	Longer	Extremely long
Mission type	Not used in critical manned missions	Manned	Manned
Orbit	Used in some LEO missions	GEO, MEO, LEO	GEO, MEO, LEO
Cost	Less expensive	More expensive	Significantly more expensive

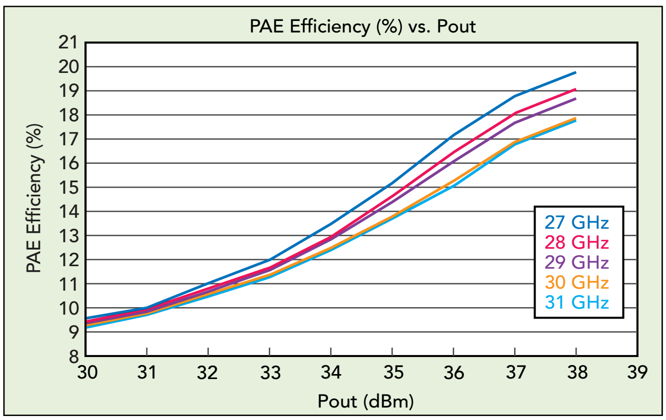

Fig. 5 **ICP2840 PAE for various frequencies.**

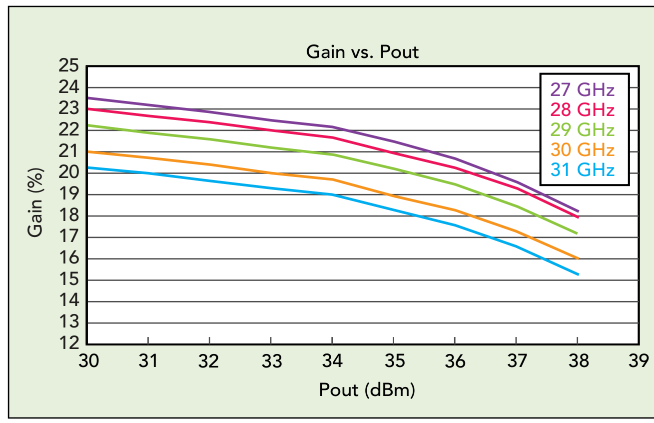

Fig. 6 **ICP2840 gain for various frequencies.**

COMPONENT SELECTION FOR SPACE

The emergence of the commercial space industry with private launch companies, small satellite constellations and sub-orbital tourism, along with other efforts to reinvent the traditional space industry, has created a different component design and selection mindset. With shorter missions, component selection requires cost-effectively meeting the mission goals. Component qualification requirements can vary by function, from commercial off-the-shelf (COTS) to radiation-tolerant to radiation-hardened depending on the space environment and exposure. GaN-on-SiC and GaAs components can be screened for radiation-tolerant or radiation-hardened requirements. COTS components typically have an industrial temperature range, a radiation tolerance under 1 krad (Si) and are less expensive. Radiation-tolerant components can be characterized by radiation tolerance levels from 15 to 50 krad (Si) and have higher costs. Radiation-hardened components have radiation tolerance over 100 krad (Si) and are significantly more expensive. Some of the relative performance considerations for these categories are shown in ***Table 4***.

POWER AMPLIFIERS REQUIREMENTS

PAs are fundamental in the RF signal chain. With the need to increase data rates and capacity, linear PA operation to minimize RF distortion is becoming essential. Satcom systems that use higher-order modulation schemes, such as 64-, 128- and 256-QAM, are extremely sensitive to non-linear behavior. Another challenge is achieving acceptable peak-to-average power ratios (PAPR). PAPR or the ratio of the highest power the PA will produce to its average power determines how much data can be sent and this metric is proportional to the average power. At the same time, the size of the PA needed for a given format depends on the peak power. 5G mmWave EIRP requirements mandated by the FCC include 43 dBm EIRP transmit power for the mobile handsets and base station transportable power of 55 dBm EIRP. These and other conflicting challenges can be met with GaN-on-SiC PAs for satcom, 5G, aerospace and defense applications.

POWER AMPLIFIER TECHNOLOGIES

GaN-on-SiC has a high power density, allowing amplifiers using this technology to generate highly linear output power with high efficiency. GaN-on-SiC PAs can operate at frequencies in the Ka- and Ku-Bands ranging from 12 to 40 GHz with broad bandwidths for commercial and defense satcom and 5G applications. In addition to the frequency characteristics, GaN devices exhibit high gain and better thermal properties than other technologies allowing this technology to be used for a wide range of RF applications. The PAE for a Microchip GaN amplifier is shown in ***Figure 5***. ***Figure 6*** shows the gain characteristics for this same device.

CONCLUSION

The space market is thriving as satellite constellations fill a valuable role in the vision of global high speed connectivity. Traditional satellites in GEO are evolving to provide high data rate connectivity and large numbers of satellites in LEO constellations have started to expand connectivity options. The transmitter and receiver architectures for these and other wireless and wired communications networks are very similar. This article has presented these architectures, along with some of the important trade-offs and selection criteria for these space-based applications. ■

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2 to 18 GHz MLPDA Employs Tapered Balun Feed Structure

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This article describes a microstrip log periodic dipole array (MLPDA) antenna operating over S-, C-, X- and Ku-Bands that employs a tapered balun feed structure. The antenna has good input-matching characteristics and end-fire radiation performance over the 2 to 18 GHz operating band with an average peak gain of 6.2 dBi. It is cost-effective and compact without the need for complicated or loaded structures.

Log periodic dipole array (LPDA) antennas have been employed in wireless communication systems since their invention in 1957 by DuHamel and Isbell.[1] The conventional LPDA is well-suited for applications requiring bandwidth up to a decade, an end-fire pattern and reasonable gain. MLPDA antennas are good candidates for use in modern communication devices as they are easy to fabricate, are low-cost, have low power consumption and are also suitable for integration with microwave integrated circuit modules.[2]

LPDA antennas printed on an electrically thin dielectric substrate were first introduced by Campbell et al. in 1977.[3] Since then, considerable research has been conducted using various techniques to increase bandwidth, reduce size, improve front-to-back ratio, lower the cross-polarization level and increase gain.[4,5] However, the impedance bandwidth of microstrip antennas is inherently narrow and designing an MLPDA antenna that provides stable radiation characteristics over a wide bandwidth is challenging.

Recently, several solutions have been proposed to solve this problem. Yang et al.[6] fed the antenna with a half-mode substrate integrated waveguide with added metal plates. Chu et al.[7] used a similar technique with a bow tie parasitic cell for 5G. The complexity associated with this type of feed is its main disadvantage. Yang et al.[8] adopted a feed approach with double-sided parallel stripline from the backside operating in the 2.5 to 6 GHz frequency range. The drawback is that this requires a four-layer circuit board for antenna construction. Hereth et al.[9] investigated the use of dipole trimming and parasitic elements in the 3.4 to 9.5 GHz band but the addition of the parasitic elements increases the antenna size. Although these designs enhance antenna performance in general, bandwidths remain relatively narrow and the designs could only be realized with specialized technologies.

