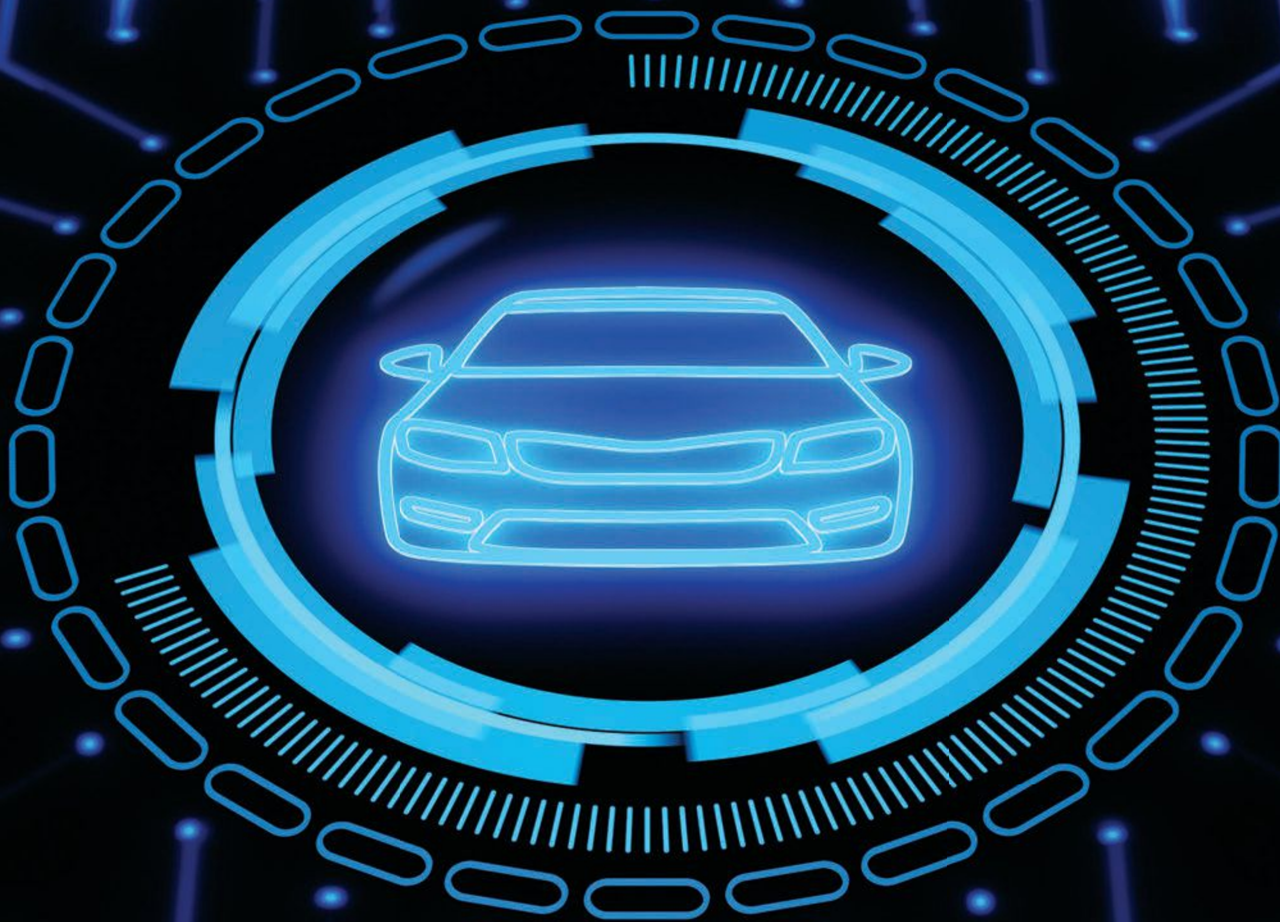
Vol. 68 • No. 9
September 2025

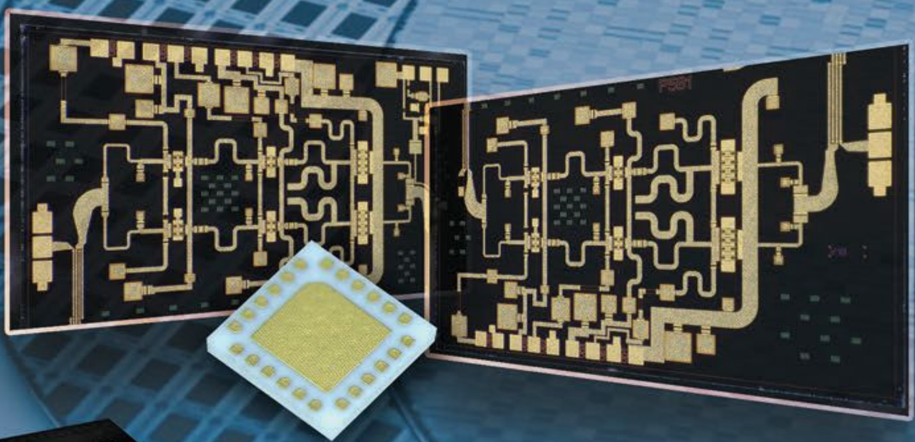
Microwave Journal



horizon house®
Founded in 1958
mwjournal.com

MILLER MMIC

Advancing RFIC Design Through Human-AI collaboration and competition



Miller MMIC is a global provider of RF semiconductor solutions with expertise in GaAs and GaN processes. We offer a diverse range of products tailored to various wireless applications. Our product lineup encompasses a wide array of offerings, including Low Noise Amplifiers, Distributed Amplifiers, Power Amplifiers, Driver Amplifiers, RF Switches, RF PIN Diode Switches, and numerous other voltage- and digitally-controllable RF components.

QFN and SiP (System-In-Package) available

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

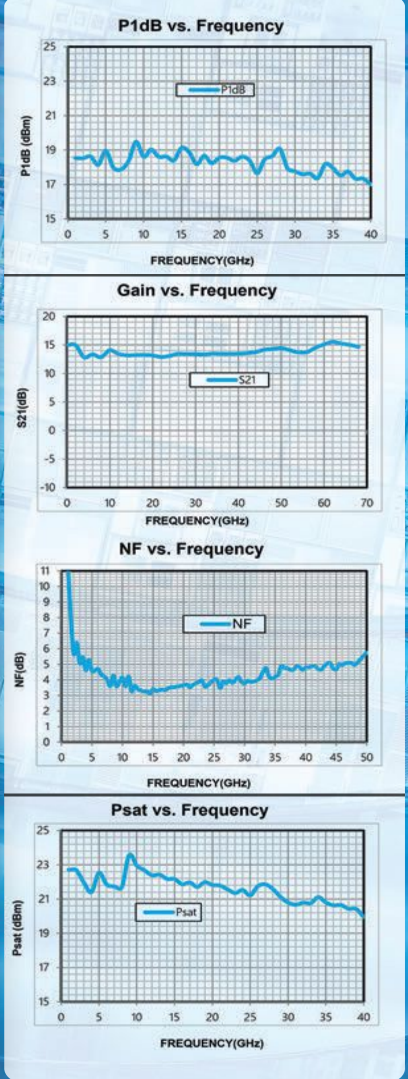
PN	Freq Low (GHz)	Freq High (GHz)	Gain (dB)	NF(dB)	P1dB (dBm)	Voltage (VDC)	Current (mA)	Package
MM3006	2.0	20.0	19.5	2.5	22.0	7.0	130	die
MM3014	6.0	20.0	15.0	-	19.5	5.0	107	die
MM3017T	17.0	43.0	25.0		22.0	5.0	140	die
MM3031T	20.0	43.0	20.0		24.0	5.0	480	die
MM3051	17.0	24.0	25.0	-	25.0	5.0	220	die
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



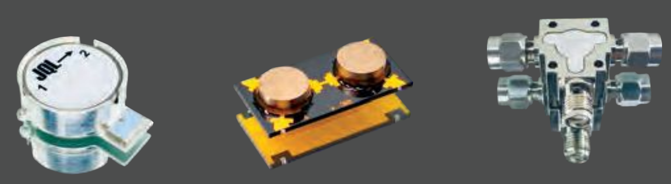
CALL US 1-833-2MILLER(264-5537)
WWW.MILLERMMIC.COM

MILLER MMIC

sales@millermmic.com
support@millermmic.com

ADVANCED TECHNOLOGY & INNOVATIVE SOLUTIONS FOR MISSION CRITICAL APPLICATIONS

DORADO JQL FERROCOM

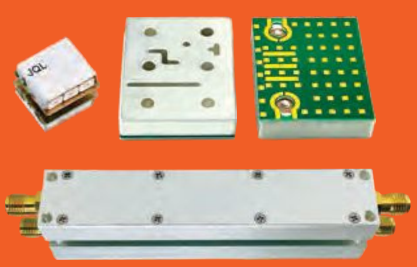


ISOLATORS & CIRCULATORS

SURFACE MOUNT, MICROSTRIP, DROP-IN, COAXIAL & WAVEGUIDES

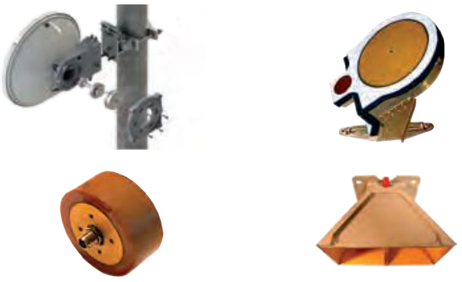
EMS

DESIGN & ASSEMBLY OF ELECTRONIC BOARDS



FILTERS & MULTIPLEXERS

CERAMIC,
CERAMIC WAVEGUIDE,
CAVITY & DISCRETE



ANTENNA

MICROWAVE ANTENNA:
SINGLE & DUAL POLARIZATION, 6 TO 80 GHZ

SPIRAL, HORN & BICONICAL ANTENNA:
500 MHZ TO 40 GHZ

MADE IN USA

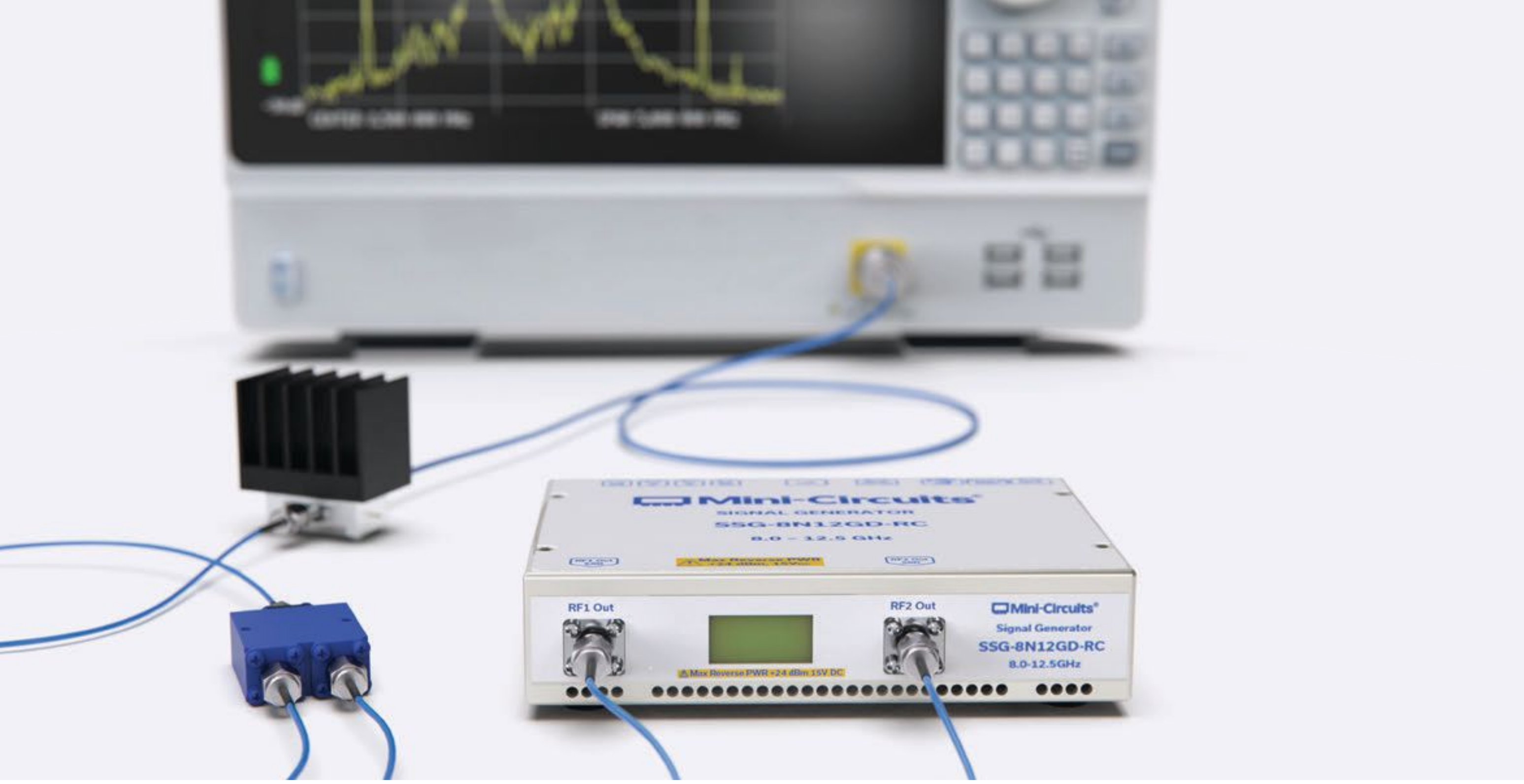
+1-(888) 236-9828 (US)
+1-(630) 246-7833 (INTL)

FOR MORE PRODUCT INFORMATION
GET IN TOUCH WITH US

US Operations
1255 Armour Blvd.,
Mundelein, IL 60060
USA

JQLTECHNOLOGIES.COM
DORADO-INTL.COM
FERROCOMRF.COM
SALES@JQLTECHNOLOGIES.COM

European Operations
Via Palazetti, 22
40068 San Lazzaro di Savena BO
ITALY



SSG SERIES

Signal Generators

Single-Channel & Dual Channel

LEARN MORE

Highlights

- Wide output power range
- Dual outputs with 360° independent phase control
- Pulsed, CW, AM, FM, and chirp modulations
- USB, Ethernet & PoE control interfaces
- Daisy chain port for multi-module control
- Compact housing, 3.6 x 5.1 x 1.2″

Model Number	Frequency	Output Power	# Channels	Release Status
SSG-8N12G-RC	8 to 12.5 GHz	-55 to 23 dBm	1	Production
SSG-8N12GD-RC	8 to 12.5 GHz	-55 to 23 dBm	2	Production
SSG-5N9G-RC	5 to 9 GHz	-55 to 23 dBm	1	Production
SSG-5N9GD-RC	5 to 9 GHz	-55 to 23 dBm	2	Production
SSG-9G-RC	0.01 to 9 GHz	-50 to 15 dBm	1	Q2, 2025
SSG-9GD-RC	0.01 to 9 GHz	-50 to 15 dBm	2	Q2, 2025
SSG-R7N6G-RC	0.7 to 6 GHz	-55 to 23 dBm	1	Q2, 2025
SSG-R7N6GD-RC	0.7 to 6 GHz	-55 to 23 dBm	2	Q3, 2025
SSG-1R5G-RC	0.02 to 1.5 GHz	-55 to 23 dBm	1	Q3, 2025
SSG-1R5GD-RC	0.02 to 1.5 GHz	-55 to 23 dBm	2	Q3, 2025

PWR SERIES

Power Sensors

Turn Your PC into a High-Performance Power Meter

LEARN MORE

- Dynamic range options spanning -60 to +20 dBm
- CW, true RMS, peak and average measurement capability
- Sample rates up to 80 million samples per second
- 50 and 75Ω models
- Software package supports automated measurement with statistical analysis and time domain plots
- No external calibration required

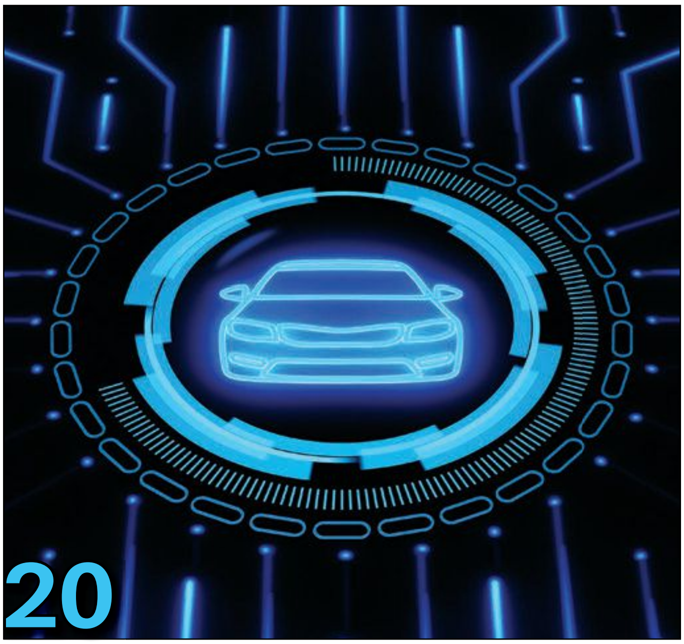
Model #	Control Interface	Measurement Type	Freq. Range (MHz)	Input Power Range (dBm)	Measurement Speed (ms)
PWR-40PW-RC	USB & Ethernet	Peak & Avg.	500-40000	-20 to 20	5.00E-05
PWR-18PWHS-RC	USB & Ethernet	Peak & Avg.	50-18000	-60 to 20	1.30E-05
PWR-18RMS-RC	USB & Ethernet	RMS	50-18000	-60 to 20	0.5
PWR-9PWHS-RC	USB & Ethernet	Peak & Avg.	50-9000	-60 to 20	0.000013
PWR-9RMS-RC	USB & Ethernet	RMS	50-9000	-60 to 20	0.5
PWR-8P-RC	USB & Ethernet	Peak & Avg.	10-8000	-60 to 20	0.002
PWR-8FS	USB	CW	1-8000	-30 to 20	10
PWR-8GHS	USB	CW	1-8000	-30 to 20	30
PWR-8GHS-RC	USB & Ethernet	CW	1-8000	-30 to 20	30
PWR-8PW-RC	USB & Ethernet	Peak & Avg.	10-8000	-60 to 20	0.00005

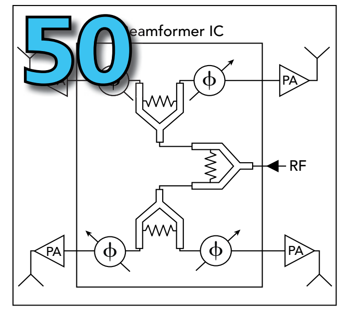
Mini-Circuits®

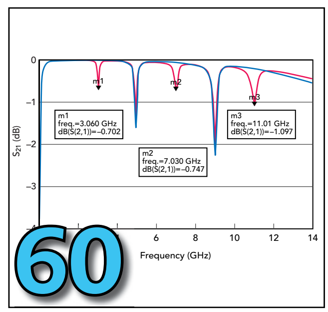

RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
BROADBAND SSPA / EMC BENCHTOP
SOLID STATE POWER AMPLIFIER
0.1-22GHZ
ULTRA BROADBAND SSPA
RFLUPA01M22GA
4W 0.1-22GHZ
RFLUPA0218GB
20W 1-19GHZ
6-18GHZ 800W
CW REMC06G18GG
18-40GHZ 200W
CW REMC18G40GQ
0. 1-6GHZ VHZ,
UHF, L, S, C BAND
RFLUPA02G06GC
100W 2-6GHZ
RFLUPA0706GD
30W 0.7-6GHZ
MADE IN
USA
6-18GHZ C, X, KU BAND
RFLUPA08G11GA
50W 8-11GHZ
RFLUPA0618GD
60W 6-18GHZ
RFLUPA06G12GB
25W 6-12GHZ
18-50GHZ K, KA, V BAND
RFLUPA18G47GC
2W 18-47GHZ
RFLUPA27G34GB
15W 27-34GHZ
RFLUPA47G53GA2
10W 47-53GHZ
RFLUPA27G34GB
30W 18-40GHZ
BENCHTOP RF MICROWAVE SYSTEM POWER AMPLIFIER
REMC02G06GE
600W 2-6GHZ
REMC18G40GC2
40W 18-40GHZ
RAMP30G65GG
8W 30-65GHZ
RAMP06G18GA
10W 6-18GHZ
RAMP00M65GA
DC-65GHZ
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
San Diego, CA, US
Carrollton, TX, US
Ottawa, ONT, Canada
Frankfurt, Germany

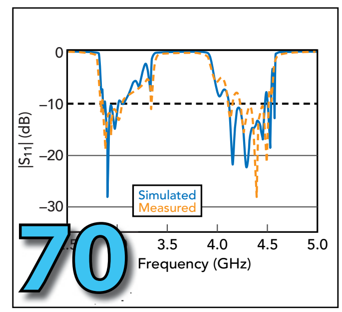
Microwave Journal
CONTENTS

September 2025
Vol. 68 • No. 9
Automotive & Connected Vehicles
mwjournal.com









Time Travel

18 **San Franciscan Transportation: A Living Timeline**
Del Pierson, Microwave Journal

Cover Feature

20 **Enabling Ubiquitous Automotive Connectivity with NTNs**
Jeremy Carpenter, Myca Communications and Chris Keimel, Menlo Micro

Perspective

34 **From Chatbots to Channels: Why Machine-to-Machine AI Is the Key to Monetizing 5G and 6G**
Armando Montalvo, Digital Global Systems (DGS)

Technical Features

50 **Optimizing Satcom FPA Design with Integrated AiP/SiP Chipset**
E. Lourandakis, A. Katsounaros, P. Fioravanti, G. Kontogiannopoulos and C. McMahon, Circuits Integrated Hellas SA

60 **Predicting Resonant Behavior of Surface-Mount Capacitors**
Chris DeMartino and Larry Dunleavy, Modelithics Inc.