A simple feed was proposed by Abutarboush et al.[10] This solution proposes a flexible MLPDA antenna on an ultra-thin DuPont™ Kapton® film substrate with a paired CPW parallel strip combination connected through a conductive via. Casula et al.[11] suggested the same feed method, but this technique did not significantly improve bandwidth.

Compared to the previous feed techniques, a tapered microstrip balun is relatively easy to fabricate and connect to external SMA connectors. In addition, it offers the potential for wideband impedance matching.[12-14] This work demonstrates a wideband 2 to 18 GHz MLPDA antenna with an integrated balun transformer. In this approach, the feed transitions from a microstrip line to a double-sided parallel stripline. CST Studio is used for preliminary numerical studies to obtain an optimal design before fabrication and measurements.

ANTENNA DESIGN

The structure is like a standard, wire LPDA and it uses a typical LPDA design strategy.[15] The LPDA antenna is shown in ***Figure 1***. It comprises a set of dipole elements alternately printed on both sides of a microstrip substrate that is fed with an SMA connector to match the 50 Ω input impedance.

The resonant frequency of each dipole element changes periodically in conjunction with a logarithmic function related to the dipole size. Given N dipole

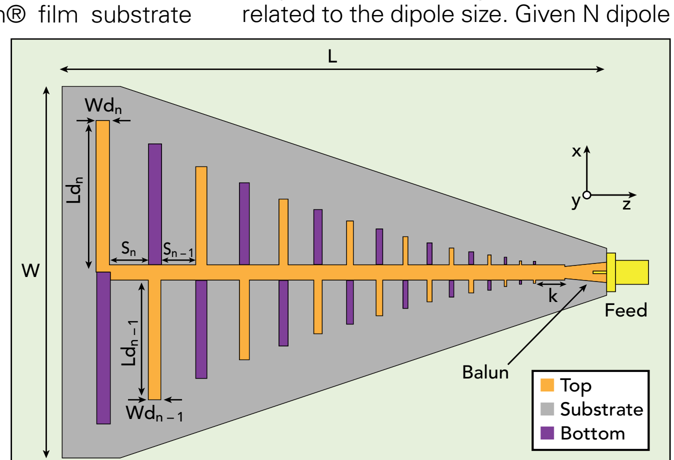

Fig. 1 **Antenna geometry.**

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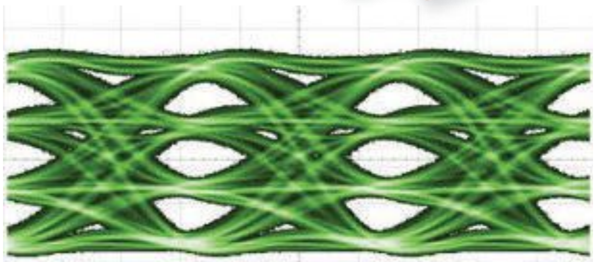

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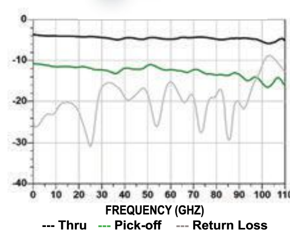

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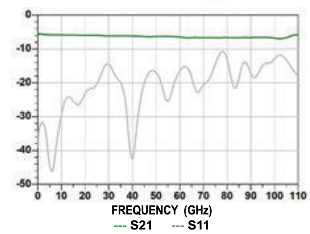

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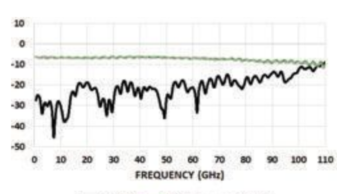

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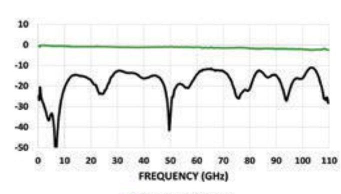

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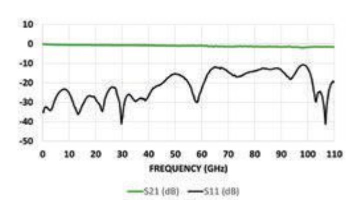

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elements:

Ld_n = Length of the dipole element d_n

Wd_n = Width of the dipole element d_n

S_n = Inter-element spacing between two adjacent dipoles

W_L = Width of the microstrip feed line

L_L = Length of the microstrip feed line

K = Feed length

These geometrical parameters must be properly tuned to realize a working antenna.

For a given desired bandwidth, where f_{min} and f_{max} are lower and upper cutoff frequencies, the design starting point is the definition of the parameters α, τ and σ considering the empirical rules defined by Milligan.[16]

The aperture angle α is given by ***Equation 1***:

$$\alpha = \tan^{-1}\left(\frac{Ld_n}{2 * L_L}\right) \quad (1)$$

The scaling factor, τ, which is the ratio between lengths of two consecutive dipoles, Ld_n and Ld_{n-1}, is the most important design parameter. This relationship is shown in ***Equation 2***:

$$\tau = \frac{Ld_{n-1}}{Ld_n} = \frac{Wd_{n-1}}{Wd_n} = \frac{S_{n-1}}{S_n} \quad (2)$$

The spacing constant σ is given by ***Equation 3***:

$$\sigma = \frac{S_n}{4Ld_n} \quad (3)$$

The desired operating frequency range with upper and lower truncation constants, t_1 and t_2, determined for τ and σ are combined to compute the length of the longest element and determine the number of elements required. The longest element length is given by ***Equation 4***:

$$Ld_n = t_1 \cdot \lambda_n \quad (4)$$

where λ_1 is the longest operating wavelength and t_1 is determined empirically from ***Equation 5***:[16]

$$t_1 = 1.01 - 0.519\tau \quad (5)$$

The upper truncation t_2 constant is defined as shown in ***Equation 6***:

$$t_2 = 7.08\tau^3 - 21.3\tau^2 + 21.98\tau - 7.30 + \sigma(21.82 - 66\tau + 62.12\tau^2 - 18.29\tau^3) \quad (6)$$

The truncation constants and the frequency band determine N as shown in ***Equation 7***:

$$N = 1 + \frac{\log(t_2/t_1) + \log(f_{min}/f_{max})}{\log(\tau)} \quad (7)$$

To determine the widths of the dipole elements and the feed line, the first assumption is that the required input impedance is real. The average characteristic impedance Z_0 of the cylindrical dipole is given in ***Equation 8***:[17]

$$Z_0 = 120\left(\ln\frac{Ld_n}{2a_n} - 2.25\right) \quad (8)$$

where a_n = radius of the equivalent cylindrical dipole.