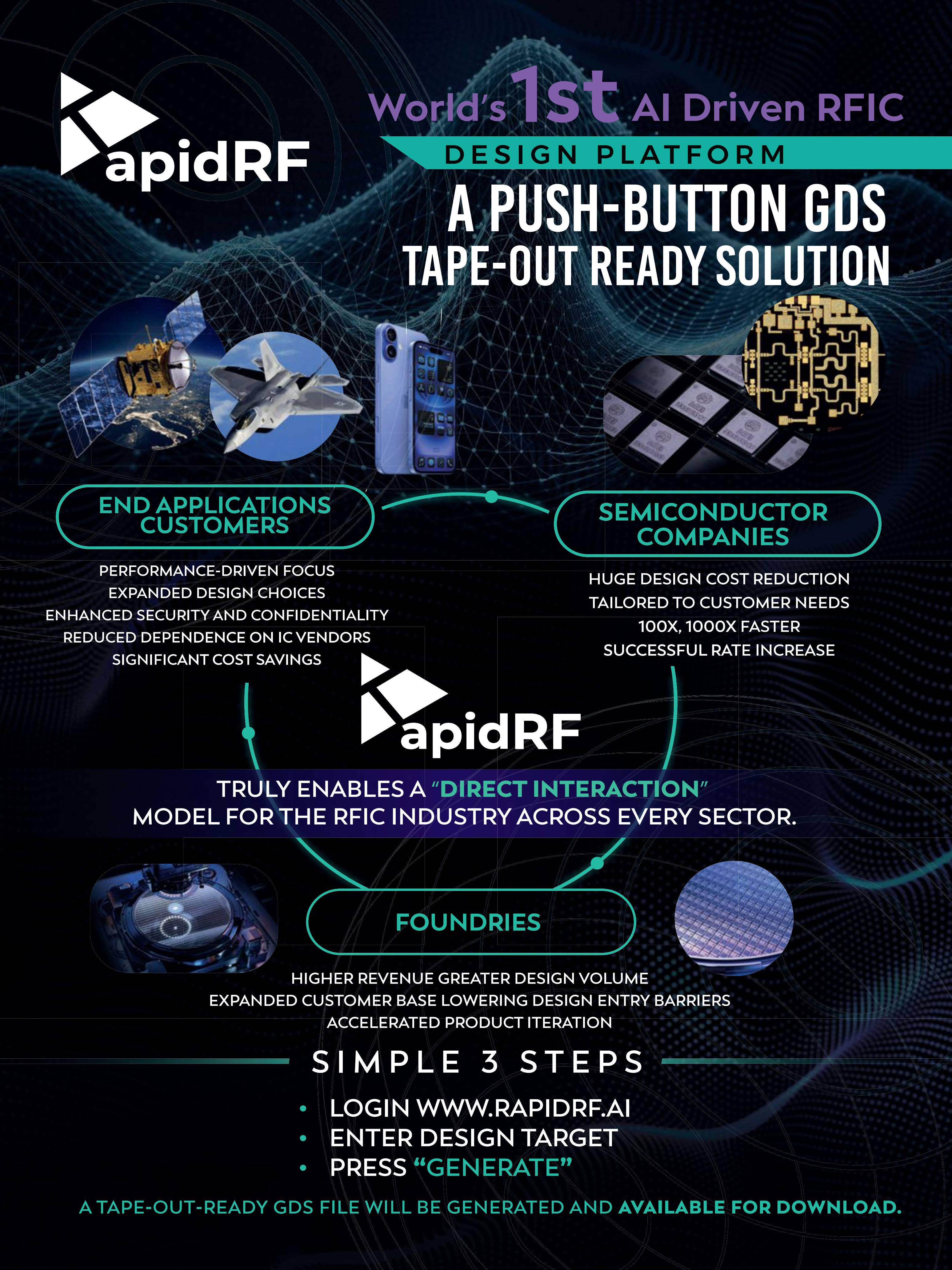
70 **Dual-Band Filtering Horn Antenna Using a Metamaterial**
Xianfeng Tang, Xiangqiang Li, Che Xu, Qingfeng Wang and Jianqiong Zhang, Southwest Jiaotong University

ACCESS NOW!
digital.microwavejournal.com

eXclusive Digital Content ›››

93 **An Inexpensive Tunable S- and X-Band RF Source for Microwave Laboratory**
Manoj Kumar, Mansi Goyal and Gowrish Basavarajappa, Indian Institute of Technology Roorkee

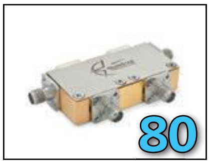
68 YEARS OF PUBLISHING EXCELLENCE

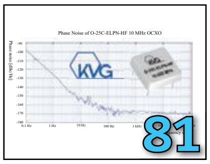

apidRF
World's 1st AI Driven RFIC
DESIGN PLATFORM
A PUSH-BUTTON GDS
TAPE-OUT READY SOLUTION
END APPLICATIONS CUSTOMERS
PERFORMANCE-DRIVEN FOCUS
EXPANDED DESIGN CHOICES
ENHANCED SECURITY AND CONFIDENTIALITY
REDUCED DEPENDENCE ON IC VENDORS
SIGNIFICANT COST SAVINGS
SEMICONDUCTOR COMPANIES
HUGE DESIGN COST REDUCTION
TAILORED TO CUSTOMER NEEDS
100X, 1000X FASTER
SUCCESSFUL RATE INCREASE
apidRF
TRULY ENABLES A "DIRECT INTERACTION"
MODEL FOR THE RFIC INDUSTRY ACROSS EVERY SECTOR.
FOUNDRIES
HIGHER REVENUE GREATER DESIGN VOLUME
EXPANDED CUSTOMER BASE LOWERING DESIGN ENTRY BARRIERS
ACCELERATED PRODUCT ITERATION
SIMPLE 3 STEPS
• LOGIN WWW.RAPIDRF.AI
• ENTER DESIGN TARGET
• PRESS "GENERATE"
A TAPE-OUT-READY GDS FILE WILL BE GENERATED AND AVAILABLE FOR DOWNLOAD.

Microwave Journal

CONTENTS

mwjournal.com





Product Feature

76 **Pocket Alarm for Microwave and Gamma Radiation**
Ultraview

Tech Briefs

80 **Cryogenic Circulators & Isolators for Quantum**
QuinStar Technology, Inc.

81 **Low Phase Noise 10 MHz OCXO**
KVG Quartz Crystal Technology GmbH

Departments

17	Mark Your Calendar	83	New Products
39	Defense News	86	Book End
43	Commercial Market	88	Ad Index
46	Around the Circuit	88	Sales Reps
82	Making Waves	90	Fabs & Labs

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.

POSTMASTER: Send address corrections to Microwave Journal, PO Box 1028, Lowell, MA 01853 or e-mail mwj@e-circ.net.com. Subscription information: (978) 671-0446. This journal is issued without charge upon written request to qualified persons working in the RF & microwave industry. Other subscriptions are: domestic, $130.00 per year, two-year subscriptions, $200.00; foreign, $225.00 per year, two-year subscriptions, $400.00; back issues (if available) and single copies, $20.00 domestic and $30.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

Posted under Canadian international publications mail agreement #PM40612608

STAFF

Group Director: Carl Sheffres
Associate Publisher: Michael Hallman
Media Director: Patrick Hindle
Brand & Content Director: Jennifer DiMarco
Technical Editor: Del Pierson
Associate Technical Editor: Cliff Drubin
Editorial & Media Specialist: Kelley Roche
Associate Editor: Kaitlyn Joyner
Multimedia Staff Editor: Barbara Walsh
Electronic Marketing Manager: Chris Stanfa
Senior Digital Content Specialist: Lauren Tully
Digital Content Specialist: Vincent Carrabino
Director of Production & Distribution: Edward Kiessling
Art Director: Janice Levenson
Graphic Designer: Ann Pierce

EUROPE
Office Manager: Nina Plesu

CORPORATE STAFF
CEO: William M. Bazzy
President: Ivar Bazzy
Vice President: Jared Bazzy

EXECUTIVE EDITORIAL OFFICE
685 Canton Street, Norwood, MA 02062
Tel: (781) 769-9750
FAX: (781) 769-5037
e-mail: mwj@mwjournal.com

EUROPEAN EDITORIAL OFFICE
16 Sussex Street, London SW1V 4RW, England
Tel: Editorial: +44 207 596 8730 Sales: +44 207 596 8740
FAX: +44 207 596 8749

SUBSCRIPTION SERVICES
Send subscription inquiries and address changes to:
Tel: (978) 671-0446
e-mail: mwj@e-circ.net

www.mwjournal.com

Printed in the USA

Microwave Journal ONLINE .COM

eLEARNING CENTER

9/16 Unlock Next-Level mmWave Performance with PolyStrata® Technology
Sponsored by: RFMW/Nuvotonics

9/17 Online Panel: mmWave
Sponsored by: Qorvo, MathWorks, VA Diodes, Marki Microwave

9/30 ANSYS Virtual Workshop Series
Designing with Juliano and Katerina eLearning Series: Antenna Array Design
Sponsored by: ANSYS

WHITE PAPERS

jfw
Mesh Network Testing

TELEDYNE e2v Everywhereyoulook
Non-Uniform Sampling for High-Bandwidth ADCs: Reducing Data Throughput Without Sacrificing Fidelity

Look for additional content from:

REMTEC® maury

Executive Interview

Naveen Yanduru, CEO at Axiro Semiconductor, discusses his background in semiconductors, his leadership path to CEO of Axiro and his plans for Axiro's growth and success.

Follow us @Pathindle @MWJEditor

Join us at the RF and Microwave Community

Become a fan at facebook.com/microwavejournal

RF BINGO!

Have you ever heard someone say, "Well, that wasn't on my 2025 bingo board!" after something unexpected happened? If you haven't, let me introduce you to an event-based bingo board, where we make 25 predictions and check them off as they occur! Unlike regular bingo, this won't be competitive, but rather a fun, casual and interactive way to track some top-level events in the RF/microwave industry.

Check It Out Now
www.microwavejournal.com/blogs


ENGINEERED FOR EXCELLENCE, PROVEN BY PERFORMANCE
3H Comunication Systems offers RF/microwave filter solutions that are innovative, high quality, cost-effective, DC to 50 GHz, with a 5-year warranty.
LC • CERAMIC • CAVITY • PRINTED • MULTIPLEXERS • SWITCHED FILTER BANKS • MULTI-FUNCTION ASSEMBLIES
3H Communication Systems
AS9100 & ISO9001:2015 CERTIFIED
949.529.1583 | sales@3hcomm.com
3HCommunicationSystems.com

KEY APPLICATION

AEC-Q200 Qualified Parts for Automotive Systems

The Industry's Widest Selection

- 100's of qualifiable models
- 30+ years design & manufacturing experience
- Industry-leading quality & engineering support
- Best-in-industry stability of supply
- Multiple active patents

Mini-Circuits®

MARK YOUR CALENDAR

STAY CONNECTED TO COMING EVENTS

SEPTEMBER

21-26
EuMW 2025
Utrecht, The Netherlands
www.eumw.eu

3-6
Global MilSatCom
London, U.K.
www.smgconferences.com/defence/uk/conference/global-milsatcom

OCTOBER

8-10
COMSOL Conference 2025
Boston, Mass.
www.comsol.com/conference

18-20
Space Tech Expo EU
Bremen, Germany
www.spacetechexpo-europe.com

12-15
BCICTS
Scottsdale, Ariz.
https://bcicts.org

27-30
IEEE RFID-TA
Valence, France
https://2025.ieee-rfid-ta.org

NOVEMBER

2-7
AMTA
Tucson, Ariz.
https://2025.amta.org

DECEMBER

2-5
APMC 2025
Jeju, Korea
www.apmc2025.org

6-10
IEDM 2025
San Francisco, Calif.
www.ieee-iedm.org

9-11
AOC 2025
National Harbor, Md.
https://aoc2025.crows.org

ONLINE PANEL SERIES

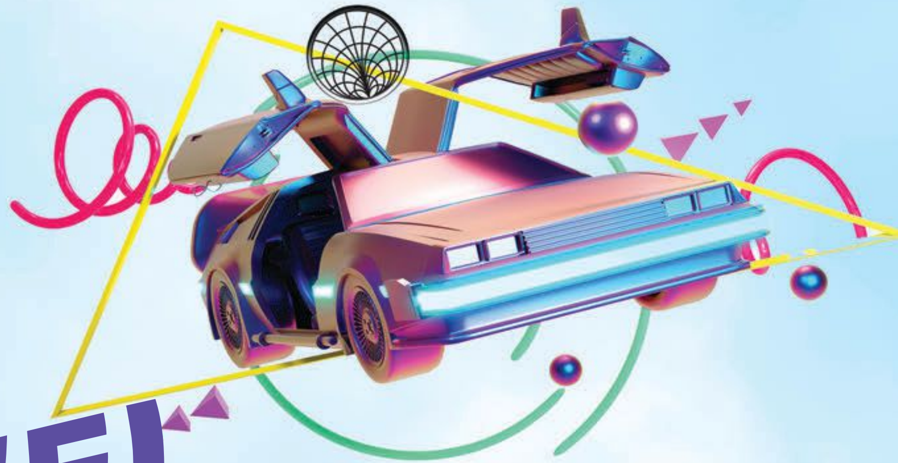
10/8
New Technologies Driving Military Radar

Call for Papers Deadlines

10/1 IEEE IMFW 2026

11/14 German Microwave Conference

FOR DETAILS VISIT MWJOURNAL.COM/EVENTS



TIME TRAVEL

Del Pierson
Microwave Journal, Norwood, Mass.

San Franciscan Transportation: A Living Timeline

Every day in The Golden City, including during IMS2025, an autonomous car crosses paths with a cable car, proudly showing off the two ends of a 150-year transportation timeline. Both revolutionized the city, with cable cars offering a quicker and safer mode of transportation than horse-drawn carriages, and autonomous vehicles providing more cost-effective rides for commuters and tourists alike. They both sparked excitement and controversy, as all new technology does. The cable car remains an impressive application of simple technology, prompting thoughts about the influence of radio on modern transportation. Let's use San Francisco to dive into the timeline and see how radio had an increasingly strong influence on transportation.

Both timelines began in the 19th century, with cable cars first in action in 1873 and the first radio patent approved in 1897. A few years later, in 1908, Henry Ford introduced the Model T, the first mass-produced car. About a decade later, in 1919, the world experienced the first clear transmission of human speech over radio. This late 19th- to early 20th-century period marked the beginning of two separate timelines that needed separate incubation but were destined to converge.

Following about a decade of separate growth, each industry produced a step-change technology. The RF industry was evolving beyond AM, and amateur radio operators invented FM. Meanwhile, the auto industry was just beginning to embrace and implement AM radio as a form of entertainment, marking the first real interaction between the auto and radio industries.

Radio's transformative impact on the auto industry began at the turn of the century, when GPS became commercially available and radio became more than entertainment. Although push-to-start technology was introduced in luxury cars in the 1990s, the early 2000s saw an increase in this RFID technology in everyday commuter cars, and today, this is the standard.

The early 2000s brought Bluetooth technology. Not only could Bluetooth be used for calling, but it paved the road for future music and navigation broadcasting, allowing entertainment personalization and a higher safety rating. As humans were safer and happier in cars, radio engineers worked on the latest technology: autonomous vehicles.

In 2008, LiDAR technology was put to the test: delivering a pizza via a robotic Prius. The pizza delivery was a successful mission, prompting the next milestone: the first fully autonomous ride on public roads. The success of this mission in 2015 led to a significant increase in confidence, accelerating the transition from R&D products to reliable tools for autonomous cars. After five years of rigorous testing and revisions, Waymo introduced a fleet of autonomous cars in Phoenix, and last year, in 2024, they were introduced in San Francisco.

The radio and automobile industries are highly intertwined, but have not always been this way. San Francisco's cable cars are an easy example of transportation before radio. Riding one downtown and seeing the effort and skill needed by the driver makes one appreciate the comforts and safety measures given to us by modern radio applications.

Cover Feature
Invited Paper

Enabling Ubiquitous Automotive Connectivity with NTNs

Jeremy Carpenter
Myca Communications, Hampshire, U.K.

Chris Keimel
Menlo Micro, Irvine, Calif.

The provision of safety, infotainment and convenience services to vehicle occupants via wireless connectivity is a fundamental design consideration for automotive OEMs, not only to meet regulatory obligations, but also as a competitive differentiator in the market. As electric vehicles become more prevalent, consumer purchase priorities are migrating from performance-oriented criteria to the features available to the user, such as remote vehicle access and in-car theatre. This migration is evident particularly as higher levels of autonomous driving are rolled out and the driver becomes less involved in actively driving and more engaged in the consumption of services. ***Figure 1*** shows a visual rendering of automotive connectivity.

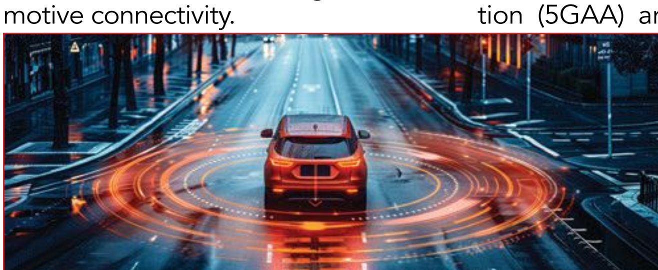


Fig. 1 **Visual rendering of a connected vehicle.**

OEMs therefore wish to ensure seamless user experience for services and applications, most of which will run in the cloud and be enabled remotely, thereby creating a software-defined vehicle. Currently, these services are primarily delivered via terrestrial cellular networks (TNs); however, the automotive industry faces the challenge that significant coverage gaps still exist, particularly in sparsely populated rural areas in countries such as Australia, Canada and the U.S. Furthermore, in instances of TN infrastructure damage due to conflict or environmental disaster, non-terrestrial networks (NTNs) offer communications resilience. OEMs, government organizations and industry bodies such as the 5G Automotive Association (5GAA) are actively exploring the role that NTNs can have in providing complementary wireless connectivity in areas with limited cellular network coverage. Olaf Eckart, partner manager at BMW Group and NTN Work Item lead at the 5GAA, succinctly expresses the automotive industry's goal: "No connection is not an option."

CURRENT SITUATION

The possibility of operational NTNs has emerged due to two fundamental enablers. The first enabler is the number of technical developments and the economies of scale of satellite launchers to deploy the hundreds of low Earth orbiting (LEO) satellites in multiple missions required to form complete constellations. The second enabler is the provision for NTN within the 3rd Generation Partnership Project (3GPP) release 17 (R17) and subsequent releases, which provides a framework for the implementation of NTN and its integration with TNs.

The 5GAA has taken the lead in navigating the path for the automotive industry to adopt NTN. It breaks down the use cases into data rate categories, including narrowband (less than 400 Kbps), such as telephony, road safety and remote services, wideband (less than 10 Mbps), such as fleet monitoring, diagnostics and OTA software up-


The only QPL Certified MECHANICAL SWITCH House!
Quick Turn RF FILTER Prototypes are in our DNA!
Huge Library of PASSIVES with Best in Show HIGH POWER COUPLER offering!
RLC ELECTRONICS L-4241A S/N 2206001
RLC ELECTRONICS HIGH POWER COUPLER
RUGGED & RELIABLE
AGILE & ADAPTIVE
HIGH POWER & VARIETY
RLC
RF MECHANICAL SWITCHES, RF FILTERS & RF PASSIVES
AS9100 CERTIFIED, MADE IN USA
High Performance Precision Microwave Components
Serving the world-wide aerospace & defense community since 1959
Robust Catalog Portfolio - no hassle, quick turn, custom solutions our specialty
RLC Electronics | 83 Radio Circle, Mt. Kisco, NY 10549 | 914-241-1334 | sales@rlcelectronics.com | www.rlcelectronics.com

dates and broadband (more than 10 Mbps), such as video entertainment and gaming.

Currently, satellite constellations such as EchoStar and ViaSat-Inmarsat are operational and providing connectivity to mobile terminals via IoT-NTN. Satellite company Skylo Technologies currently provides direct-to-device satellite connectivity to over 5 million subscribers using specific 3GPP R-17 compliant, commercially available devices, such as Google Pixel 9 and Samsung Galaxy. Furthermore, Starlink, a satellite internet constellation operated by SpaceX, has more than 300 Gen 2 satellites in space and has started to offer direct-to-device NTN service to LTE smartphones in the U.S. in cooperation with T-Mobile. Starlink also delivers broadband wireless to consumer premises, operating in the Ku- and Ka-Bands using proprietary protocols. However, the signal attenuation caused by a car prohibits in-vehicle operation of the devices. Furthermore, although there have been many positive feasibility announcements by OEMs such as BMW and telematic control unit (TCU) vendors such as Harman and MediaTek, there are no available vehicles on the market today that offer NTN connectivity. The non-availability of 3GPP-compliant LEO constellations operating in S-Band around 2 GHz and compatible with existing automotive wireless connectivity remains a significant barrier.

According to the 5GAA, the first mass deployment of such services in automotive can be expected around 2027. This timing is driven by the long lead times for chip development, integration and validation. Initial automotive services are expected to be narrowband use cases, including safety and fleet management, such as emergency calling and stolen vehicle recovery, implemented within the framework of 3GPP R17. Subsequently, wideband NR-NTN use cases, such as teleoperated driving support and internet browsing, are expected in 2029 within 3GPP R17/18. Finally, broadband NR-NTN use cases, such as high-definition video streaming and cloud gaming, are forecast to start after 2030 at the earliest.

When comparing TNs and NTNs, three fundamental technical differences are apparent. Firstly, there is a significant difference in the wireless connection distance. While typical TN cell sizes are hundreds of meters, LEO satellite sizes can be hundreds of kilometers, and GEO satellite sizes can reach up to 36,000 km. Secondly, the entire network is in constant motion. Thirdly, the carrier frequencies are more diverse, covering L-, S-, Ku- and Ka-Bands. The frequency diversity creates link budget and latency challenges, additional signal propagation fading considerations and tracking and bandwidth requirements both on the vehicle and in the satellite. Furthermore, the operation of NTNs has several extra dimensions compared with TNs, including cell reselection, intra-satellite/inter-beam handover, inter-satellite handover, NTN to TN handover and TN to NTN handover. These extra dimensions present additional design requirements for network architects to ensure seamless mobility, especially where individual LEO satellites are only visible from the ground for a matter of minutes, and the vehicle itself could be travelling at 150 km/hr.

Technology developments required to complement the current TN connectivity of vehicles with additional NTN connectivity depend on the specific frequency band and satellite constellation, as well as the data rate and latency requirements of the use case. These break down principally into changes in the vehicle's wireless connectivity (TCU and antennas), the in-vehicle network and enhancements to satellite beamforming.

VEHICLE CONSIDERATIONS

The primary module responsible for external wireless connectivity in vehicles is the TCU, integrating cellular, non-cellular and navigational wireless standards including 4G, 5G, C-V2X and GNSS, as well as connecting to the in-vehicle network to enable services such as telephony, video streaming and autonomous driving. For initial implementations of NTN, the TCU will be required to integrate a 3GPP R17-compliant chipset and will be able to leverage its existing 5G radio bands. For example, Skylo is working with Harman, a Samsung subsidiary, to enable bidirectional emergency messaging in vehicles through Harman's Ready Connect TCU. This allows for emergency alerts and real-time weather updates to be delivered over satellite, which is particularly useful in disaster scenarios if cellular networks fail. However, commercially available NTN-enabled vehicles are still unavailable. Furthermore, support of wideband and broadband use cases requiring Ka- and Ku-Band connectivity will be a step change in radio technology for TCUs and antennas.

The roof-mounted antennas currently used to connect the TCU to the outside world already have the L-Band frequency coverage; however, the radiation pattern is oriented to provide connectivity to terrestrial base stations. Initial studies conducted by the 5GAA indicate that roof-mounted omnidirectional antennas will be sufficient to support S-Band LEO satellites, and this, along with integration of next-generation TCUs, is expected to be the first step in the hardware changes required to implement automotive NTN. However, the more demanding link budget needed to support GEO satellites will require a phased-array antenna to be accommodated within the roof of a vehicle, which presents size, weight and cost challenges for OEMs. This implementation, while possible on a conventional car if an appropriate antenna is developed, is perhaps more practical on a commercial or agricultural vehicle.

In the digital domain, the increased volume of data and more complex processing associated with the adoption of wideband NTN use cases will drive up in-vehicle network bit rates and place increased demands on the digital signal processing executed by domain controllers, zonal controllers and the central processors.

Matthias Kaestner, corporate vice president of Automotive Products Group at semiconductor supplier Microchip Technology Inc., believes there needs to be consolidation in the networking standards used in vehicles to reduce the burden on gateways to translate communications between various protocols

Three Pillars of Future of Automotive Networks

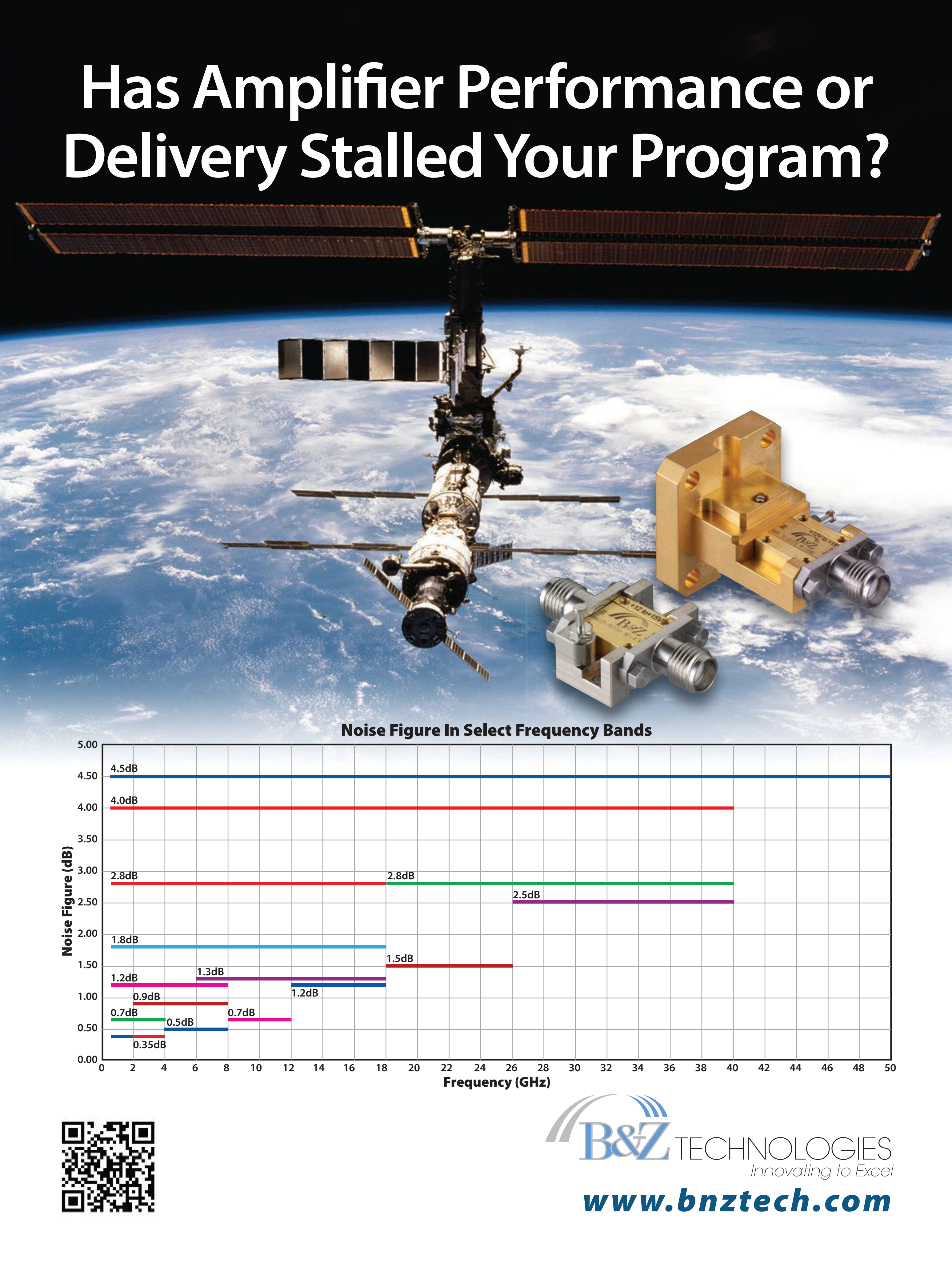
OPEN ALLIANCE	PCI EXPRESS	ASA
Ethernet • Open Standard • Scalable Bandwidth • 10 Mbps to 10 Gbps • Standardized Security • Time-Sensitive Network • Common SW Stack Layers • Service Based – Some/IP	***PCI Express*** • Open Standard • SoC Interconnect • Shared Memory • Highest Speeds • Lowest Latency	***Automotive SerDes Alliance*** • Open Standard • High-Speed Sensor Connectivity • Asymmetric Data Rates • Low-Power • Lower Cost Compared to Symmetric Links

Fig. 2 **The three pillars of automotive networks. Credit: Microchip Technology, Inc.**

and to create more efficient networks. These break down into three fundamental categories, as shown in ***Figure 2***, Ethernet to support scalable and secure digital communications, PCI Express (PCIe) for short-distance, very high speed SoC interconnections and serializer/deserializer (SerDes) for cost and power-efficient asymmetrical communications, such as transmission of video from a camera or for infotainment. Kaestner explains that to enable the automotive industry to move forward with software-defined vehicles, higher levels of autonomous driving and new technologies such as NTN, the existing distributed network architecture is too bulky and inefficient, necessitating the adoption of zonal-oriented architecture, primarily using Ethernet.

As bus speeds increase, already at 5 GHz for standards such as Multi-GigBASE-T1 Ethernet and 64 Gbps for PCIe Gen 6, frequencies are in the microwave domain with all the associated transients, coupling and isolation issues familiar to analog RF designers. As this boundary becomes blurred, the linearity and signal integrity of high speed communications become more prominent, and this also applies to the testing of ICs. ***Figure 3*** shows an illustration of evolving in-vehicle networks as a data center on wheels, showing the shift to centralized computing, zonal architecture and a high speed Ethernet backbone, as bus speeds push into the microwave domain.

The increased number of more complex sensors, such as high-definition video and MIMO radar, required to implement higher levels of autonomous driving and the consumer requirement for data-rich infotainment such as streaming HD video and real-time gaming, are driving up the volume and data rates of in-vehicle networks and the processor power needed in the high performance computer (HPC). This


Has Amplifier Performance or Delivery Stalled Your Program?
Noise Figure In Select Frequency Bands
Noise Figure (dB)
Frequency (GHz)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
4.5dB
4.0dB
2.8dB
2.8dB
2.5dB
1.8dB
1.5dB
1.3dB
1.2dB
1.2dB
0.9dB
0.7dB
0.7dB
0.5dB
0.35dB
B&Z TECHNOLOGIES
Innovating to Excel
www.bnztech.com

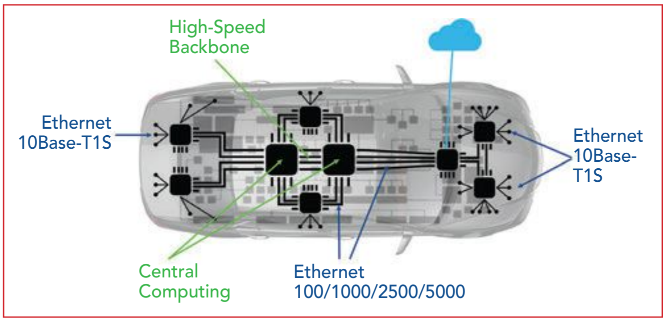


Fig. 3 **Illustration of evolving in-vehicle networks.**

also necessitates more complex and faster testing of the HPC. Current semiconductor-based switches used to test the HPC do not have the necessary linearity, speed or isolation for the next generation of HPC with PCIe Gen6 signals running up to 64 Gbps. Furthermore, they cannot meet the demands of high-precision DC parametric test sequences.

Significant research has been conducted in recent years to develop a new switch category able to address and support the test and measurement of existing and next-generation chip-based products advancing high speed Ethernet, PCIe Gen6 and future generations, as well as SerDes. The multitude of communication platforms and protocols drives switch technology to greater density in smaller form factors and reduces power consumption to minimize heat while expanding frequency coverage, life expectancy and linearity. Today's microelectromechanical systems (MEMS) switches, such as those from Menlo Micro, deliver linearity of IP3 > 90 dBm and insertion loss below 1 dB across a frequency range of DC to 50 GHz. This performance enables test capabilities for accuracy and integrity across even the most demanding IC testing environments. ***Figure 4*** shows Menlo Micro's platform switch, which enables high speed digital testing of in-vehicle integrated circuits, providing the signal integrity, insertion loss and isolation essential for validating current and next-generation in-vehicle systems. ***Figure 5*** shows eye diagram data through the Menlo Micro switch showing 64 Gbps PAM4 performance.