The width of the longest printed microstrip dipole element is approximatively equal to the perimeters of the cylindrical dipole as determined by ***Equation 9***:[3]

$$Wd_n = \pi a_n \quad (9)$$

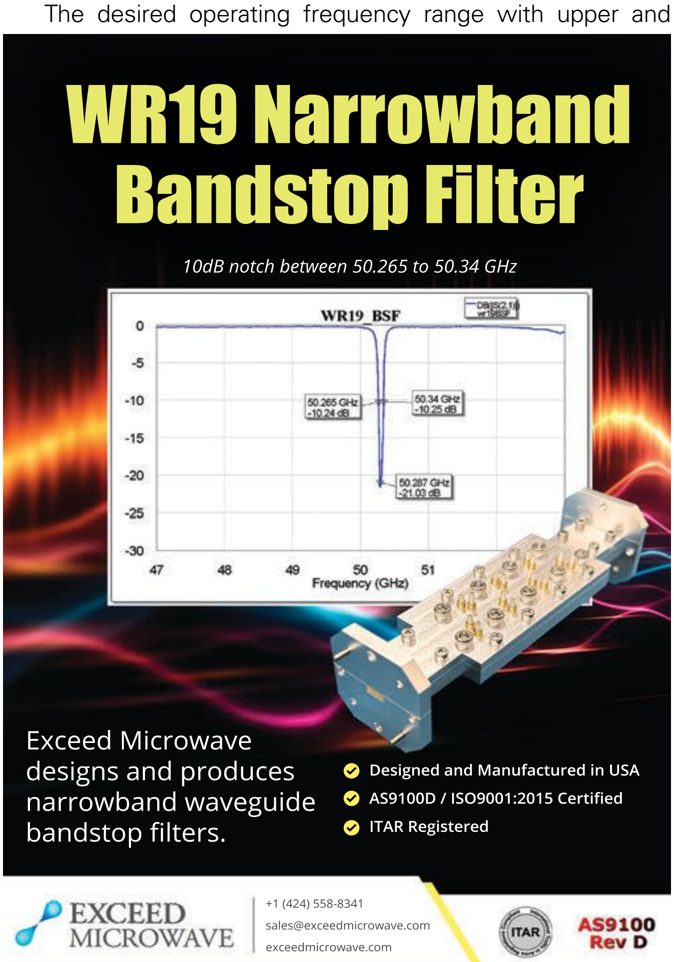
After determining the length and width of the largest dipole element from Equation 4 and Equation 9, the lengths and widths of the remaining dipoles Wd_n and Ld_n for n = 1, 2, 3…N-1 are calculated by iterating the scaling factor τ.

The prototype is fabricated on low-cost FR4 with a thickness of 1.5 mm, a loss tangent of 0.02 and a dielectric constant of 4.3. To cover the 2 to 18 GHz frequency range, N is de-

TABLE 1

MLPDA ANTENNA DESIGN PARAMETERS

Symbol	Parameter	Value
L	Length of substrate	97.5 mm
W	Width of substrate	62 mm
W_L	Width of parallel strip line	2.8 mm
τ	Scaling factor	0.9
σ	Spacing factor	0.086
α	Aperture angle	32 degrees
k	Feed length	5.42 mm
Ld_{16}	Length of largest dipole	27.25 mm
Wd_{16}	Width of largest dipole	2.6 mm
S_{16}	Spacing between d_{16} and d_{15}	9.4 mm
N	Number of dipole elements	16



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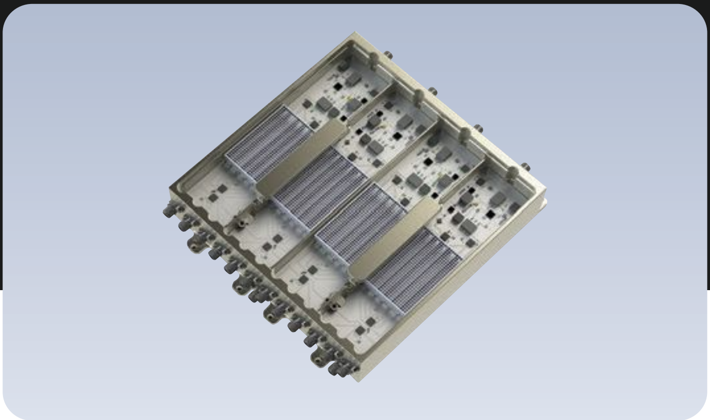

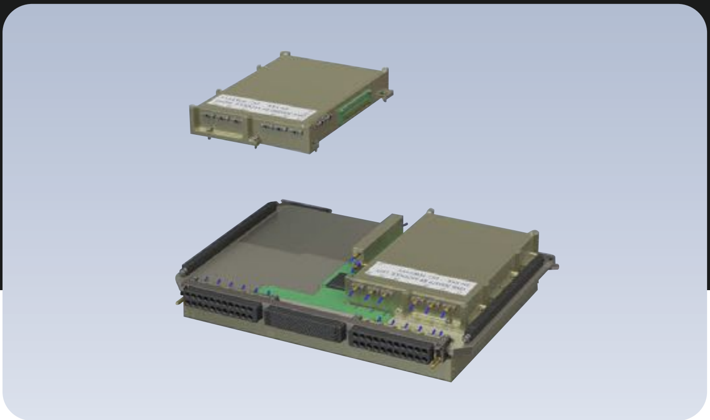

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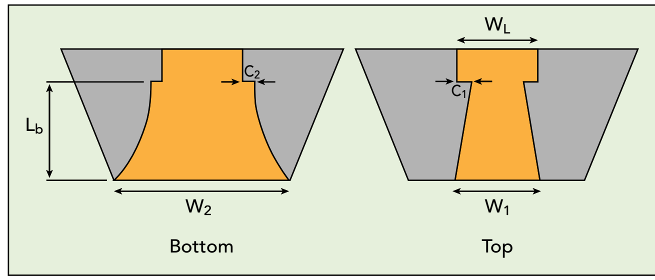

Fig. 2 Balun geometry.

TABLE 2

BALUN PARAMETERS

Parameter	L_b	W_1	W_2	C_1	C_2
Value (mm)	7.5	3.8	6.5	0.5	0.5

termined to be 16, with τ = 0.9 and α = 32 degrees. The dimensions are optimized using CST Microwave Studio software. The design parameters used for analysis are listed in ***Table 1***.

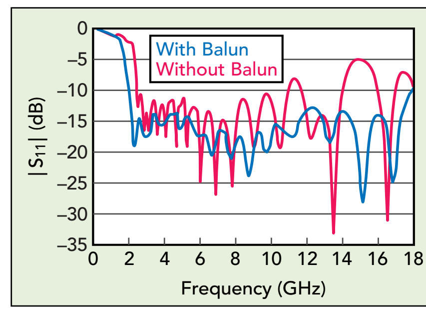

Fig. 3 MLPDA antenna simulated reflection coefficient with and without a balun.

BALUN DESIGN

The operating band of a conventional LPDA may be arbitrarily widened by properly extending the geometry of the antenna structure and increasing the number of dipole elements.[15] However, to practically achieve very large bandwidths, a balanced feed is required. From the simulation results, the antenna input impedance changes significantly as a function of frequency from 2 to 18 GHz. Hence, a balun is used to provide impedance matching.

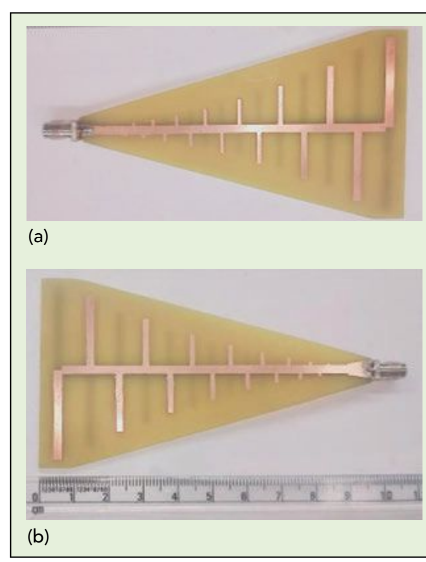

Fig. 4 MLPDA prototype antenna: top view (a) and bottom view (b).