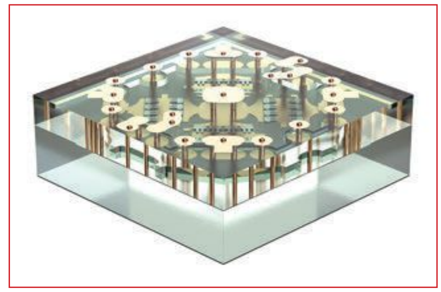
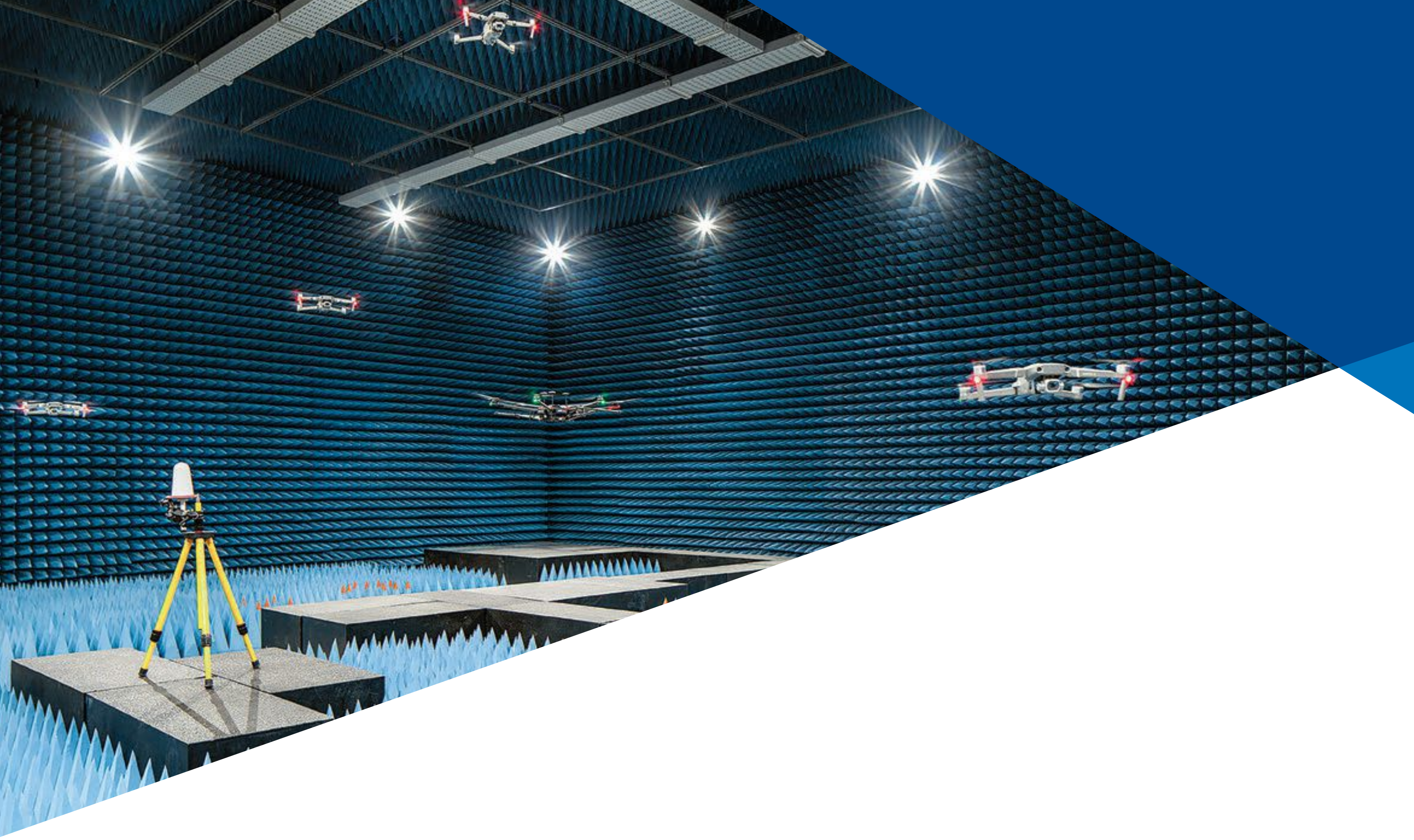


Fig. 4 **Menlo Micro's RF platform switch.**

As Russ Garcia, CEO of Menlo Micro, observes, "Faster data rates and high speed buses are essential for next-generation applications, especially edge AI and automotive connectivity that enable autonomous driving and other critical services to the car. This is increasing the need for ultra-fast linear testing, not previously available, for HPCs, xPUs and other semiconductors



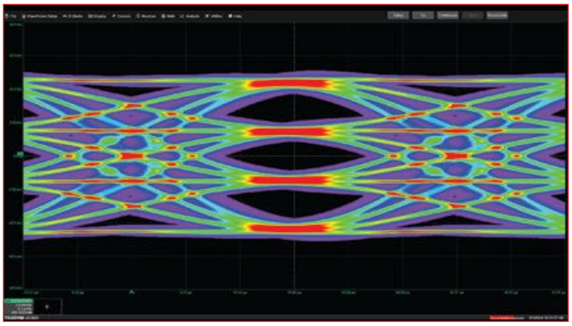


Fig. 5 Eye diagram data through the Menlo Micro switch.

and IoT devices. System-in-package solutions, based on MEMS switch technology, provide the automotive ecosystem with a fully integrated differential loopback testing solution designed for demanding high speed digital applications based on the latest SoC interconnections, SerDes and PCIe Gen 6 standards."

SATELLITE CONSIDERATIONS

Moving from the vehicle to the satellite, one of the primary considerations of satellite design to enable NTN is the wireless link, and this places demand on the beamforming. Agile, efficient and effective beamforming is critical to ensuring the availability and quality of service of the NTN communications link. However, system designers need to reconcile these requirements without burdening the satellite with an impractical demand for size, weight and power. On satellites, switches fulfill the role of routing signals in the payload and control the operation of attenuators and phase shifters that feed phased-array antennas to manage the beamforming. A typical satellite may host hundreds of switches.

Similar performance demands placed on switches by high speed digital test needs align with the needs for chip-scale solutions for high-power miniature wideband beamformers. Beamforming is essential for NTN connectivity, with satellite switches routing signals and controlling phased-array antennas under strict SWaP constraints — mirroring performance demands seen in high speed digital test systems. For example, a beamformer typically consumes up to 25 percent of a satellite's energy budget. By replacing the beamformer's solid-state switches with MEMS switches and taking advantage of the favorable power consumption and insertion loss, the power consumption can be reduced to less than 5 percent of the energy budget without compromising reliability. Furthermore, the frequency range over which the switch can achieve less than 1 dB of insertion loss is from DC to 50 GHz. Linearity issues in the RF domain degrade the spectral purity and give rise to unintentional modulation. Because the linearity of the MEMS switches can be several orders of magnitude superior to typical solid-state switches, the system can operate at higher powers without significant distortion, thus improving energy efficiency and the quality of the service delivered over the system to end users. It forces a rethink of the multi-band approach to payload design towards unified

RF-LAMBDA

MADE IN USA

THE LEADER OF RF BROADBAND SOLUTIONS

EMC Broadband RF Power Amplifier

High Power Solid State

HUNDREDS IN STOCK

FAST SHIPPING

FREQUENCY UP TO 90GHZ

POWER UP TO 2KW CW

BENCHTOP AND RACKMOUNT

REMC06G18GG 6-18GHZ 400W

- AUTOMATIC BUILT IN SELF CALIBRATION AND BIAS ADJUSTMENT.
- OVER TEMPERATURE, CURRENT, INPUT POWER PROTECTION.
- VSWR MEASUREMENT AND OPEN CIRCUIT PROTECTION.
- USER FRIENDLY CONTROL INTERFACE.
- REMOTE ETHERNET CONTROL AND FIRMWARE UPDATE.
- HIGH POWER EFFICIENCY AND LIGHTWEIGHT.

RAMP42G47GA 42-47GHZ 8W

REMC02G06GE 2-6GHZ 500W

REMC18G40GQ 18-40GHZ 200W CW

RAMP18G40GB-U 18-40G 20W

RAMP05M80GC 0.5-80GHZ

ultra-broadband satellite communication systems as well as beamformer solutions on future vehicle platforms. ***Figure 6*** shows an artistic rendering of satellite-to-car connectivity.

Historically, system engineers have had to make difficult switch selection decisions, trading off specifications between electromechanical relays (EMRs) and solid-state switches, and accepting the associated compromises. EMRs offer lower insertion loss and higher power handling, whereas solid-state switches can cover higher frequency ranges and have longer life expectancy. Semiconductors, as the name implies, are inherently lossy, which impacts the efficiency and energy budget of the host device, consuming power and generating heat, even when in the off state. The compromises inherent in these two options create a bottleneck restricting the migration to the energy-efficient, compact and low-cost satellites required for NTN constellations.

Fig. 6 **A rendering of NTN automotive connectivity.**

TEST AND MEASUREMENT

For NTN chipset developers, TCU vendors, OEMs and the satellite supplier, a key challenge is how to ensure the functionality of modules and the end-to-end system without an available operational network to verify performance. Test and measurement vendors such as Rohde & Schwarz fulfill a critical role by providing test equipment able to emulate NTNs in the lab. A radio communications tester such as the Rohde & Schwarz CMX500, shown in ***Figure 7***, can emulate the end-to-end network, including the radio channel and the core, to provide comprehensive handover, including TN to NTN, NTN to TN, intra- and inter-satellite, as well as interoperability testing of modules and devices from different vendors. The physical distance from the vehicle to the satellite causes a very long delay, so verifying time synchronization is another crucial test performed by the radio communications tester.

Holger Rosier, technology manager at Rohde & Schwarz, states, "NTN is the emerging dimension in automotive connectivity, promising ubiquitous vehicle connectivity. How well the ecosystem can address the challenges of latency, new frequency bands, the Doppler effect, fading and integration with terrestrial networks will determine the speed at which NTN is adopted. Validation of antenna design, transceiver performance, handover and protocol conformance are essential to ensuring correct operation of NTN and the applications it will support."

Fig. 7 **The Rohde & Schwarz CMX500.**

The movement of LEO satellites causes a significant Doppler shift, so a tester is required to ensure correct frequency synchronization between the satellite and the device it serves. NTN also presents specific test challenges to verify the propagation of the signal from ground to satellite and vice versa. Here, new fading profiles such as the combination of atmospheric and terrestrial fading and the emulation of weather-specific effects can be integrated into the test setup, usually provided by the radio communication tester. The addition of a GNSS simulator, such as the Rohde & Schwarz SMBV100B, to the test setup enables GNSS measurements, including constellation-specific satellite ephemerals.

Key test categories include RF, protocol, application, carrier acceptance and interoperability testing. These tests are conducted by accredited test laboratories within the industry, adhering to standards set by GCF and PTCRB for certification as well as regulatory requirements. Before an NTN-enabled device is released to the market, conformance testing is required to ensure compliance with specific technical standards, such as those set by 3GPP, ETSI, FCC and ITU.

CONCLUSION

Vehicle OEMs have the vision of the always-connected vehicle, particularly with the migration to high levels of autonomous driving and the realization of software-defined vehicles. However, significant limitations still exist in the coverage of TNs, so the potential for NTNs to offer a complementary method of providing wireless connectivity to vehicles is being actively examined. Key market enablers are the commoditization of satellite launch technology and the integration of NTN into 3GPP, while key technological enablers are the development of appropriate vehicle antennas, upgrade of TCUs and in-vehicle networks and the enhancement of satellite beamforming enabled by advanced MEMS switches.

As HPC data rates increase to gigahertz, the boundary between the digital domain and the RF domain becomes blurred, bringing a requirement for high linearity, ultra-fast IC testing, which the application of MEMS switches can address. Network emulation provided by test equipment vendors is critical to allow the development of NTN components, modules and systems without available operational NTNs. Although there is considerable uncertainty in the roadmap for narrowband, wideband and broadband use cases, there is a critical role for NTNs to provide continuity of automotive connectivity. ■

ACKNOWLEDGMENT

We would like to acknowledge Menlo Microsystems, Microchip, BMW Group, Rohde & Schwarz and the 5G Automotive Association for their valuable contributions to this article.

References:

1. "Maximising the Benefit of Future Satellite Communications for Automotive," *5GAA*, September 2024.
2. "5G NTN Takes Flight: Technical Overview of 5G Non-terrestrial Networks," Reiner Stuhlfauth, Rohde & Schwarz, PD 3683.7383.52, Version 01.00, July 2022.
3. "Vehicle Features Supported by Wireless Connectivity," Rohde & Schwarz, PD 3608.9518.82, V01.02, September 2023.
4. O. Eckart, "Satellite-based Communication: Benefits and Requirements from the Perspective of the Automotive and Transport Industry," *BMW Group*, July 2025.
5. P. Hansen, "Update on Networks," *The Hansen Report*, July 2024.

From Chatbots to Channels: Why Machine-to-Machine AI Is the Key to Monetizing 5G and 6G

Armando Montalvo
Digital Global Systems (DGS), Tysons, Va.

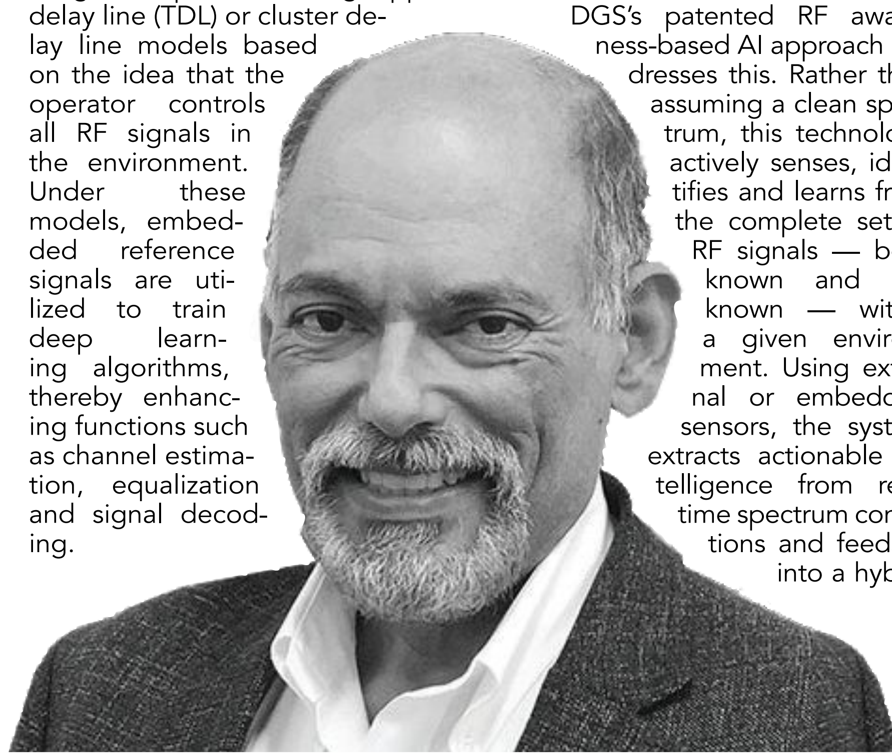
As 5G networks mature and 6G appears on the horizon, mobile network operators (MNOs) are understandably eager to extract new value from their infrastructure investments. However, in the pursuit of monetization, too many are chasing the wrong kind of artificial intelligence (AI). Most of today's high-profile telco AI initiatives focus on cost-cutting, replacing customer service representatives with chatbots powered by large language models (LLMs). While such tools are certainly flashy, their impact is primarily confined to the billing department, not the network.

At Digital Global Systems (DGS), we see a far more transformative opportunity — one that not only reduces operating expenses but also drives new service revenues. It is time to shift the conversation from human-to-machine interfaces to machine-to-machine intelligence, where AI enables next-generation applications through ultra-reliable low-latency communication (URLLC) and dynamic spectrum optimization. The future of AI in telecom is not in replacing call center agents — it is in re-architecting how the radio access network (RAN) adapts, performs and creates value at the physical layer.

REAL-TIME INTELLIGENCE FOR THE PHYSICAL LAYER

Modern wireless networks are increasingly software-defined and virtualized. This architectural flexibility opens the door to embedding AI directly into the signal processing chain, especially within the L1 (physical layer) and L2 layers of the RAN stack. These are not chatbot domains. They are mission-critical environments where microsecond decisions significantly impact the viability of applications such as autonomous vehicles, smart factories and augmented reality.

Most AI efforts in this space have relied on traditional channel modeling assumptions — using tapped delay line (TDL) or cluster delay line models based on the idea that the operator controls all RF signals in the environment. Under these models, embedded reference signals are utilized to train deep learning algorithms, thereby enhancing functions such as channel estimation, equalization and signal decoding.



However, in today's congested, contested and increasingly shared spectrum environments, those assumptions break down. RF environments now include a diverse mix of unmanaged signals — from Wi-Fi and CBRS to military comms and private 5G — that introduce significant uncertainty and noise. Deep learning models trained in sanitized environments often struggle to generalize, resulting in degraded performance when it matters most.

THE FOUNDATION OF REVENUE-GENERATING AI

DGS's patented RF awareness-based AI approach addresses this. Rather than assuming a clean spectrum, this technology actively senses, identifies and learns from the complete set of RF signals — both known and unknown — within a given environment. Using external or embedded sensors, the system extracts actionable intelligence from real-time spectrum conditions and feeds it into a hybrid

machine learning framework that includes support vector machines, convolutional neural networks and domain-specific knowledge models.

The result is not just smarter RAN operations, it's monetizable performance. DGS's methodology enables MNOs to meet the stringent requirements of URLLC applications and dynamic spectrum sharing, unlocking new service opportunities across verticals. We are talking about deterministic latency in manufacturing automation, guaranteed throughput for drone traffic management and seamless handovers for immersive AR/VR experiences in stadiums and smart cities.

MONETIZATION THROUGH PERFORMANCE GUARANTEES

For example, LLMs might help a telco save a few dollars per customer on support calls. RF-aware machine-to-machineAI, by contrast, enables entirely new service classes that command premium pricing. Consider these examples:

- **Smart factories** require wireless networks that guarantee sub-10 ms latency with 99.999 percent reliability. RF-aware AI can continuously monitor and mitigate interference, ensuring that these SLAs are met, even in shared spectrum bands like the 3.5 GHz CBRS. That translates into revenue from industrial contracts, not just cost avoidance.
- **Teleoperated robotics** — from logistics to remote surgery — demands low jitter and high availability. Traditional AI models trained in lab environments cannot respond quickly enough to the unpredictable spectrum dynamics of real-world deployments. Machine-to-machineAI adapts in real time, optimizing transmission paths and prioritizing critical data flows.
- **Public safety and defense communications** benefit from DGS's patented ability to detect and classify non-cooperative signals, including interference and potential threats, in near real time. That kind of capability is not just valuable, it is billable, especially in multi-agency or defense-contracted scenarios.

In these use cases, the value is not in reducing headcount but in creating performance guarantees that were previously impossible to meet. Those guarantees are the foundation of differentiated services and premium pricing.

FROM STATIC MODELS TO LIVE LEARNING MACHINES

Conventional channel modeling techniques fail in contested environments because they treat unknown signals as unstructured noise. DGS's RF-aware system rejects this oversimplification. Instead, we utilize inferential signal processing and hybrid AI models to identify patterns in co-channel activity, infer potential interference sources and dynamically reallocate spectrum usage in real time.

This approach draws on a decade of patented innovation in:

- Signal detection and channelization by inference processing
- Drone signal recognition via pattern classification
- Blind signal classification using constant spectral component analysis
- Prediction of interference patterns to inform RAN configuration
- Dynamic optimization of RF environment sampling.

Critically, this intelligence can be embedded into the software functions of the radio unit, distributed unit (DU) or centralized unit (CU), or integrated into the RAN intelligent controller (RIC) or multi-access edge computing layers. The result is a self-optimizing network, not just in name, but in function. It is a network that does not rely on a central cloud to make decisions, but one that responds in the moment, at the edge, where performance makes or breaks the service.

REAL MACHINE LEARNING FOR REAL MACHINES

One of the most significant differences between our approach and the prevailing AI trends in telecom is this: We build systems for machines talking to machines, not machines impersonating humans.

LLMs are good at parsing language but lack the timing, determinism and explainability needed to operate in real-time, mission-critical environments. DGS's RF-aware machine learning models are designed with physical layer constraints in mind. They prioritize computational efficiency, operate under low size, weight and power conditions and adapt to RF changes in milliseconds, not seconds.

Furthermore, our AI doesn't just predict — it acts. By feeding learned environmental data back into the scheduling, resource allocation and modulation decisions of the RAN, we create a closed-loop optimization cycle. This is what true "machine intelligence" looks like: sensing, interpreting and executing within a dynamic physical system.

4G TO 6G: DEPLOYABLE NOW, SCALABLE TOMORROW

DGS's RF awareness-based AI can be deployed today in existing 4G LTE and 5G O-RAN architectures using external sensors or software updates to existing RAN components. As network operators transition to vRAN and disaggregated architectures, our models become valuable, enabling performance enhancements across DU, CU and RIC functions without requiring new hardware.

At the same time, DGS's work is laying the groundwork for 6G, where native support for shared spectrum, spectrum sensing and dynamic allocation will be critical. By developing and proving out these capabilities now, we ensure that MNOs can lead, not lag, when the 6G wave arrives.

CONCLUSION: THE REAL AI OPPORTUNITY IS IN THE AIR

The telecom industry is at an inflection point. It can continue to chase marginal gains from LLMs that reduce customer service costs, or it can embrace a more fundamental shift — one that enables new business models, new service guarantees and new revenue streams powered by M2M AI.

DGS RF awareness-based AI transforms the network from a static delivery mechanism into an intelligent, adaptive service platform. It is time to move beyond the hype and focus on where AI truly creates value: in the airwaves, optimizing the physical layer and enabling the next generation of reliable, low-latency wireless services. ■

Cliff Drubin, Associate Technical Editor

XQ-67A Demos Autonomy and Datalink Interoperability During High Desert Flight Test

AFRL's XQ-67A, a second-generation Autonomous Collaborative Platform (ACP), successfully demonstrated integration of government reference autonomy during a recent flight test in the California High Desert.

The flight showcased the integration of government-owned autonomy on the XQ-67A, paired with active tactical datalink communications, to enable dynamic mission execution and real-time coordination with both crewed and uncrewed systems. The event marked a major milestone in advancing scalable, modular autonomy and seamless interoperable crewed-uncrewed teaming (C/U-T).

"This successful test underscores the Defense Department's commitment to fielding autonomous systems that can integrate into joint operations using existing tactical networks," said Mike Atwood, vice president of Advanced Programs for General Atomics Aeronautical Systems, Inc. (GA-ASI). "Government-owned autonomy on the XQ-67A is a concrete step toward deployable, combat-relevant autonomy that works with and alongside crewed platforms."

GA-ASI-Jets (Source: General Atomics Aeronautical Systems)

During the flight, the XQ-67A executed test points to validate the integration of mission systems on the aircraft, including autonomy, mission computing, networking, power and thermal management and datalinks. Through a tactical datalink, the aircraft received real-time updates and situational data, giving it the ability to coordinate seamlessly with crewed aircraft and other autonomous systems in the future.

The XQ-67A platform, built by GA-ASI under contract with AFRL, plays a critical role in exploring the platform sharing approach to achieving scalable affordable mass. Its performance in this flight test advances the Air Force's vision for an integrated autonomous force that can support and augment current and future crewed platforms.

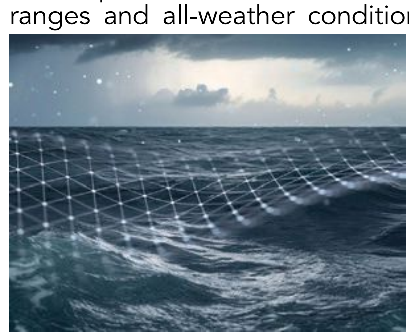
The successful demonstration in the high desert highlights the promise of combining government-owned autonomy with proven tactical communications infrastructure. This approach accelerates technology transition and supports AFRL learning objectives regarding the integration of mission systems within the context of the highly relevant XQ-67A testbed.

AI-Powered Technology Revolutionizes Maritime Surveillance

Lockheed Martin has achieved a breakthrough in AI and airborne surveillance with the potential to detect and track maritime targets with unprecedented accuracy. In a recent flight test on the United States' west coast, the Lockheed Martin engineering teams successfully demonstrated technology to automatically recognize targets using an AI-powered synthetic aperture radar (SAR) with embedded sensor control autonomy.

SAR is the gold standard technology for imaging targets at sea, like warships, but traditionally requires manual interpretation of images. AI unlocks the full potential of SAR for enhanced object detection with faster, more accurate and automated image analysis. By leveraging AI-powered SAR target recognition, warfighters will be able to quickly differentiate a combatant vs. civilian vessel without the need for manual analysis.

"This is a major leap for harnessing AI to help enhance situational awareness and decision-making capabilities, with unparalleled threat identification across extended ranges and all-weather conditions," said John Clark, senior vice president of technology and strategic innovation at Lockheed Martin. "We are committed to continuing to advance this capability, including data integration from multiple sensors, to create more accurate insights and help the warfighter make informed decisions in the maritime battle space."



SAR Visualization (Source: Lockheed Martin)

This groundbreaking achievement, developed by the Lockheed Martin AI Center (LAIC), Skunk Works®, and Rotary Mission Systems (RMS) team, is a significant advancement of situational awareness in maritime target recognition.

In the demonstration, the SAR automatic target recognition (ATR) capability, enabled by machine learning operations (MLOps) tools for rapid retraining, successfully classified targets of interest in near real-time. SAR ATR was coupled with autonomous sensor control, which re-tasked the radar in real time based on target detections. This capability was deployed on low Size, Weight, and Power (SWaP) hardware in the field and rapid edge processing, without the need for large cloud compute or ground stations.

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

Texas, DARPA to Establish Testbed to Use Autonomy to Fight Wildfires

DARPA is partnering with the Texas A&M University System's George H.W. Bush Combat Development Complex (BCDC) to advance capabilities for autonomous wildland firefighting. The initiative will tap key technology developed under the Aircrew Labor In-cockpit Automation System (ALIAS) program, which has successfully designed, developed and demonstrated the ability to retrofit existing aircraft to enable fully autonomous flight.

"Working together with Texas, we have an opportunity to use autonomous helicopters to completely change the conversation around wildfires from containing them to extinguishing them," said Stuart Young, DARPA program manager for ALIAS.

In its recently passed two-year budget (FY26-27), the Texas Legislature committed $59.8 million to BCDC to advance the goal of cost effectively saving more lives and property during wildland fires. "We see it every year. Texas gets more than its share of disasters, and we at the Texas A&M System promise to continue our work to leverage the latest technologies and innovative ideas to make our great state as safe as possible," said Glenn Hegar, chancellor of the Texas A&M University System.

DARPA's Commercial Strategy Office, which works to transition breakthrough technologies to market for both commercial and defense applications, has facilitated resources to support software application development, high-fidelity simulation environments and testbed integration for using ALIAS to fight wildfires.

"Partnering on a testbed at the state level provides an unparalleled opportunity to rapidly field new technology and ensure outsized impact to Americans both in and out of uniform," said DARPA Director Stephen Winchell. "The solutions achieved through collaboration with the BCDC support both economic and national security while demonstrating complex fully autonomous capabilities in challenging real-world conditions."

The ALIAS automation toolkit, MATRIX, was built and is maintained by Sikorsky as the lead performer on the ALIAS program. In the past year, Sikorsky led proof-of-concept demonstrations of autonomous fire suppression in California and Connecticut using MATRIX and a commercially developed wildfire software solution.

"ALIAS helps us with a manpower problem, since it addresses and augments the pilot availability issues through the optional autonomy. It helps us with safety, because we can fly in more dangerous conditions. It helps us with throughput, because we can get more water on fires by fighting them 24/7, including when they're most vulnerable; the sensors can see through smoke and darkness, so we can fight fires at night," said Young.

UP TO 110 GHz

High-Frequency Solutions

Amplifiers & Modules for mmWave Applications

WAVEGUIDE AMPLIFIERS

- Bandwidths from 40 to 110 GHz
- Low noise, high gain & medium power options
- WR10, WR12, WR15 & WR15 interfaces
- Ideal for TRP & TIS over-the-air testing

CONNECTORIZED AMPLIFIERS

- Bandwidths from 50 kHz to 95 GHz
- 2.92, 2.4, 1.85 & 1.0mm connector options
- Gain up to 45 dB
- NF as low as 1.7 dB
- Power up to 1W

VARIABLE GAIN AMPLIFIERS

- Bandwidths from 18 to 54 GHz
- Gain up to 50 dB
- Calibrated 17 dB attenuation with analog or TTL control
- PSAT up to +1W
- Interactive GUI with telemetry

Mini-Circuits®

Cliff Drubin, Associate Technical Editor

Nearly US$1 B Dollars Flow into Automotive Radar Startups

According to IDTechEx's latest report, "Automotive Radar Market 2025-2045: Robotaxis & Autonomous Cars," newly established radar startups worldwide have raised nearly US$1.2 B over the past 12 years; approximately US$980 M of which is predominantly directed toward the automotive sector. Through more than 40 funding rounds, these companies have driven the implementation and advancement of radar technologies in key areas such as autonomous driving and advanced driver assistance systems (ADAS). The funding peak occurred in 2021 and 2022, propelled by the surge in robotaxis and Level 4/5 autonomous driving. While there has been a modest uptick in 2024, investment levels are unlikely to reach the previous highs.

This influx of capital can be attributed to three key drivers. First, the automotive industry's growing demand for safety and robust environmental perception highlights radar's all-weather, high-reliability detection capabilities. Second, the rise of electric vehicles and robotaxis has opened up broader application scenarios for radar. Finally, emerging technologies such as 4D imaging radar, high-resolution radar and radar-on-chip solutions continue to improve sensing accuracy and data fusion, maintaining long-term investor confidence in the radar market.

> Radar in ADAS systems has expanded dramatically in the last two decades.

During this funding wave, companies like Arbe, Uhnder and Mobileye have taken the lead by launching multiple high performance radar products. These solutions use innovations such as high-resolution sensing and digital beamforming (DBF), leading to notable gains in detection accuracy and processing speed. Concurrently, advancements in semiconductor manufacturing have decreased production costs, enabling OEMs to integrate radar systems into premium models and across a broader range of mass-market vehicles.

Although the 2021-2022 funding boom has cooled, 2024 remains a critical year for potential investor activities. IDTechEx projects that radar technology will move into a "practical development" phase, wherein mass-production orders and more mature autonomous driving business models catalyze the next growth cycle. Industry players must address challenges in three key areas: technology innovation — such as 4D imaging, ultra-wideband and multi-functional integration; cost control — ensuring high performance while continuously reducing costs; and commercial adoption — forming close partnerships with Tier 1 suppliers and OEMs to facilitate large-scale deployment.

Previously, radar's limited vertical resolution often led to misdetections in scenarios like overpasses. When a vehicle is parked under a bridge, conventional 3D radars might merge the overpass structure with the car's roof into a single detection, causing the system to misjudge clearance and overlook collision risks. As the industry shifts toward higher-level autonomy, vehicles must accurately distinguish bridges, other vehicles and pedestrians — potentially hundreds of meters ahead — and respond safely.

To address these challenges, startups and Tier 1 suppliers are expediting the development of 4D imaging radar. Compared to 3D radar, 4D imaging radar offers more granular object data across horizontal, vertical, depth and velocity dimensions. Leveraging multi-antenna arrays and digital beamforming (DBF), 4D radars significantly enhance spatial resolution and object classification, reducing false alarms and missed detections in complex traffic conditions.

IDTechEx's review of automaker brochures over the past 25 years shows that the use of radar in ADAS systems has expanded dramatically in the last two decades. A decade ago, radar-enabled features like adaptive cruise control (ACC) were limited to luxury models. Today, with decreasing sensor costs and tighter safety requirements from organizations such as NCAP, functionalities like automatic emergency braking (AEB) and blind spot detection (BSD) have become increasingly prevalent. In 2023, 71 percent of newly sold vehicles are equipped with AEB — a 16 percentage point increase over 2020 — while ACC adoption reached 55 percent, up from 52 percent in 2022 and 40 percent in 2020. BSD usage has also climbed from 28 percent in 2020 to 40 percent in 2023. These figures reflect consumers' growing focus on safety, and efforts by OEMs and suppliers to bring more advanced radar sensing solutions to a broader range of vehicle segments.

Of particular note is BSD's trajectory toward 360-degree monitoring, which requires multiple short-range radars placed around the vehicle and is complemented by forward radar to enable safety features such as Pedestrian Automatic Emergency Braking in more complex scenarios. IDTechEx anticipates strong growth for radar-driven ADAS and autonomous functions in the coming years, offering substantial opportunities across the automotive value chain.

The IDTechEx report, "Automotive Radar Market 2025-2045: Robotaxis & Autonomous Cars," provides a comprehensive analysis of the global automotive radar landscape, covering radars for autonomous cars and robotaxis, long-range radar, short-range radar, radar cocooning, 4D imaging radar, high-channel-count radars, semiconductor technologies for radar, waveguide antenna and detailed market forecasts.

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

Global NTN and D2C Market Revenue to Grow as Tech Giants, Satellite Operators and MNOs Transform Global Connectivity

The Non-Terrestrial Networks (NTN) and Direct-to-Cellular (D2C) market is entering a transformative phase in 2025, driven by strategic advancements from Apple, SpaceX, AST SpaceMobile, satellite operators, and mobile network operators (MNOs). ABI Research forecasts that the NTN-D2C segment will potentially reach US$25 billion in service revenues by 2035, with over 200 million connections.

"The D2C market is experiencing a seismic transformation, with industry leaders such as Apple, SpaceX, and AST SpaceMobile driving satellite-enabled connectivity into the consumer mainstream," explains Victor Xu, Industry Analyst at ABI Research. "Apple's strategic control of 85 percent of Globalstar's network capacity is a groundbreaking move, enabling the company to deliver reliable satellite services while laying the foundation for more advanced satellite-based applications across its ecosystem of devices."

Apple's partnership with Globalstar, starting with a US$450 M investment in 2022 and an additional US$1.5 B in 2024, has established Apple as a leader in consumer satellite services. Key features include Emergency SOS, Roadside Assistance, Messages and Find My App for off-grid sharing. Looking ahead, Apple may introduce tiered satellite messaging and AirTag tracking subscriptions, potentially bundled with Apple One. This partnership aims to extend SatCom capabilities to iPads, Apple Watches and MacBooks, expanding satellite technology's reach into outdoor and rugged device markets. This strategic move could also lead to new ruggedized devices designed for extreme environments, aligning with Apple's ecosystem-driven strategy and positioning the company in emerging markets for satellite-enabled consumer devices.

SpaceX has also emerged as a key player in the D2C space. It deployed over 330 D2C satellites in 2024, using eNodeB modems to enable direct LTE connectivity with smartphones. With partnerships across major MNOs, including T-Mobile, KDDI, Optus, Kyivstar, and Rogers, SpaceX is leading in satellite-to-phone connectivity globally.

AST SpaceMobile, like SpaceX, has formed partnerships with over 45 MNOs, including AT&T, Vodafone, and Telefónica, covering around 2.8 billion users. These alliances boost AST SpaceMobile's global scalability. The growth of the D2C market is further supported by regulatory advancements like the FCC's Supplemental Coverage from Space (SCS), enabling satellite operators to use terrestrial spectrum. Partnerships between satellite operators and MNOs, such as SpaceX, T-Mobile and AST SpaceMobile, will benefit from SCS, allowing seamless satellite-terrestrial network integration and opening new consumer markets and revenue opportunities.

Nxbeam

Ku/ Ka/ V/ E-Band Power Amplifier MMICs

Maximized performance for linear power applications

Ku/Ka-Band MMIC Die and Packaged MMICs

MMIC Die:

NPA1020-DE	12.5 - 14.5 GHz	15 W
NPA2020-DE	23.0 - 25.0 GHz	10 W
NPA2001-DE	26.5 - 29.5 GHz	35 W
NPA2002-DE	27.0 - 30.0 GHz	35 W
NPA2003-DE	27.5 - 31.0 GHz	35 W
NPA2004-DE	25.0 - 27.5 GHz	40 W
NPA2030-DE	27.5 - 31.0 GHz	20 W
NPA2040-DE	27.5 - 31.0 GHz	10 W

QFN Packaged MMICs:

NPQ2101-SM	27.5 - 31.0 GHz	5 W
NPQ2103-SM	27.5 - 31.0 GHz	8 W
NPQ2105-SM	27.5 - 31.0 GHz	12 W
NPQ2107-SM	27.5 - 31.0 GHz	15 W

Contact Nxbeam for Flange Packaged Options

V-Band MMICs

MMIC Die:

NPA4000-DE	47.0 - 52.0 GHz	1.5 W
NPA4010-DE	47.0 - 52.0 GHz	3.0 W

E-Band MMICs

MMIC Die:

NPA7000-DE	65.0 - 76.0 GHz	1.0 W

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Narda-MITEQ has been acquired by the publicly traded electronics manufacturer **Amphenol Corporation** in May 2025. Narda-MITEQ is a leader in the design and manufacture of advanced RF and microwave components and subsystems used in military, space and commercial applications. Amphenol designs, manufactures and markets electrical, electronic and fiber-optic connectors, interconnect systems, antennas and specialty cables that are used by OEMs, defense contractors, telecom providers and automotive suppliers in the military, aerospace, industrial, automotive and broadband sectors.

COLLABORATIONS

OKI, in collaboration with **NTT Innovative Devices Corporation**, has established mass production technology for high-power terahertz devices using crystal film bonding technology for heterogeneous material bonding to bond indium phosphide-based uni-traveling carrier photodiodes onto silicon carbide with excellent heat dissipation characteristics for improved bonding yields. Terahertz devices are anticipated to play a core technology role in supporting high-capacity low-latency communications for the next-generation 6G communication standard and high-precision non-destructive inspection for improved safety. Based on these results, both companies are working on product development, aiming to start mass production in FY2026.

ACHIEVEMENTS

Quantic Wenzel has earned AS9100D certification for its quality management system at its Austin, Texas, facility. The certification reinforces Quantic Wenzel's ability to meet stringent customer requirements and deliver consistent, ultra-low phase noise frequency control and timing products. This achievement builds on a legacy of aerospace excellence. Thirty years ago, Quantic Wenzel delivered its first space-qualified oscillator, a milestone that laid the foundation for decades of innovation. Since then, Quantic Wenzel's products have supported shipborne radar, airborne electronic warfare systems and some of the world's most advanced scientific research programs.

SV Microwave announced it has been named Manufacturer of the Year in the Trailblazers category by the South Florida Manufacturers Association (SFMA), along with having eight employees nominated for Employee of the Year. A company must have 131 to 199 employees to be eligible for the Trailblazer category. The company also celebrates the achievements of Evan Bensemana and Lideivy Gonzales Cruz, who were recognized as Employee of the Year in the Engineering (Bensemana) and Production (Gonzales Cruz) categories, respectively, at this year's Recognition of Excellence Ceremony.

NEOTech announced that its Westborough, Mass., facility has successfully completed the rigorous AS9100 Bi-Annual Surveillance Audit with zero findings, a testament to the company's unwavering commitment to quality, security and operational excellence. AS9100 is the aerospace industry's gold standard for quality management systems, encompassing stringent requirements to safeguard the integrity, reliability and traceability of mission-critical components. NEOTech's performance in this latest surveillance audit confirms that its processes continue to meet or exceed the most demanding standards required by top aerospace and defense OEMs.

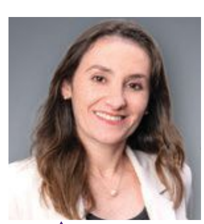
CONTRACTS

Filtronic has been awarded a new contract to supply filter and diplexer assemblies to **Airbus Defence and Space**, supporting the production of additional satellites for Eutelsat OneWeb. The contract will see Filtronic deliver flight sets in 2026, as part of efforts to expand the OneWeb low Earth orbit (LEO) satellite constellation. Built by Airbus in Toulouse, these satellites will contribute to Eutelsat OneWeb's mission of delivering global broadband connectivity. Eutelsat OneWeb, formed in 2023 through the merger of Eutelsat Communications and OneWeb, is the world's first fully integrated satellite operator combining geostationary orbit and LEO satellite technologies.

PEOPLE

▲ *James Eisenhaure*

Naprotek, LLC announced that **James Eisenhaure** has been appointed chief financial officer. Eisenhaure has been serving as interim CFO since earlier this year and now formally steps into the role. During his interim tenure, Eisenhaure played a key role in leading the company through the successful closeout of its FY2024 financial audit. His leadership and collaboration across teams ensured a smooth and timely process, reinforcing Naprotek's commitment to operational discipline and financial transparency. Eisenhaure brings a strong background in financial operations, with prior leadership roles at Insurcomm, Cirtec Medical and Metrigraphics.