This balun serves as a broadband impedance transformer to maximize power transfer. A balun based on the Klopfenstein microstrip tapered line is designed[18] with the results shown in ***Figure 2***. The balun contains two tapered lines printed on both sides of the substrate. The bottom and top lines combine to form a microstrip line at the unbalanced input of the balun. At the balanced output, both conductors are connected to one part of the antenna, constituting a balanced parallel strip. The impedance of the parallel strip is equal to the antenna input impedance. Along the balun, the top side includes a linearly ta-

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pered impedance transformer while the bottom side is an exponentially tapered microstrip. The exponentially tapered curve is described by ***Equation 10*** with s and r defined through CST parametric optimization:

$$y = se^{rx} \qquad (10)$$

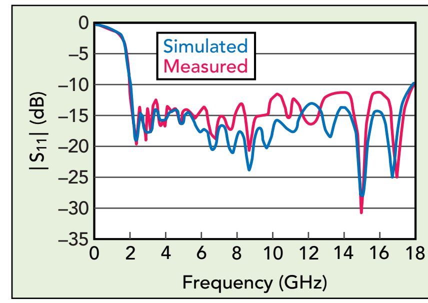

Fig. 5 Simulated and measured MLPDA antenna reflection coefficient.

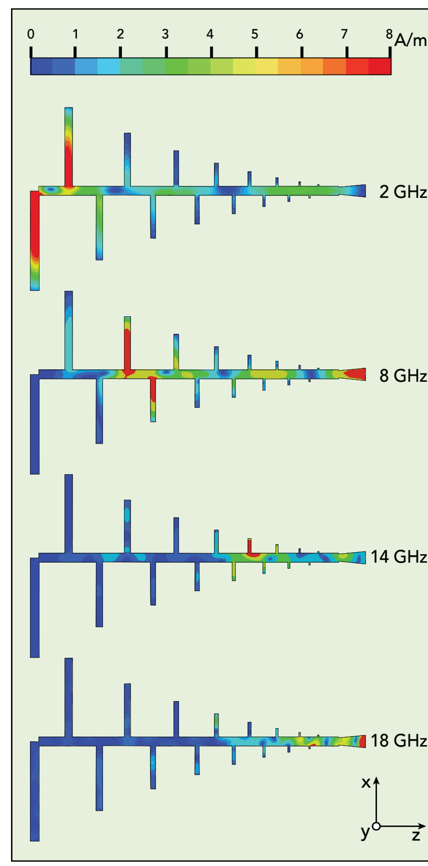

Fig. 6 Simulated antenna surface current distribution at different frequencies.

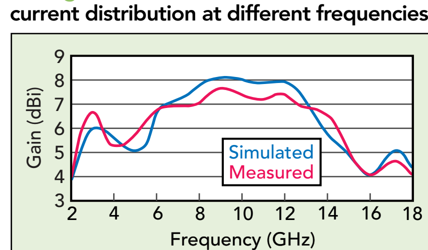

Fig. 7 Simulated and measured antenna peak gain.

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The antenna input impedance is approximately 166 Ω; therefore, the balun is designed to transform the unbalanced 50 Ω microstrip line to the antenna's 166 Ω balanced impedance. The balun's profile is optimized for minimum return loss, maximum bandwidth and reduced size. The balun dimensions are listed in ***Table 2***.

RESULTS AND DISCUSSION

An antenna with and without the balun feed is designed and simulated using CST Microwave Studio. Their reflection coefficients are compared over frequency in ***Figure 3***. They are similar below 8 GHz, but $|S_{11}|$ without the balun increases considerably beyond 10 GHz. The antenna with the balun exhibits an $|S_{11}|$ less than - 10 dB over a fractional bandwidth of 160 percent centered at 10 GHz.

Figure 4a shows the top view of the prototype MLPDA antenna and ***Figure 4b*** shows the bottom view. A Keysight N5224A vector network analyzer is used to measure its electrical performance. ***Figure 5*** shows the measured and simulated $|S_{11}|$ of the antenna, displaying good agreement between simulated and measured results. Small differences are attributed to tolerances in fabrication and assembly not accounted for in the ideal model.

The surface current distribution is an efficient way to explain the antenna's behavior. ***Figure 6*** shows simulated current distributions on the antenna at 2, 8, 14 and 18 GHz. The active region moves toward the smaller dipoles when the operating frequency increases, as expected.

Antenna gain is also evaluated through measurement and simulation over the frequency band. The results are shown in ***Figure 7*** and the simulated values are in close agreement with measurements. Peak gain is a maximum value of 8.16 dBi at 9 GHz and a minimum value of 3.9 dBi at 16 GHz.

Gain decreases at the operating bandwidth extremities. This can be explained by examining the radiation mechanism of the MLPDA. For a given resonating frequency, longer ele-

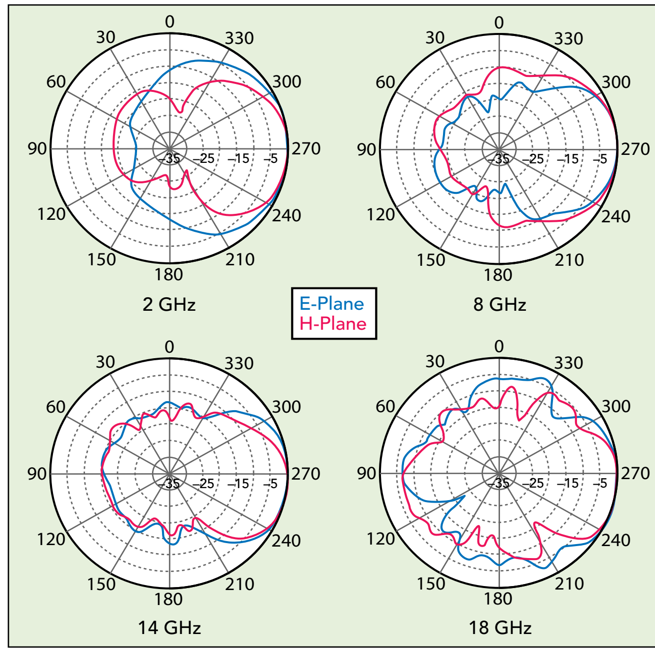

Fig. 8 **Radiation patterns at different frequencies.**

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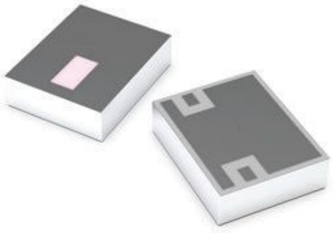

Model Number	Passband (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)
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BFCQ-1982+	17700-20200	100-14500	55	24000-40000	45
BFCQ-1162+	10700-12700	100-8800	40	15100-27000	38

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ments, as compared to those at resonance, act like reflectors while smaller arms act like directors. At the lowest frequencies, the gain degradation is due to the absence of a reflector behind the largest MLPDA element while the gain degradation at upper frequencies is attributed to the lack of directors before the shortest element.

Normalized radiation patterns for the broadband-fed MLPDA antenna are shown in ***Figure 8***. They include end-fire radiation patterns at 2, 8, 14 and 18 GHz in the xz plane (E-plane) and the yz plane (H-plane). As mentioned previously, the pattern at 18 GHz becomes less directional in the absence of directors.

CONCLUSION

A wideband MLPDA antenna comprising 16 radiating elements and an integrated balun is printed on a low-cost substrate, which allows a simple realization and compact size. It demonstrates a 16 GHz impedance bandwidth and stable directional radiation patterns with an average gain of 6.2 dB. It is proposed for use in wideband portable devices operating in the 2 to 8 GHz range. ■

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When system engineers call for ultra-reliable, high performance military grade cables & connectors, the obvious choice is...
Today's advanced military platforms depend on the quality, selection, support and service that are the hallmarks of IW's product lines. We offer a range of jacket materials, armoring, and a wide variety of connectors including SMA, TNC, N, SC, 2.4 mm, and 7 mm to provide highly reliable, application specific solutions.
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e nysales@insulatedwire.com

Military-Grade Omni Antenna is TAA-Compliant

Fairview Microwave, a leading supplier of on-demand RF and microwave products, has recently released the FMANOM1143 antenna. This antenna has a maximum input power of 200 W with 4 dBi gain and it measures 5 x 5 x 5.12 in. with a female N-type connector. This MIL-STD-810-compliant omnidirectional antenna is specifically designed for 500 MHz to 6 GHz vehicle-mounted military applications.

This wideband antenna features standard U.S. 4-hole or NATO 3/6-hole patterns and is designed to excel in mission-critical applications such as vehicle navigation, personnel communications, vehicle communications, electronic warfare and jamming with its wideband dipole array seamlessly operating across a wide range of frequencies. The FMANOM1143 military-grade antenna meets MIL-STD-810 standards, guaranteeing its durability and adherence to strict quality standards. Additionally, this antenna is Trade Agreements Act-compliant, making it suitable for government and defense applications where compliance is of utmost importance. The radome-protected radiator enhances durability and the absence of a ground plane requirement opens a range of diverse mounting possibilities, making it a good choice for electronic warfare and jamming scenarios where flexibility is paramount. Designed to weather challenging conditions, the FMANOM1143 stands out as a durable communication solution. Operating in temperatures from -40°C to +71°C, this antenna meets MIL-STD-810 standards for humidity, shock, vibration, blowing rain and immersion. With impact resistance at 40 km/h and a water immersion depth of one meter, the FMANOM1143 ensures unwavering connectivity in active hostile and harsh environments. This rugged omnidirectional antenna is in stock and available for same-day shipping.

VENDORVIEW

Fairview Microwave
An Infinite brand
Lewisville, Texas
fairviewmicrowave.com

High-Purity Signal Source Operates to 54 GHz

Continuing the effort of developing high performance, yet affordable signal generators, AnaPico recently launched a new APLC series of signal sources. The frequency range is from 9 kHz to 54 GHz with available models for 12.75, 20, 40 and 54 GHz. The SSB phase noise performance at 10 Hz and 20 kHz from a 10 GHz carrier frequency is -90 dBc/Hz and -130 dBc/Hz, respectively. Harmonics are typically better than -50 dBc and non-harmonics are typically better than -85 dBc. The maximum output power is frequency band-dependent, ranging from +15 to +25 dBm.

The source supports AM/FM/PM and pulse modulation schemes and achieves a pulse on/off ratio of 100 dB with a pulse rise/fall time of about 2 ns. Like AnaPico's other signal sources, the APLC series features 5 to 15 μs frequency switching times. The compact benchtop/portable instrument can be used in a variety of applications like RF and microwave component testing, as an RFLO, for ADC IC and circuit testing, in high-end load-pull test systems, with intra-pulse frequency chirping function and in general use cases requiring fast list sweeping. Optional internal references are available with different long-term stability levels.

Multi-channel models with up to four independently adjustable APLC channels in a 2-HU rack-mountable chassis are available. All channels are phase-coherent. Multiple APLC-X devices can be phase-synchronized to ensure system scalability. With the additional phase-coherent switching feature, the APLC-X models are especially applicable for applications such as radar and EW signal generation, quantum computing, MIMO signal generation and receiver testing. Please refer to www.anapico.com for more information.

VENDORVIEW

AnaPico AG
Zurich, Switzerland
www.anapico.com

Solid-State TWTA Replacement Operates 2 to 8 GHz

Exodus Advanced Communications has developed a solid-state high-power amplifier (HPA) system for S- and C-Band testing applications. The AMP2085E-1LC amplifier can replace TWTs for general radiated susceptibility requirements such as EMI-Lab/RS103 and electronic warfare applications. It operates from 2 to 8 GHz and the amplifier produces 250 W minimum (300 W typical) CW or pulsed output power over the frequency band with a P1dB of 150 W. The amplifier incorporates a class A/AB design with 54 dB minimum gain, better than -20 dBc harmonics at rated output, -60 dBc maximum spurious performance and a maximum 5 dB peak-to-peak power gain flatness.

The amplifier provides extensive control and monitoring, including optional calibrated power monitoring. Monitoring is possible via the color display or remote control. The color touchscreen shows the forward and reflected power, real-time VSWR, system voltages and currents, operating temperatures of the PA module/heat sinks and internal system temperature. The unit incorporates more than 20 dB of gain control that is accessible from the screen or the remote interface.

The AMP2085E-1LC is rack-mountable or it may be used on a bench. The HPA has type N female connectors for the RF input and optional RF sampling ports, along with a type SC female RF output connector to handle the high transmit power. The Exodus Advanced Communications' product lines use LDMOS, GaN HEMT and GaAs technology for its devices with many of the devices manufactured internally. In addition to the HPA family, Exodus designs LNAs, modules and multi-band systems for applications with frequencies ranging from 10 kHz to more than 75 GHz.

VENDORVIEW

Exodus Advanced Communications
Las Vegas, Nev.
exoduscomm.com

DC to 67 GHz Narrow Body RF Edge Launch Connectors

Samtec introduced a new family of edge launch connectors operating as high as 67 GHz. These connectors are commonly used in lab settings for high frequency test and measurement applications, high speed digital component test and evaluation boards. The 185-EL Series operates from DC to 67 GHz, the 240-EL Series operates from DC to 50 GHz and the 292-EL Series operates from DC to 40 GHz. Connector interfaces include 1.85 mm, 2.40 mm and 2.92 mm.

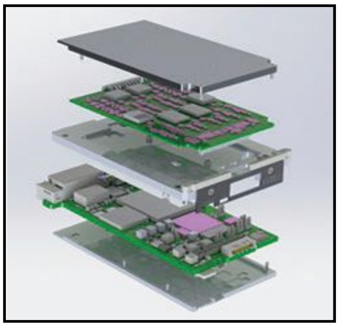
Installing these connectors on the board's edge makes aligning the launch pin with the circuit trace easier, ensuring better ground alignment to minimize RF leakage. Samtec's RF edge launch connectors compression mount to the printed circuit board (PCB) without solder. Proper alignment and the elimination of solder improves the signal integrity performance versus soldered edge launch, vertical or angled launch connectors.