▲ *Diana Toruno*

Accumet Engineering Inc. has announced the promotion of **Diana Toruno** to general manager. A long-serving manufacturing expert at the company, Toruno brings decades of experience in precision manufacturing operations. Her leadership has been integral to maintaining and growing Accumet's technical and manufacturing capabilities and advancing its quality-first manufacturing culture. Diana is the embodiment of the

For More Information For up-to-date news briefs, visit mwjournal.com

American success story. Originally from Colombia, she began her journey at Accumet in the processing department and had steadily advanced by embracing greater technical and managerial responsibilities at every step.

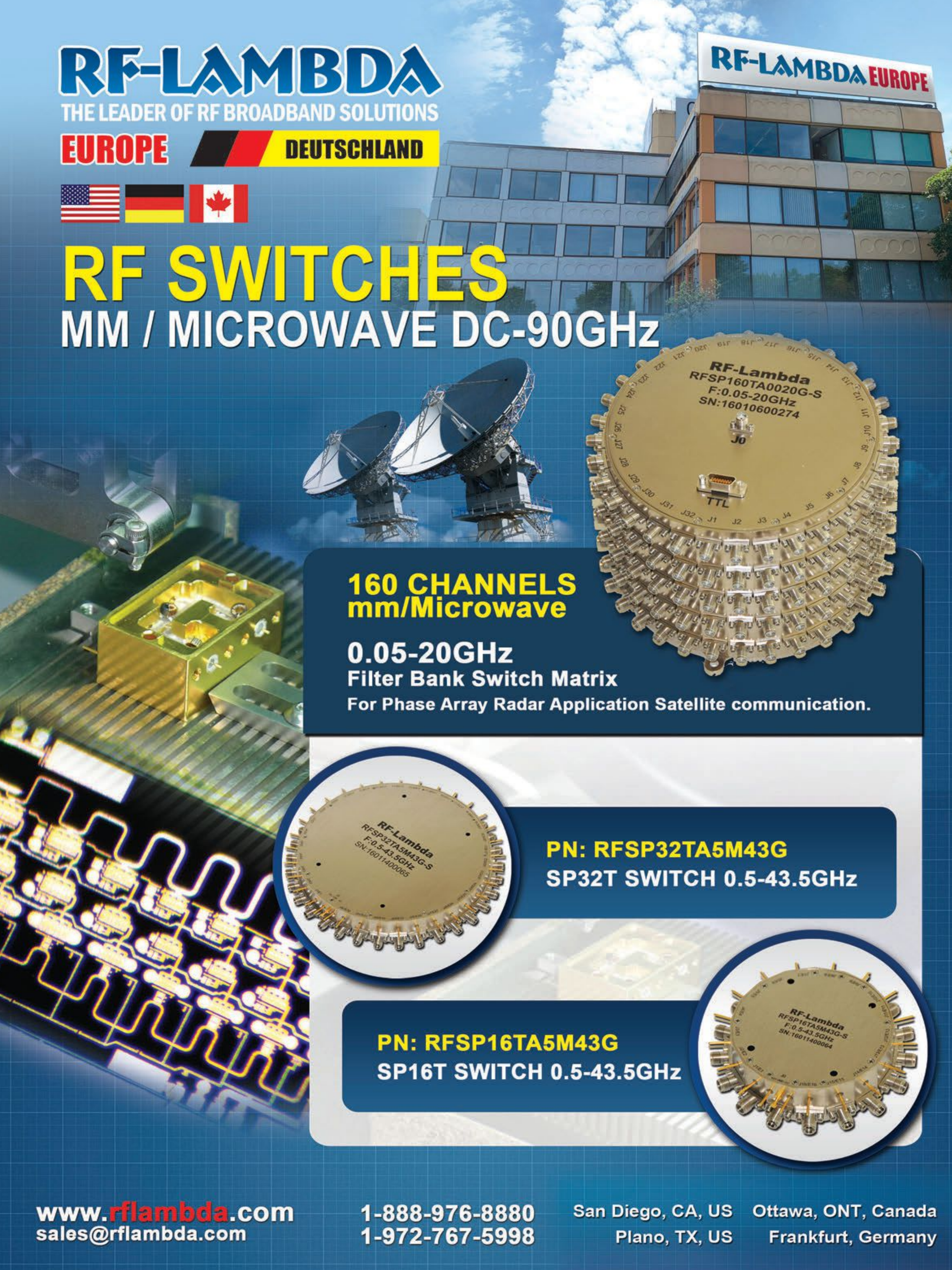
REP APPOINTMENTS

Altum RF announced a sales representative agreement with **RF Alliance**, covering customers located in New Jersey, New York and east Pennsylvania. Founded in 2005 with headquarters in West Milford, N.J., RF Alliance specializes in technical knowledge and support of RF, microwave, mmWave, frequency control and analog components. RF Alliance has expertise and solid relationships across various RF markets and applications including telecommunications, satellite, test and measurement, defense and aerospace markets.

ERZIA announced a new strategic partnership with **ACETEC**, naming them the exclusive ERZIA representative for Southern California. With over 30 years of experience, ACETEC has built a strong reputation as a trusted representative and technical sales leader in the RF, microwave and test equipment industries. Known for their deep industry expertise, responsive service and long-standing customer relationships, ACETEC is ideally positioned to expand ERZIA's footprint in one of the most dynamic technology regions in the world.

Insight SIP announced it has signed a distribution agreement with **New Yorker Electronics**. Founded in 1948, New Yorker Electronics is a third-generation, family-run distributor that serves customers in the defense, aerospace, automotive, medical, IoT and energy industries. The company maintains a wholly U.S.-based staff across its offices in New Jersey and Texas. Insight SIP is a pioneer in ultra-miniature RF modules, delivering highly integrated module solutions for Bluetooth, Wi-Fi, ultra-wideband and LoRA. Their innovative modules enable compact, high performance designs suitable for a wide range of industries, with a strong focus on IoT solutions.

Samtec Inc. has announced it has signed **Richardson RFPD** as an authorized distributor of the full line of Samtec's RF cable and connector products, including the new family of distinctive orange Nitrowave™ high performance microwave cable assemblies that are phase and amplitude stable with flexure. Richardson RFPD, an Arrow Company, is an award-winning distributor known for its industry-leading expertise in RF and microwave products, providing system designers with a range of specialized components and expert design support. Richardson RFPD has over 400 employees and more than 35 locations across the globe, and regional distribution hubs in Asia, Europe and North America.

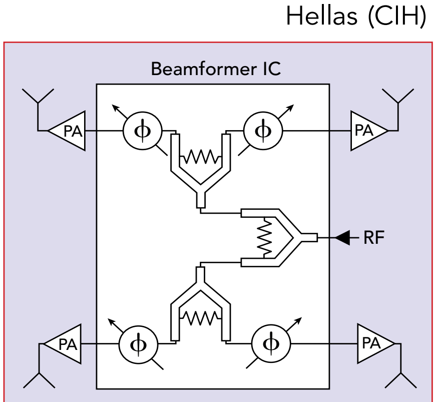

RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
EUROPE
DEUTSCHLAND
RF-LAMBDA EUROPE
RF SWITCHES
MM / MICROWAVE DC-90GHz
RF-Lambda
RFSP160TA0020G-S
F:0.05-20GHz
SN:16010600274
160 CHANNELS
mm/Microwave
0.05-20GHz
Filter Bank Switch Matrix
For Phase Array Radar Application Satellite communication.
PN: RFSP32TA5M43G
SP32T SWITCH 0.5-43.5GHz
PN: RFSP16TA5M43G
SP16T SWITCH 0.5-43.5GHz
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
San Diego, CA, US
Plano, TX, US
Ottawa, ONT, Canada
Frankfurt, Germany

INVITED PAPER

Optimizing Satcom FPA Design with Integrated AiP/SiP Chipset

E. Lourandakis, A. Katsounaros, P. Fioravanti, G. Kontogiannopoulos and C. McMahon
Circuits Integrated Hellas SA, Attica, Greece

The rapid expansion of global satellite communication (satcom) systems,[1] especially with the growing deployment of LEO satellite constellations, has created an urgent need for advancements in active antenna technology.[2] Flat panel antennas (FPAs) are critical for delivering reliable, high speed connectivity and have been heavily investigated over the last few years.[3] Current silicon-based designs for the phased antenna array face a radiated power per element bottleneck that causes upscaling of the array sizes to meet the transmit (Tx) link metrics. Circuits Integrated Hellas (CIH) has developed a groundbreaking approach to address these limitations by integrating III-V compound semiconductors with silicon technologies within a unified 3D package.[4] Heterogeneous IC integration has attracted noticeable traction over the last few years,[5] and CIH's approach allows users to integrate components like power amplifiers (PAs), phase shifters and splitters within a unique, compact configuration. To date, no other commercial offering integrates III-V compound semiconductors and silicon ICs within a unified 3D system-in-package (SiP) and antenna-in-package (AiP) platform for FPAs. This article explores the technology and why it enables an unprecedented level of miniaturization, efficiency and cost-effectiveness.



▲ Fig. 1 **Conceptual diagram of 2 x 2 phased array antenna.**

PHASED ANTENNA ARRAY

In its simplest form, a phased antenna array for Tx operation is an antenna array where the individual elements are placed on a $\lambda/2$ grid, where λ represents the free space wavelength of the transmitted electromagnetic wave. An RF signal is equally distributed to each antenna branch, where its amplitude and phase are selectively manipulated by a typically silicon circuit with the collective term of beamformer IC, as shown in ***Figure 1***. A 2×2 phased antenna array building block can be used to implement larger antenna arrays, depending on the transmission link needed for a specific satcom link.

CIH designs performant III-V components that fit the $\lambda/2$ array required in FPAs for ultra-high performance. This capability is at the core of the 3D heterogeneous integrations targeted in CIH's development roadmap. The CIH solution involves integrating

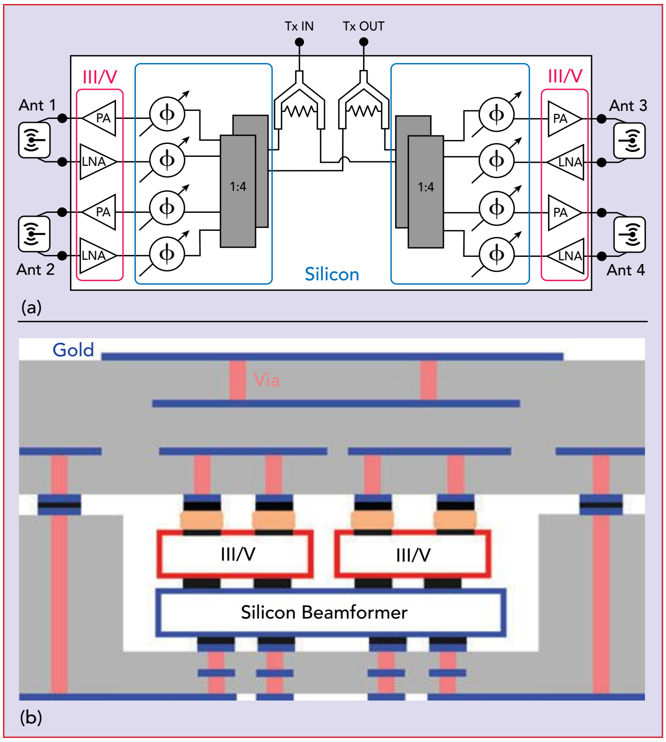


Fig. 2 **Conceptual diagram of a) Kythrion architecture and b) 3D IC SiP integration.**

high performance compound semiconductors (III-V) such as GaAs and GaN with silicon substrates in a 3D configuration, creating a unified, compact SiP/AiP structure called the Kythrion™ platform.

WHAT IS KYTHRION?

Kythrion is a family of highly integrated AiP beamforming modules designed to significantly enhance the performance and compactness of electronically steered arrays for space and ground-based satcom systems. Kythrion modules offer shared Tx/receive (Rx) apertures, multi-beam capability and ultra-fine control with 8-bit phase and gain resolution. With power-efficient analog front ends, on-chip telemetry and beam memory, Kythrion enables compact terminals with size, weight, power and cost (SWaP-C) metrics, achieving up to 36 dBm Tx output power and sub-1 dB receiver noise figures. These modules are tailored for next-generation FPAs for which performance per area, integration and fast beam agility are mission-critical. ***Figure 2*** shows a conceptual architecture of the Kythrion 3D IC heterogeneous integration platform, where ***Figure 2a*** demonstrates the architecture for Tx/Rx satcom phased antenna arrays and ***Figure 2b*** shows a conceptual diagram of heterogeneous SiP integration.

Kythrion modules are intended for both transmit and receive operation, as shown in Figure 2, featuring an integrated dual-band antenna with switchable right-handed circular polarization (RHCP) and left-handed circular polarization (LHCP), supporting flexible link configurations across diverse orbital regimes. They include on-chip decoupling capacitors and electrostatic discharge (ESD) protection, are fully DC and RF tested at wafer level to ensure compliance with stringent electrical specifications and incorporate solutions for enhanced reliability and moisture ruggedness. Housed in low-temperature cofired ceramic (LTCC) packages with low thermal resistance, the modules enable PCB integration and reduced time-to-market, making them ideal for mission-critical satellite terminals and scalable RF front-end architectures.

ENABLER 1: ANTENNA-IN-PACKAGE

AiP is a technology used to integrate an antenna directly into a semiconductor package, such as a system-on-chip (SoC), to save space and improve performance. This technology uses advanced packaging techniques to place the antenna near the RF circuitry. The antenna is typically designed to operate at a specific frequency band and has a certain polarization, depending on the application. Most commercial satcom take place in the Ku- or Ka-Band. The Ku-Band is usually selected for television broadcasting and data communication, whereas Ka-Band is used for high data rate communication links and broadband satellite services. Circularly polarized antennas are desirable in terms of polarization since they maintain communication between the transmitter and receiver, regardless of their relative orientation, and

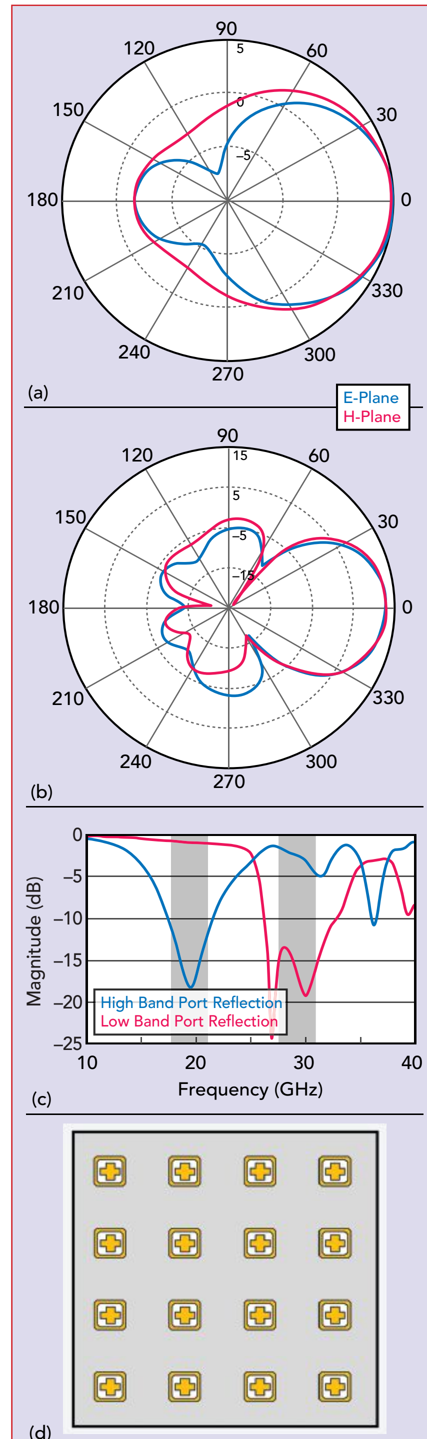


Fig. 3 **(a) Single antenna radiation pattern (b) 4 x 4 antenna array radiation pattern (c) S-parameters of a single antenna (d) top view of a 4 x 4 antenna array.**

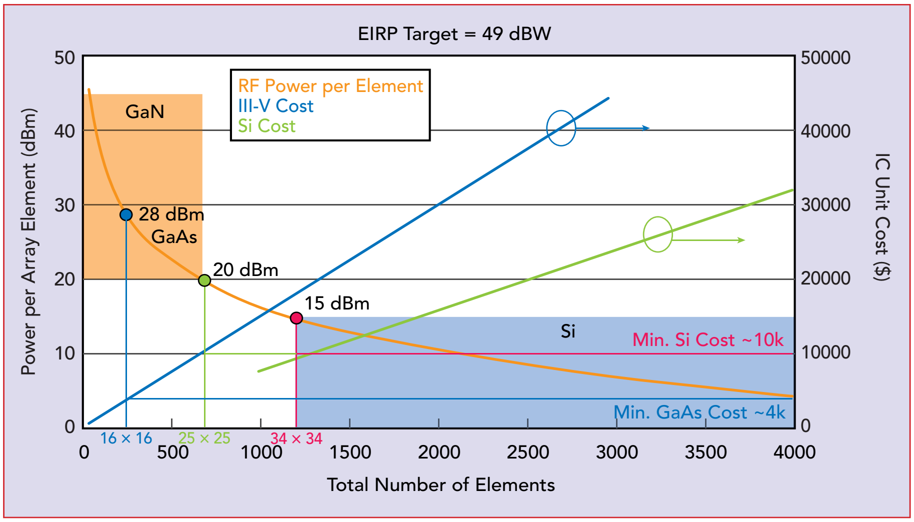


Fig. 4 Tx antenna array sizing analysis.

are excellent for mobility, weather penetration and reduction of multipath reflections.

CIH has developed a compact, single-aperture antenna element that integrates dual-band and dual polarization capabilities within a streamlined form factor. This advanced design supports simultaneous Tx and Rx operation, enabling full-duplex functionality and enhanced system efficiency. The element also provides circular polarization, making it well-suited for applications that demand robust performance in multipath and dynamic environments.

Building on this core technology, CIH has also engineered a Tx/Rx 4 × 4 antenna array based on the same dual-band, dual polarization element architecture as shown in ***Figure 3***. ***Figure 3a*** shows the radiation pattern of a single Tx/Rx antenna array and ***Figure 3b*** shows the radiation pattern of a 4 x 4 antenna array. ***Figure 3c*** shows the S-parameters of a single Tx/Rx antenna and ***Figure 3d*** shows a top view of a 4 x 4 Tx/Rx antenna array. This scalable array solution offers integration density, improved beamforming flexibility and superior isolation between channels, making it ideal for next-generation communication systems, including 5G, satellite and advanced radar platforms.

ENABLER 2: HETEROGENEOUS INTEGRATION

For sizing an antenna array, as shown in ***Figure 4***, CIH assumes a single patch antenna element has a gain of approximately 6 dBi, which is a typical value for microstrip patch antennas. ***Equation 1*** shows the calculation for the theoretical gain of the antenna array G_{array}.

$$G_{array} = 10\log_{10}\left(N * 10^{\frac{Gain}{10}}\right) \qquad (1)$$

Where:

N is equivalent to the number of elements

G is equivalent to the gain of an element in dBi

For example, when targeting an effective isotropic radiated power (EIRP) of 49 dBW, which is typical for a good uplink connection, we may formulate the total RF power (RF_{power}) needed from the antenna array using ***Equation 2***.

$$RF_{power}(dBm) = EIRP(dBW) + Losses(dB) + 30 \qquad (2)$$

From the generated total RF power of the array, the power associated with the PA circuitry can be calculated using ***Equations 3, 4*** and ***5***.

$$PA_{power}(dBm) = RF_{power}(dBm) - G_{array}(dBi) \qquad (3)$$

$$PA_{element}(W) = \frac{10^{\left(\frac{PA_{power}(dBm)}{10}\right)}}{1000\,N} \qquad (4)$$

$$PA_{element}(dBm) = 10\log_{10}\frac{PA_{element(W)}}{1\ mW} \quad (5)$$

Following this chain of calculations, an antenna array size can be derived for each specific EIRP level required to maintain a good satcom link. An array size analysis graph is presented in ***Figure 4*** for EIRP = 49 dBW, which is a typical Tx metric for a satcom uplink.