The solderless design of the 185-EL, 240-EL and 292-EL Series connectors allows them to be reusable and field replaceable, accommodating up to 500 mating cycles. This feature makes the connectors extremely cost-effective. Samtec's RF edge launch connectors are easy to install and do not cause damage to a PCB.

The recommended board thickness for Samtec's solderless RF edge launch connectors is 0.040 to 0.100 in. The recommended board-mount torque is 0.5 to ~ 0.8 in.-lbs. The complete electrical and mechanical data can be found on the product spec sheets for each series.

Samtec offers a full line of off-the-shelf solutions for microwave and mmWave applications from 18 to 110 GHz. Samtec precision RF products support next-generation technology advancements in wireless communication, automotive, radar, satcom, aerospace, defense and test and measurement applications. Customization of products, both quick-turn modifications and new designs, is also available.

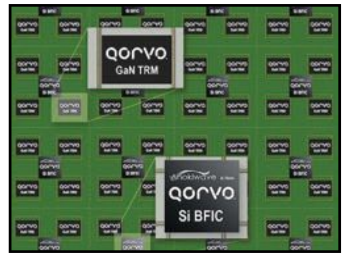
Samtec
New Albany, Ind.
www.samtec.com



Analog Devices' Pre-Released ADSY1100 3UVPX System

Analog Devices' ADSY1100-series is a family of wideband multichannel RF digitizers in a 3UVPX SOSA™-aligned format. The system is built around ADI's next-generation "Apollo" MXFE™ product (AD9084) featuring DAC sample rates up to 28 GSPS and ADC sample rates up to 20 GSPS in a 4 Tx/ 4 Rx configuration. ADSY1100's integrated digital signal processing reduces system power consumption, while the integrated RF tuner reduces end system size and complexity.

Analog Devices
www.analog.com/en/products/adsy1100.html



ICs that Power High Performing X-Band Phased Array AESAs

Together Anokiwave and Qorvo provide the most capable components for high performing X-Band radars. Silicon quad core beamforming ICs feature selectable dual Rx beam to support monopulse or dual polarization operation. GaN T/R FEMs with a range of transmit output powers complement and interface directly with the beamformer ICs. Independent phase/amplitude setting at each element is achieved through direct SPI control. These ICs are widely proven in military and commercial platforms and are available with short lead time.

Anokiwave Is Now Qorvo
www.anokiwave.com

Site Master Cable and Antenna Analyzer with Integrated Spectrum Analyzer

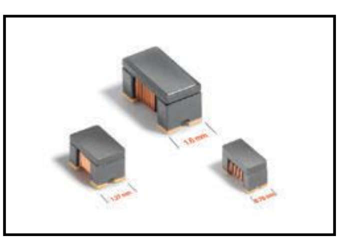
Discover the ultimate field-testing solution with the Next Generation Anritsu Site Master Cable and Antenna Analyzer with Integrated Spectrum Analyzer, perfect for professionals across industries and ideal for general purpose and installation and maintenance applications. From telecommunications to aerospace and defense, benefit from versatile cable and antenna analysis, real-time spectrum analyzer, advanced interference detection and vector signal analysis capabilities. Elevate your testing experience and maximize efficiency with the industry-leading Site Master Cable and Antenna Analyzer with Integrated Spectrum Analyzer.

Anritsu
www.anritsu.com

Thermoelectric Refrigeration Cooling/Heating System

Cernexwave's Thermoelectric Refrigeration Cooling/Heating System is a great solution to bring your components to the optimum temperature for testing. They have a temperature control range of -45°C to +120°C with fast temperature change speed and high accuracy. The large cooling/heating plate dimensions and small overall footprint allow these units to be used for a great range of components in labs of any size.

Cernexwave
www.cernexwave.com



Outgassing Compliant USB Common Mode Chokes from Critical Products & Services

FRA Family common mode chokes virtually eliminate common mode noise in high speed, differential-mode signal transmission applications such as USB 3.0, HDMI, SATA, IEEE1394 and LVDS, supporting data rates up to 4.8 Gbit/s. They are offered in three standard sizes, 0603 (AR312FRA), 0805 (AR336FRA) and 1206 (AR376FRA), all of which pass NASA low outgassing specifications. The use of a chemically-resistive adhesive also helps these parts withstand aggressive solvents.

Coilcraft
www.coilcraft.com

Innovative and Reliable Technology Solutions

CPI Electron Device Business is a global manufacturer of electronic components and subsystems focused primarily on communications, defense and medical markets. With a heritage of technological excellence that spans decades, CPI EDB develops, manufactures and globally distributes innovative and reliable technology solutions used in the generation, amplification, transmission and reception of microwave signals for commercial and military applications. CPI EDB serves customers in the communications, defense, medical, industrial and scientific markets.

CPI Electron Device Business
www.cpii.com

S-Band Satcom Uplink SSPA Delivering 4 KW

VENDORVIEW

Empower RF Systems Model 2176 is a compact, high-power GaN on SiC solid-state CW amplifier. At 27 inches tall, it's less than half the size of typical legacy uplink HPAs. It offers broader band flexibility, improved spectral purity for increased data rates, and multiple output modes including ALC and AGC. It features high availability, high efficiency, excellent EVM, M2M control and a user-friendly web GUI. With in-depth health monitoring and high reliability, it's ideal for critical "on air" applications.

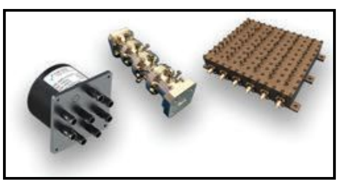
Empower RF Systems
www.empowerrf.com/markets/satcom-amplifier.php?source=MWJ

Eravant's Space and Military Applications are Certified

VENDORVIEW

Eravant's quality management system has been certified by DEKRA to the AS9100D standard, based on and including ISO 9001:2015. Eravant's validation capabilities for space and military applications include thermal-vacuum test chambers and thermal-shock testing. Eravant offers components, subsystems and custom design services from 18 to 330 GHz.

Eravant
www.eravant.com



High Performance Passive Components

VENDORVIEW

Exceed Microwave provides custom high performance passive microwave component designs up to 110 GHz for defense, space and commercial applications. Exceed Microwave is AS9100 certified and ITAR registered, providing high-quality, high performance passive components. They provide various types of designs, each with its own unique values and are designed and made in the U.S. Many of Exceed's designs offer extremely high Q factor, allowing very low insertion loss and high-power handling.

Exceed Microwave
www.exceedmicrowave.com

Exodus AMP2030-LC 1.0–6.0 GHz, 300 W, 200 W P1

VENDORVIEW

Exodus AMP2030-LC is ideal for broadband EMI-Lab, communication and EW applications. Class A/AB linear design for all modulations and industry standards. Covers 1.0 to 6.0 GHz, producing 300 W Minimum, 200 W P1dB and 55 dB minimum gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability and ruggedness. Integrated in Exodus' compact 5U chassis weighing approximately 35 kg.

Exodus Advanced Communications
www.exoduscomm.com

Ultra Flexible Cable Line Expanded

VENDORVIEW

HASCO, Inc., a global supplier of just-in-time RF and microwave components, has expanded their line of ultra flexible cables designed specifically for demanding microwave interconnect requirements. The HLB098 Littlebend Flexible Cable line now includes the HLB098-NJBH-NJBH-L, terminated with high performance Type N bulkhead connectors. The HLB098-NJBH-NJBH-L are phase and amplitude stable and well suited for dense microwave packaging with a 5.0 mm minimum bend radius in a 0.098 in. stainless steel braid. Also available in SMA, SMP, 1.0 mm, 1.85 mm, 2.4 mm and 2.92 mm connectors.

HASCO, Inc.
www.hasco-inc.com

Recently Released Configurations

HUBER+SUHNER offers a comprehensive portfolio of high performance RF and microwave cable assemblies for challenging defense applications. These assemblies are comprised of the SUCOFLEX 100, MULTIFLEX CT, SPUMA RS and MINIBEND coaxial cable families, all MIL qualified. In addition, HUBER+SUHNER has recently released configurations that incorporate stainless steel 316L connectors, offering outstanding mechanical durability and able to withstand extremely harsh environments: SMA, TNC and N series and straight male, right angle male and bulkhead types.

HUBER+SUHNER
www.hubersuhner.com

100+ GHz Ultra-Broadband Components

HYPERLABS builds precision components for ultra-broadband RF, high speed data, electro-optical and other cutting-edge applications. Designed with signal integrity in mind, these parts maintain clean eyes and introduce minimal perturbations. The expanded lineup of 100+ GHz parts now includes baluns, DC blocks, bias tees, power splitters and dividers, attenuators, terminations, pick-off tees and inverters. All HYPERLABS products are designed and manufactured in the U.S. and are compliant with RoHS, REACH and ITAR regulations.

HYPERLABS
www.hyperlabs.com/components/110-ghz/

Coaxial Cables for Defense

Insulated Wire Inc. designs and manufactures a range of coaxial cable from 0.034 to 0.750 in. including low loss/phase stable, hand-formable and semi-rigid cable types. IW specializes in supporting high performance systems with cable assemblies operating up to 110 GHz for land/sea/airborne defense platforms (e.g. EW, radar, comms) with ruggedization options and a range of jacket types available, including low outgassing solutions for space applications. IW also provides the additional capability to integrate their wire and cable products into custom composites.

Insulated Wire Inc.
www.insulatedwire.com

Ultra-Compact High Performance SSPAs with Demonstrated Reliability

Kratos has an extensive portfolio of ultra-compact power amplifiers covering 1 to 50 GHz with power levels ranging from 50 W CW to 2 kW pulsed. Offering SWaP-C solutions and fast turn-around times for custom designs and production, Kratos' capabilities extend into Integrated Microwave assemblies supporting various EW, radar and communications applications meeting unique mission specific electrical and environmental requirements. 2024 product development includes frequency coverage of V- and W-Bands.

Kratos Microwave USA
www.kratosdefense.com/about/divisions/microwave-electronics/us

Beamforming Solutions with Butler Matrices

VENDORVIEW

The KRYTAR Butler Matrix family uses KRYTAR's own high performance 90- and 180-degree hybrid couplers providing superior phase accuracy, amplitude imbalance, stability, high isolation, low insertion loss and VSWR, and repeatability. Offering coverage of multiple microwave bands, from 0.5 to 40 GHz, a KRYTAR Butler Matrix is the ideal choice for antenna array beamforming, 5G NR (New Radio) testing, mmWave testing, MIMO testing, multipath simulation and performance evaluation and many other applications.

KRYTAR
www.krytar.com

100 MHz OCXO with Ultra-Low Phase Noise and Ultra-Low G-Sensitivity

KVG recently launched a new 100 MHz OCXO combining ultra-low phase noise and ultra-low g-sensitivity in a 26 mm x 26 mm package. Noise floor is lower than -182 dBc/Hz and phase noise at 100 Hz Offset is below -135 dBc/Hz. In combination with superior phase noise performance, G-sensitivity is guaranteed to be below 0.5 ppb/g, on request also below 0.2 ppb/g, which guarantees reliable performance even in harsh environments.

KVG Quartz Crystal Technology GmbH
https://kvg-gmbh.de/

LadyBug LB5967L RF Power Meter

VENDORVIEW

LadyBug's LB5967L Power Meter provides accurate measurements from 9 kHz to 67 GHz. The sensor's wide frequency range, high dynamic range and fast measurement speed make it ideal for source calibration, eliminating multiple sensors often used to cover this frequency range. The RMS responding diode based sensor accurately measures signals with any modulation bandwidth. Interfaces include: USB HID, USBTMC, Optional LAN (HiSLIP) with PoE, SPI and I2C. Includes LadyBug's multi-threaded software package.

LadyBug Technologies
www.ladybug-tech.com/product/the-lb5967l-9-khz-to-67-ghz-true-rms-power-sensor/

Defense & Aerospace

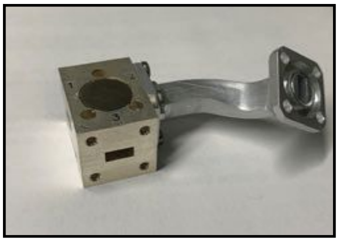
Empower your Signal

GaN Wideband Amplifier Solutions for EW, Jammer, and Milcom Applications

- Covering upto 18GHz
- Compact Design
- Cutting-Edge GaN Technology
- High Efficiency and Excellent Performance
- Customizable Solutions Capable

For more information please visit us at **https://rfhic.com/contact/**

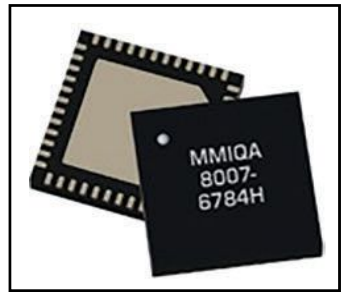
RFHIC®



High Performance Components Since 1988

M Wave Design Corporation has been supplying low loss, high performance Ferrite and Waveguide components since 1988. The company specializes in high-mix, low volume microwave components. The unit illustrated above was a system design "afterthought" by its customer who ran out of space. M Wave solid modeled and built the WR28 full-band circulator and waveguide run into their package constraints and "on time and in budget." M Wave Design Corporation designs and manufactures a broad range of custom passive microwave hardware from 100 MHz to 50 GHz.

M Wave Design Corporation
https://mwavedesign.com



MMIQA-0218HPSM Is Your Mission-Critical Solution

VENDORVIEW

The MMIQA-0218HPSM from Marki Microwave is a versatile surface-mount IQ mixer with an integrated broadband LO driver amplifier. It offers 2 to 18 GHz RF/LO and DC to 3 GHz IF bandwidth support and features 7.5 dB I+Q conversion loss and 28 dBc image rejection across the band. The MMIQA-0218HPSM is an ideal solution for IQ, single sideband and image reject mixing applications with wide bandwidths. The integrated drive amplifier requires no pre-driver or sequencing. Now available at RFMW.