A traditional silicon-based array requires a 34 × 34 element configuration at 15 dBm per element, while an equivalent GaAs III-V enabled array achieves the same performance with just 25 × 25 elements at 20 dBm each, reducing the area by approximately 54 percent. Further optimization of the III-V parts reduces this area to 16 × 16 elements at 28 dBm, or about 22 percent of the silicon-based area, at a cost 40 percent lower than the silicon solution.

ENABLER 3: WAFER-LEVEL PACKAGE FOR III-V MMIC SIP

To achieve the integration levels required for FPAs, the CIH design approach departs from traditional compound III-V distributed components, favoring lumped passive components with improved back-end-of-line (BEOL) capabilities.

A differential unit amplifier, as described in ***Figure 5***, was designed based on a mix between transformer-based and distributed passive component design that minimizes area with minor loss of performance. Additionally, through-silicon vias (TSVs) are employed to enable low loss, low-inductance RF routing off the chip.[6]

Figure 6 shows the wafer-level chip-scale package (WLCSP) experimental results for GaAs TSV RF transitions of an assembled test chip on a PCB. Further, the measured and simulated S-parameter response of a THRU line on the GaAs WLCSP test chip is presented. The entire chain, from PCB pad through the TSV and transmission line on the GaAs chip in a back-to-back configuration, is measured and found to exhibit 0.2 dB

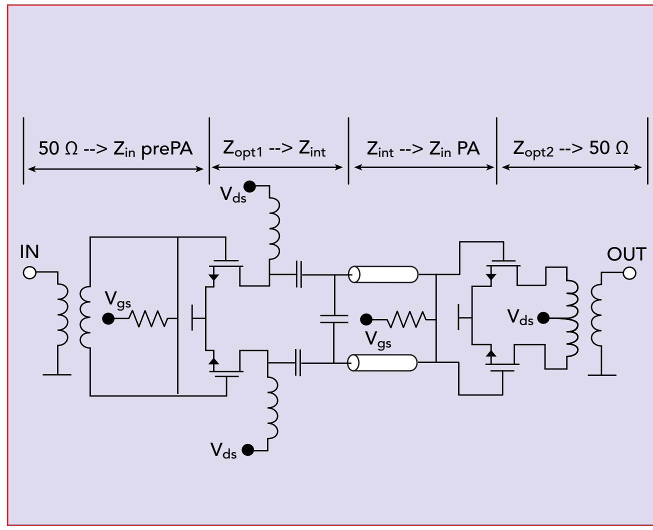


Fig. 5 PA topology for III/V MMIC design.

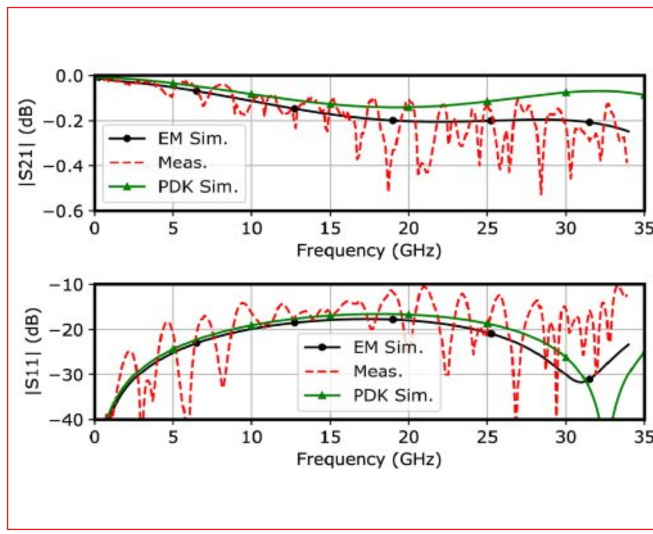
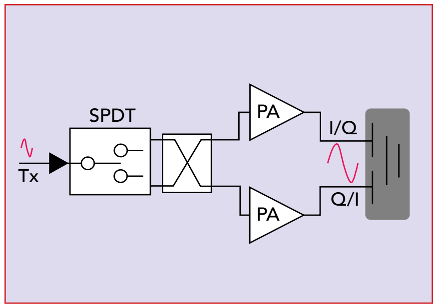


Fig. 6 Results for GaAs TSV RF transitions.



▲ **Fig. 7** **Tx unit module for polarization control.**

of insertion loss at 30 GHz. This low loss transition allows for compact MMIC design of RF circuits.

The design balances area optimization with performance retention, supported by TSV-enabled processes and air-bridge transitions. As can be seen from the de-embedded measurements, where the electrical reference plane is positioned directly below the TSV transition on the PCB level, the insertion loss of a THRU transition remains below 0.2 dB up to Ka-Band frequencies.

ENABLER – ARCHITECTURE EXAMPLE: IQ SWITCH FOR POLARITY CONTROL

One of the Kythrion variants, based on a Tx antenna element with dual polarization controlled by a dual-output amplifier switch module,[7] allows for a Tx phased antenna array with controllable right-handed or left-hand circular polarization. The conceptual architecture is shown in ***Figure 7***, where circuitry at the input of the amplifier is used to manipulate the I and Q components of the Tx signal. Depending on the configuration of the SPDT switch, the I and Q or Q and I signal constellations in the two PA branches are being amplified and fed to the Tx antenna resulting in either RHCP or LHCP.

Establishing RHCP or LHCP radiation at the antenna adds significant functionality to an antenna array based on such controllable RHCP/LHCP elements, since the uplink quality of the Tx antenna array can be controlled in real time for objects moving between satcom cells supporting either RHCP or LHCP radiation.

CONCLUSION

This work presents a pioneering approach to phased array antenna integration, achieved through the unique co-design and 3D packaging of III-V compound semiconductors with silicon technologies in a single SiP and AiP module. The engineering effort behind this platform has enabled experimental validation of key building blocks — demonstrating industry-leading miniaturization, low loss transitions and substantial reductions in array size and cost compared to conventional solutions. The architecture's features are patent-pending.

While the technology is currently in the advanced prototype and experimental validation phase, the results underscore the transformative potential of this platform for next-generation satcom. These advances are the result of a multidisciplinary team and a sustained commitment to innovation in RF and packaging design. ■

References

1. H. Al-Hraishawi, H. Chougrani, S. Kisseleff, E. Lagunas and S. Chatzinotas, "A Survey on Nongeostationary Satellite Systems: The Communication Perspective," *IEEE Communications Surveys & Tutorials*, Vol. 25, No. 1, 2022, pp. 101–132.
2. W. Hong et al., "The Role of Millimeter-wave Technologies in 5G/6G Wireless Communications," *IEEE J. Microwaves*, Vol. 1, No. 1, 2021, pp. 101–122.
3. X. Gu and D. Liu, B. Sadhu, "Packaging and Antenna Integration for Silicon-based Millimeter-wave Phased Arrays: 5G and Beyond," *IEEE Journal of Microwaves*, Vol. 1, No. 1, 2021, pp. 123–134.
4. E. Lourandakis, P. Fioravanti, G. Kontogiannopoulos and C. McMahon, "Heterogeneous AiP/SiP for Satcom," *International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH)*, May 19–22, 2025.
5. W. Shi, C. Zou, Y. Cao and J. Liu, "The Progress and Trend of Heterogeneous Integration Silicon/III-V Semiconductor Optical Amplifiers," *Photonics*, Vol. 10, No. 2, 2023, p. 161, MDPI.
6. J.-C. Chiu et al., "An Ultracompact, Low-cost, and High-performance RF Package Technique for Wi-Fi FEM Applications," *IEEE Microwave and Wireless Components Letters*, Vol. 30, No. 3, 2020, pp. 265–267.
7. P. Fioravanti, E. Lourandakis, A. Gurulian and P. Bampali, "Single Pole Multiple Throw Power Amplifier Module," *European Patent Application*, EP4489302A1.

INVITED PAPER

Predicting Resonant Behavior of Surface-Mount Capacitors

Chris DeMartino and Larry Dunleavy
Modelithics Inc., Tampa, Fla.

At RF and microwave frequencies, a real-life surface-mount multilayer ceramic capacitor (MLCC) behaves differently from an ideal capacitor. This difference can be attributed to the internal parasitic elements associated with real-life components. As a result of these elements, MLCCs typically exhibit resonances at specific frequencies. External aspects, such as the substrate and the dimensions of the solder pads on the printed circuit board (PCB), also influence performance. To accurately simulate the behavior of a real-life capacitor, a suitable model is required. One solution for capacitor models comes from Modelithics, which offers equivalent-circuit models for capacitors, inductors and resistors from many manufacturers. These models, known as Microwave Global Models™, scale with respect to part values, substrates and solder-pad dimensions. By using these models, it is possible to observe how these resonances depend on factors such as case sizes, substrates and solder-pad dimensions.

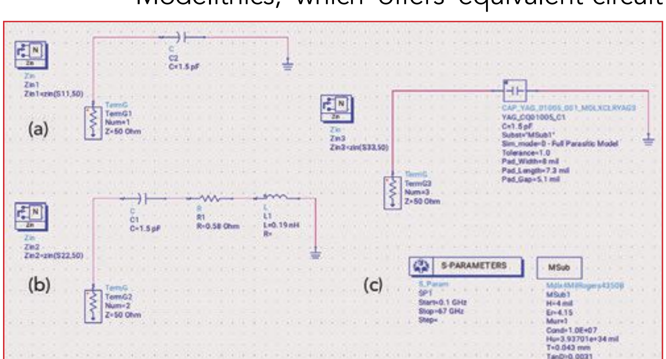


Fig. 1 **(a) Ideal 1.5 pF model, (b) simplified model of a real-world 1.5 pF and (c) the Modelithics Microwave Global Model for the YAGEO CQ0100 capacitor series.**

CAPACITOR BASICS

Ideal capacitors differ from real-life capacitors in multiple ways. ***Figure 1*** shows a simple project in Keysight Advanced Design System (ADS) that includes both an ideal 1.5 pF capacitor model (Figure 1a) and a simplified model of a real-world 1.5 pF capacitor (Figure 1b). This simplified model is a frequently used representation that includes the nominal capacitance, equivalent series resistance (ESR) and equivalent series inductance (ESL). It is referred to as a simplified model because a real-world MLCC has additional elements that are not included in this model. The project shown in Figure 1 also consists of the Modelithics Microwave Global Model for the YAGEO CQ0100 capacitor series (Figure 1c).

Since an ideal capacitor is simply a pure capacitor with no additional elements, its total impedance is equal to the capacitive reactance given by ***Equation 1***:

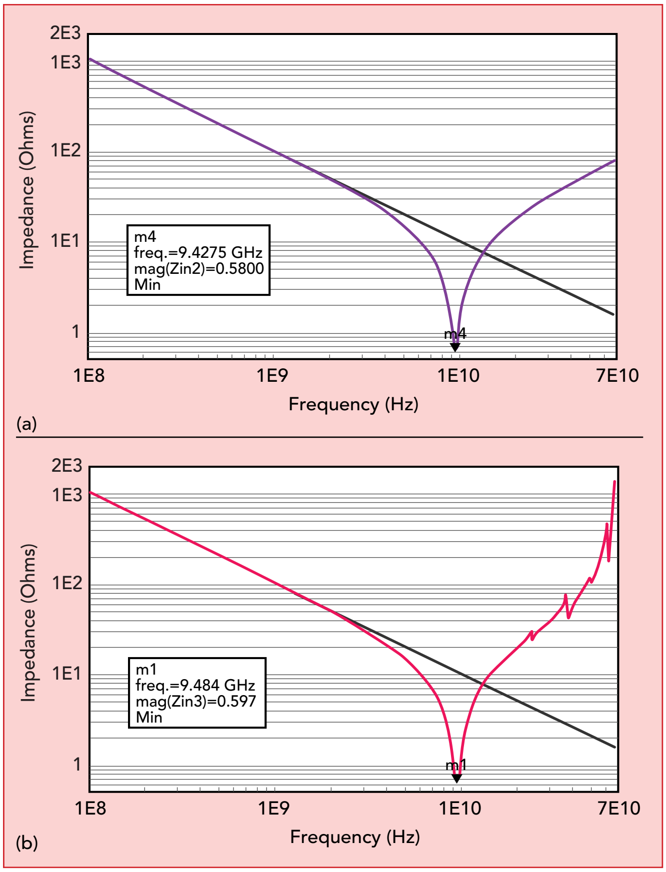


Fig. 2 (a) Impedance of the ideal capacitor (black trace) and the simplified capacitor model (purple trace). (b) Impedance of the ideal capacitor (black trace) and the Modelithics model (red trace).

$$X_c = \frac{1}{2\pi fC} \quad (1)$$

where:
f = frequency (Hz)
C = capacitance (farads)

The total impedance of the simplified real-world capacitor is given by ***Equation 2***:

$$Z = \sqrt{(ESR)^2 + (X_L - X_c)^2} \quad (2)$$

where:
ESR = equivalent series resistance
X_L = inductive reactance (from the ESL)
X_C = capacitive reactance (from the nominal capacitance)
Note that inductive reactance is given by ***Equation 3***:

$$X_L = 2\pi fL \quad (3)$$

where:
f = frequency (Hz)
L = inductance (henries)

SIMULATING THE SELF-RESONANT FREQUENCY

In Figure 1, the simplified real-world capacitor has a nominal capacitance of 1.5 pF along with an ESR of 580 mΩ and an ESL of 0.19 nH. The simplified real-world capacitor is a series RLC circuit. For a series RLC circuit, the capacitive reactance and inductive reactance have an equal magnitude at a specific frequency. This frequency, known as the resonant frequency, is given by ***Equation 4***:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (4)$$

Hence, a capacitor has a resonant frequency of the same form. This frequency, known as the capacitor's self-resonant frequency (SRF), is given by ***Equation 5***:

$$f_{SRF} = \frac{1}{2\pi\sqrt{ESL * C}} \quad (5)$$

The SRF decreases as the capacitance increases. Additionally, the capacitive reactance and inductive reactance have equal magnitude at the SRF. Hence, at the SRF, the total capacitor impedance reaches a minimum value that is simply equal to the ESR (as shown in Equation 2). Equation 5 is used to calculate an SRF of approximately 9.4275 GHz for the simplified real-world 1.5 pF capacitor shown in Figure 1.

Modelithics models capture substrate-dependent parasitic behavior and offer advanced pad features, among other capabilities. The CQ0100 series is an MLCC series (01005 size) that covers a capacitance range of 0.1 to 15 pF. The Modelithics CAP-YAG-01005-001 model is validated by measurements performed up to 67 GHz. The model covers the full range of part values for the CQ0100 series.

In this model, the capacitance value is 1.5 pF, and it uses a 4 mil thick Rogers RO4350B substrate. The dimensions of the solder pads are the default values for the length, width and gap (7.3, 8 and 5.1 mils, respectively).

Figure 2 shows the simulation results comparing the impedance of the ideal 1.5 pF capacitor to the simplified real-world 1.5 pF capacitor model (Figure 2a) and the impedance of the ideal 1.5 pF capacitor to the Modelithics model for the 1.5 pF CQ0100 capacitor (Figure 2b). For the simplified real-world capacitor, the impedance is equal to the ESR (580 mΩ) at the SRF (9.4275 GHz), and the 1.5 pF CQ0100 capacitor exhibits an SRF of 9.484 GHz.

The results show that the simplified real-world 1.5 pF capacitor and the 1.5 pF CQ0100 capacitor do not behave like ideal capacitors. In the case of the ideal capacitor, the impedance only decreases as the frequency increases. The real capacitor follows the impedance curve of the ideal capacitor up to a certain frequency, then deviates. Specifically, the impedance decreases more sharply as it approaches the SRF. At the SRF, the impedance reaches a minimum value. Above the SRF, the impedance increases as the frequency increases.

Continuing further, a real capacitor's total impedance is capacitive below the SRF, as the capacitive reactance is greater than the inductive reactance. Above the SRF, the total impedance is inductive, as the inductive reactance is greater than the capacitive reactance. In other words, above the SRF, the capacitor behaves like an inductor. Thus, a capacitor acts as a "DC blocking inductor" above the SRF.[1]

As shown in Figure 2, a real capacitor does not exhibit the same behavior as an ideal capacitor. However, comparing the behavior of the simplified real-world 1.5 pF capacitor with the behavior of the 1.5 pF CQ0100

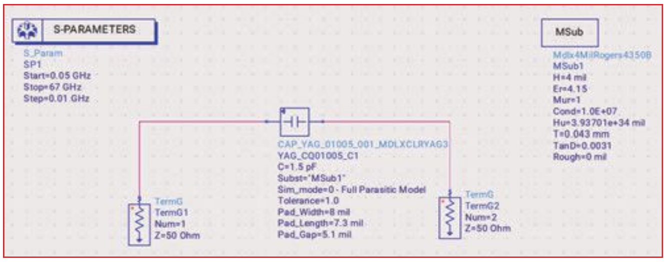


Fig. 3 ADS schematic used for an S-parameter simulation of the capacitor.

capacitor reveals more information. In Figure 2, the impedance of the 1.5 pF CQ0100 capacitor resembles the impedance of the simplified real-world capacitor model. However, above the SRF, there are some noticeable differences. Specifically, the 1.5 pF CQ0100 capacitor exhibits impedance spikes at several frequencies above the SRF. ***Figure 3*** demonstrates an S-parameter simulation of this same Modelithics model for the 1.5 pF CQ0100 capacitor in a two-port series configuration. ***Figure 4*** shows the simulated S_{21} results. For comparison, Figure 4 also shows S_{21} after performing the same S-parameter simulation of the ideal 1.5 pF capacitor.

In Figure 4, the simulated S_{21} of the 1.5 pF CQ0100 capacitor exhibits distinct attenuation notches at the same frequencies where the impedance spiked. These attenuation notches represent the parallel resonant frequencies (PRFs) that appear due to the parallel parasitic elements of an MLCC. These PRFs can also be referred to as higher-order resonances, as an MLCC has a first PRF, a second PRF, a third PRF, etc. In this case, the first, second, third and fourth PRFs are at 24.05, 36.87, 49.23 and 61.25 GHz, respectively. Therefore, while the simplified model of a real-world capacitor may be effective to some degree, it is not a complete representation of a real-world MLCC because it omits the parallel parasitic elements.

From a designer's perspective, it may be acceptable to use a capacitor above the SRF if the application requires low impedance with no requirement for the capacitor to exhibit either capacitive or inductive behavior. However, as the operating frequency approaches the first PRF, the designer must decide if the higher loss is acceptable for the application. If the loss is too high, an alternative solution may be necessary. Therefore, from a design standpoint, it is critical to determine if any PRFs fall within the intended operating frequency range. As shown, Modelithics Microwave Global Models for MLCCs enable the identification of PRFs to mmWave frequencies.