Marki Microwave
www.rfmw.com

20 GHz to 36 GHz and 28 GHz to 40 GHz YIG-Based Notch Filters for EW and ECM

Breakthrough product line of notch filters that cover mmWave frequencies. This family of new yttrium iron garnet-based filters provide superior notch depths over the 20 to 40 GHz frequency range. Two models provide tunable notches of 15 MHz minimum at 40 dB down across the 20 to 36 GHz (MLFR-2036) and 28 to 40 GHz (MLFR-2840) bands. Typical passband insertion loss is 3 dB and the passband range is 20 to 42 GHz.

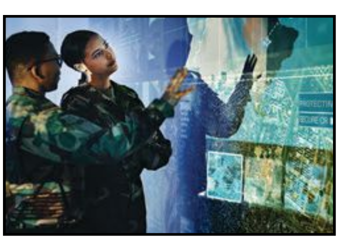
Micro Lambda Wireless
www.microlambdawireless.com

MCI
Microwave Components, Inc.

Miniature Air Coils for High Reliability, RF and Microwave Applications

Microwave Components, Inc. (MCI) in Dracut, Mass., is a small, veteran owned manufacturer of miniature air coils. MCI has proudly been delivering custom, high Q, miniature air inductors to the aerospace, defense and space markets since 1978. Materials include; bare and insulated gold, copper, silver, gold plated copper, nickel copper alloy and aluminum wire. Inductances from 1 to 1000+ nH.

Microwave Components, Inc.
www.mcicoils.com



Communications-based Specialty Products

Microwave Products Group (MPG), comprised of six elite brands: MPG Solutions®, BSC Filters™, Dow-Key Microwave®, Espy™, K&L Microwave® and Pole/Zero®, is a leading global provider of mission-critical, engineered electronic components and subsystems with seven world-class business development and manufacturing locations. Their expertise is the design and manufacture of communications-based specialty products for demanding defense, space, aerospace, automated test equipment and GPS applications where function and reliability are crucial. Visit www.mpgdover.com for more information.

Microwave Products Group (MPG)
www.mpgdover.com

See Norden's VPX Transceiver Specs

Norden's wideband VPX transceiver is used across military applications. It offers 2 to 18 GHz operation in a versatile OpenVPX platform. The NUDC2-18/1.3-2.3 includes internal LOs which provide an instantaneous IF bandwidth of 1 GHz and exceptional noise figure. The NUDC2-18_1.3-2.3 is currently in production. Contact Norden with your specific requirements and discuss custom configurations to meet your specification needs.

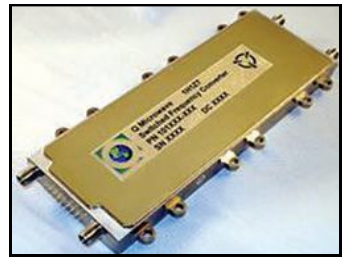
Norden Millimeter
https://nordengroup.com/wp-content/uploads/Norden-Transceiver.pdf

Hermetically Sealed RF Connectors and Adapters

VENDORVIEW

Pasternack's series of hermetically sealed RF connectors and adapters are designed to meet the stringent requirements of military and defense applications. The hermetically sealed terminal connectors and bulkhead-mount adapters in the series are developed with a variety of BNC, Type N, TNC, SMA, 2.92 mm and 2.4 mm options.

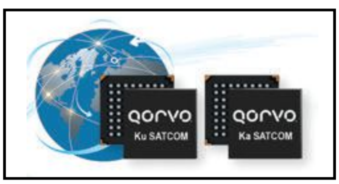
Pasternack
www.pasternack.com



RF Wideband Converter, 0.5 to 18 GHz

Q Microwave's wideband frequency-agile RF converters, capable of converting RF frequencies between 0.5 and 18 GHz, with 500 MHz of instantaneous bandwidth, for an IF range centered at 1200 MHz (950 to 1450 MHz).

Q Microwave
www.qmicrowave.com/rf-subsystems



ICs for Cost-effective and High Performing Satcom Systems

Qorvo connects the world through space. Silicon beamforming ICs feature a rich digital core that simplify flat panel active antenna designs with options for GaAs Rx gain or Tx driver stages that enable affordable flat panel phased array antennas that meet market requirements, function over full scan volume, and are thermally operational in satcom environments. GaN components for space payload systems span RF functionality and showcase the industry's highest reliability and performance.

Qorvo
www.qorvo.com/go/satcom?utm_source=mwj&utm_medium=print-ad&utm_campaign=june-adsupp

High-Power, Compact (3U) Traveling Wave Tube Amplifiers

The 9103 series is offered as 3U rack-mountable amplifiers, with standard models providing frequency coverage of 2 to 8 GHz and 6.5 to 18 GHz, with output power ratings of 300 Watts CW or 1.5 to 2 kW pulsed. All of Quarterwave's amplifiers feature low noise, high PRF, optional touchscreen interface and are fully customizable. Other models of amplifiers are capable of covering 0.8 to 40 GHz, with an output rating of up to 50 kW.

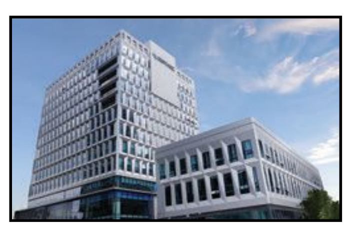
Quarterwave
www.quarterwave.com

RF and Microwave Filters and Integrated Assemblies

VENDORVIEW

Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 67 GHz. From small, lightweight units suitable for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface-mount — their talented engineers can design a unit specifically for your application.

Reactel, Inc.
www.reactel.com



GaN Wideband Amplifier Portfolio

VENDORVIEW

Discover RFHIC's GaN wideband amplifier portfolio, engineered for electronic warfare, jamming and military communication operations. Their advanced portfolio delivers unparalleled performance and reliability in challenging environments. With wideband coverage and high-power output, RFHIC's amplifiers provide superior communication and electronic warfare capabilities. Engineered with GaN technology for efficiency and durability, our solutions ensure mission success in the most demanding scenarios. Experience the power of RFHIC's GaN wideband amplifiers for your critical defense applications.

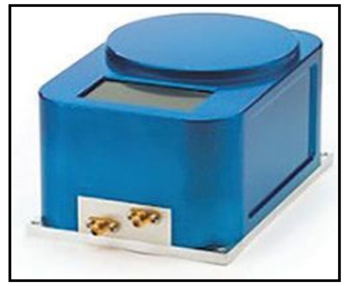
RFHIC
https://rfhic.com

R&S®FSW Signal and Spectrum Analyzer

VENDORVIEW

The R&S®FSW offers dedicated measurement applications for the most critical measurements such as group delay, linearity, gain transfer, noise power ratio (NRP), etc. It also demodulates satellite RF signals of several standards such as DVB-S2X and OneWeb. The R&S®FSW scalable, wide analysis bandwidth (up to 8.3 GHz) meets the increasing demand for wide signal bandwidths.

Rohde & Schwarz
www.rohde-schwarz.com



8 GHz Sapphire Loaded Cavity Oscillator

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