HOW CASE SIZES IMPACT CAPACITOR RESONANCES

Several factors impact capacitor resonances. One such factor is the case size of the MLCC. ***Figure 5*** shows an impedance simulation of the Microwave Global Models

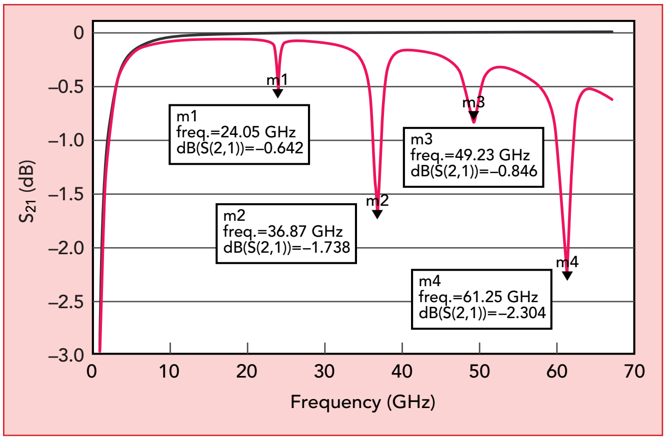


Fig. 4 Red trace: Simulated S_{21} of the CQ0100 capacitor. Black trace: S_{21} of an ideal capacitor.

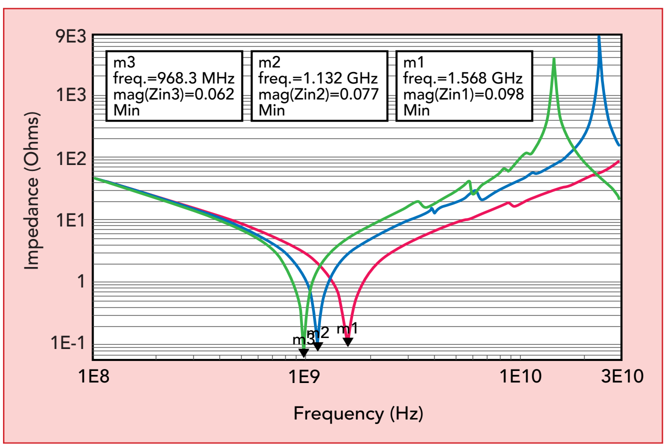


Fig. 5 Simulated impedance curves of the CBR02 (red trace), CBR04 (blue trace) and CBR06 (green trace) capacitors.

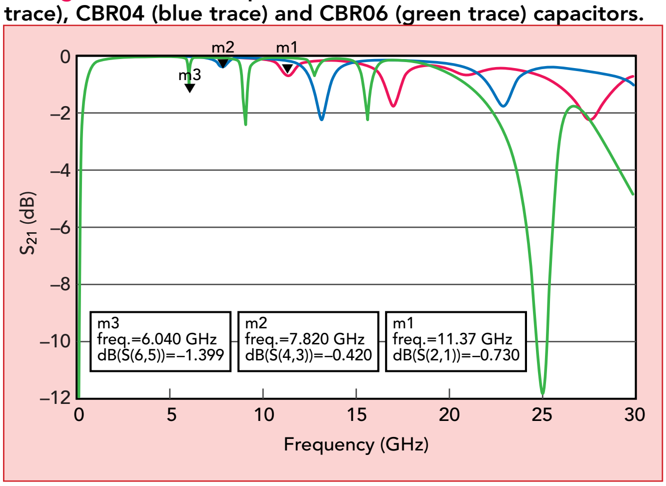


Fig. 6 Simulated S_{21} of the CBR02 (red trace), CBR04 (blue trace) and CBR06 (green trace) capacitors.

for the KEMET CBR02, CBR04 and CBR06 capacitors, which come in case sizes of 0201, 0402 and 0603, respectively. Each simulation uses a capacitor model with a value of 33 pF. The substrate used for each is 10 mil thick Rogers RO4350B.

For the CBR02, CBR04 and CBR06 capacitors with the same value (33 pF), the SRFs are 1.568 GHz, 1.132 GHz and 968.3 MHz, respectively. Therefore, increasing the case size increases the ESL and thus decreases the SRF. The impedance value at the SRF corresponds to

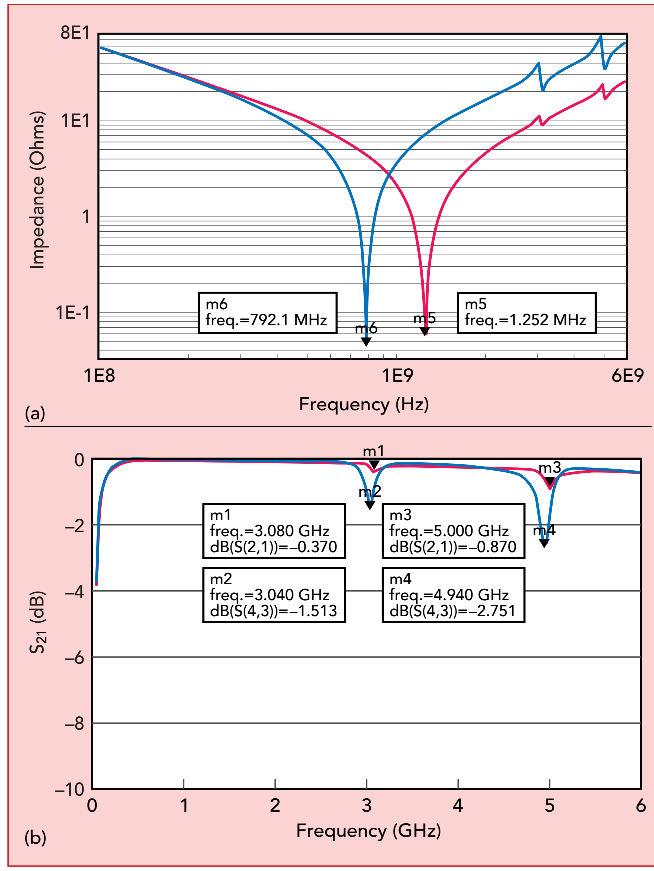


Fig. 7 (a) Simulated impedance with 10 mil (red trace) and 60 mil (blue trace) substrates. (b) Simulated S_{21} with 10 mil (red trace) and 60 mil (blue trace) substrates.

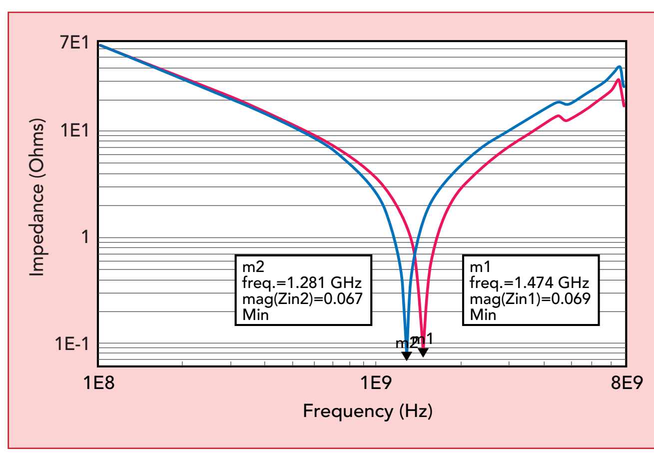


Fig. 8 Simulated impedance with pad lengths of 17 mils (red trace) and 28 mils (blue trace).

a capacitor's ESR. For the CBR02, CBR04 and CBR06 capacitors, the ESR values are 98, 77 and 62 mΩ, respectively. Thus, by increasing the case size, the ESR decreases.

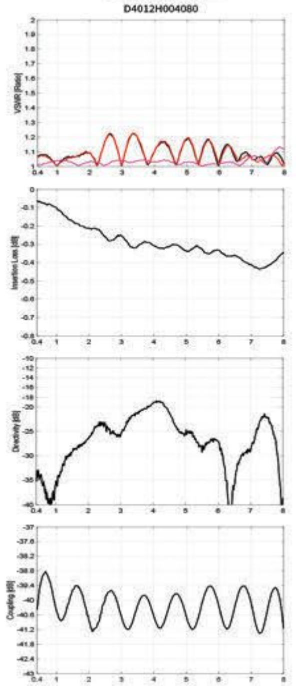
Simulating the same three capacitor models in a two-port series configuration shows that the PRFs are affected by case size. Each model is set to a value of 6.8 pF. The substrate used for each is again 10 mil thick Rogers RO4350B. ***Figure 6*** shows the simulated S_{21} of each capacitor.

For the CBR02, CBR04 and CBR06 capacitors with the same value, the first PRFs are 11.37, 7.82 and 6.04 GHz, re-

P/N	CW Power Max.(W)	Nominal Coupling (dB)	Main Line VSWR	Coupling VSWR	Insertion Loss*	Coupling	Flatness	Directivity Min.(dB)
			Max.(:1)		Max.(dB)			
0.4-8GHz Directional Coupler								
D3002H004080	120	30	1.3	1.3	0.8	30±1.0	±0.8	18
D4002H004080	120	40	1.3	1.3	0.8	40±1.0	±0.8	18
D3005H004080	250	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4005H004080	250	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3008H004080	400	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4008H004080	400	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3012H004080	600	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4012H004080	600	40	1.4	1.4	0.7	40±1.0	±1.4	14
0.4-8GHz Dual-Directional Coupler								
D3002HB004080	120	30	1.3	1.3	0.8	30±1.0	±1.0	18
D4002HB004080	120	40	1.3	1.3	0.8	40±1.0	±1.0	18
D3005HB004080	250	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4005HB004080	250	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3008HB004080	400	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4008HB004080	400	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3012HB004080	600	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4012HB004080	600	40	1.4	1.4	0.7	40±1.0	±1.6	14

*Theoretical I.L. Included

— Test Curve —
D4012H004080



spectively. Again, the PRFs decrease as the case size increases. From a design perspective, this comparison highlights the suitability of these capacitors for applications such as DC blocking. That is, the 6.8 pF CBR06 capacitor would likely not be an appropriate choice for an application if the operating passband includes the capacitor's first PRF of 6.04 GHz. In comparison to the 6.8 pF CBR06 capacitor, the 6.8 pF CBR02 capacitor would be a candidate for use in more broadband applications because it exhibits a first PRF at a much higher frequency (11.37 GHz).

SUBSTRATE AND SOLDER-PAD EFFECTS

The substrate on which an MLCC is mounted also affects the resonances. The substrate affects the parasitic elements of an MLCC and thus impacts the locations of the resonant frequencies. Simulating the Microwave Global Model for the Amotech A60F capacitor series demonstrates this impact. The model uses a value of 27 pF using two different substrates: 10 mil thick Rogers R04350B and 60 mil thick Rogers RO4003C. For both cases, the simulation includes the impedance and the S_{21} (two-port series configuration).

Figure 7a shows the simulated impedance curves for both substrates. The 10 mil thick Rogers RO4350B substrate produces an SRF of 1.252 GHz, whereas the 60 mil thick Rogers RO4003C substrate produces a lower SRF of 792.1 MHz. This illustrates that increasing the substrate thickness results in a lower SRF.

Figure 7b shows the simulated S_{21} for both cases. The results show steeper attenuation notches at the PRFs when using the 60 mil thick Rogers RO4003C substrate versus the 10 mil thick Rogers RO4350B substrate. Modelithics' capability to predict substrate-dependent performance is a key program feature.

In addition to the substrate, the SRF is affected by the dimensions of the solder pads on which an MLCC sits. Microwave Global Models scale with respect to the solder-pad dimensions. This pad scalability makes it possible to see how the SRF changes as the pad dimensions are varied. Analyzing the Microwave Global Model for the Amotech A60L capacitor series demonstrates the scalability. In this example, the value is 24 pF, and the capacitor models have two different pad lengths: 17 and 28 mils. For both cases, the pad width and pad gap are set to 20 mils each. The substrate used is 10 mil thick Rogers RO4350B. ***Figure 8*** shows the simulated impedance for both cases. Increasing the length of the solder pads from 17 to 28 mils results in a decrease in the SRF from 1.474 to 1.281 GHz. These results are expected since increasing the length of the solder pads increases the inductance and thus lowers the SRF.

MLCC HORIZONTAL AND VERTICAL MOUNTING ORIENTATIONS

It is possible to eliminate odd-order parallel resonances by mounting an MLCC in a vertical orienta-

New Bias Tees

We offer a range of in-stock, Bias Tees to address a variety of applications, including test and measurement, research and development, optical communications, satellite communications and more.

In-Stock & Shipped Same-Day

SAME-DAY SHIPPING

CUSTOM CABLES

LIVE TECH SUPPORT

fairviewmicrowave.com
+1 (800) 715-4396

Fairview Microwave®
an INFINITE brand

tion. Mounting an MLCC in a vertical orientation means that the width of the MLCC essentially becomes its height. ***Figure 9*** shows an MLCC mounted on a PCB in both horizontal (Figure 9a) and vertical (Figure 9b) orientations. While horizontal orientation is often considered the default mounting configuration, vertical orientation can be employed to eliminate odd-order parallel resonances.

Many of Modelithics' Microwave Global Models for MLCCs include an "Orientation" parameter that lets users select either "Horizontal" or "Vertical" mode. This parameter allows designers to predict the behavior of an MLCC when mounted in both horizontal and vertical orientations. ***Figure 10*** shows S-parameter (S_{21}) simulations of the Amotech A60F 27 pF capacitor in a two-port series configuration using both

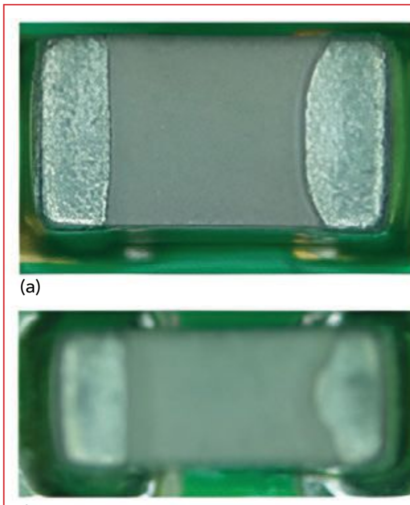


Fig. 9 MLCC in both (a) horizontal and (b) vertical orientations.

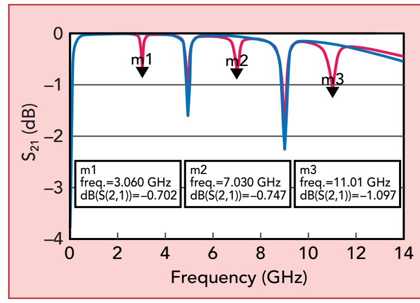


Fig. 10 Simulated S_{21} for the A60F 27-pF "Horizontal" (red trace) and "Vertical" (blue trace) modes.

"Horizontal" and "Vertical" modes. For this analysis, the substrate used is 30 mil thick Rogers RO4350B. The first-, third- and fifth-order PRFs (3.06, 7.03 and 11.01 GHz, respectively) only appear when the model is set to "Horizontal" mode. When the model is set to "Vertical" mode, these odd-order parallel resonances are eliminated.

FINAL REMARKS

Modelithics' Microwave Global Models for capacitors enable designers to determine where resonances, including SRFs and PRFs of an MLCC, appear. The resonances depend on factors such as case sizes, substrates and solder-pad dimensions. Using these inputs, the designers can determine the best capacitor for the application. ■

References

1. Johanson Technology, "SRF & PRF AND THEIR RELATION TO RF CAPACITOR APPLICATIONS," Tech Note.
2. KYOCERA AVX, "Circuit Designer's Notebook."

Dual-Band Filtering Horn Antenna Using a Metamaterial

Xianfeng Tang, Xiangqiang Li, Che Xu, Qingfeng Wang and Jianqiong Zhang
Southwest Jiaotong University, Chengdu, China

A horn antenna uses a metamaterial (MTM) located between the coaxial feed and the horn that is the foundation for dual-band operation and filtering. Simulation and measurement demonstrate good impedance matches around 3 and 4.35 GHz owing to the coupling in the coaxial feed and probe coupling in the horn. Gain on boresight is approximately 6.6 dB at 3 GHz and 9.5 dB at 4.35 GHz. Furthermore, out-of-band gain suppression is approximately 29 and 32 dB, relative to the maximum gains in the two passbands.

Horn antennas are extensively employed in communication systems owing to their wide bandwidths, good radiation patterns and simple structures.[1-3] They serve as standard gain antennas for system testing,[4,5] provide reliable feeds for antenna arrays[6-8] and can be configured as horn antenna arrays as well.[9,10]

Numerous attempts have been made to improve their performance, such as enhancing integration, improving gain, incorporating a filtering response and providing dual-band operation. For example, planar horn antennas, based on a printed circuit boards, groove gap waveguide or substrate-integrated waveguide have been developed for improved system integration.[11-13] Lenses or MTMs have been used to enhance gain.[14,15] A filtering response can be achieved by embedding split ring resonators (SRRs) or via-hole arrays.[16-18] Dual-band horn antennas can be constructed by using two helix exciters or combining them with tapered slot antennas.[19,20] Furthermore, stepped horn antennas

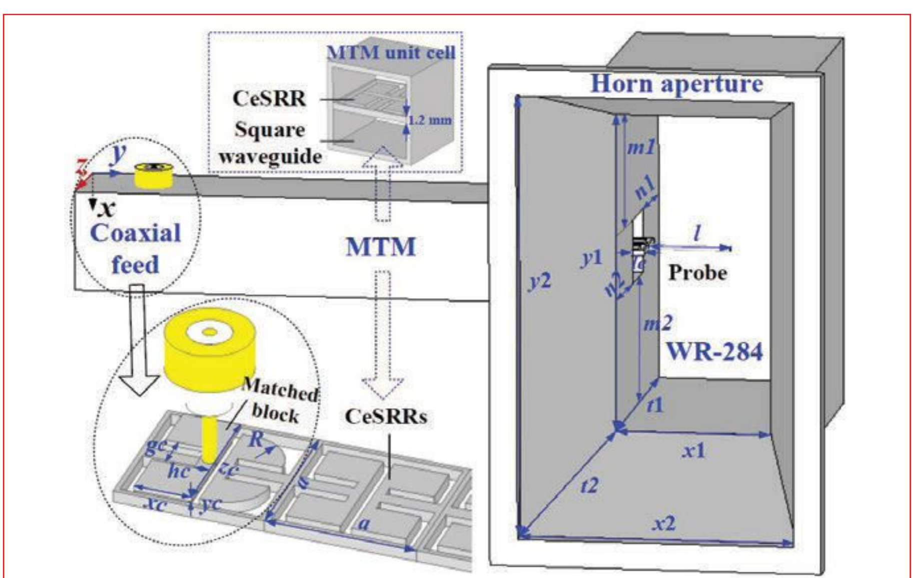


Fig. 1 Dual-Band filtering horn antenna configuration.

TABLE 1
OPTIMIZED ANTENNA PARAMETERS

Parameter	Value (mm)	Parameter	Value (mm)
a	14.5	*R*	4
xc	5.5	*yc*	0.5
zc	13	*hc*	1.5
x1	34	*y1*	72
x2	60	*y2*	100
t1	60	*t2*	53.5
l	18	*le*	2.5
m1	28.75	*m2*	28.75
n1	22.75	*n2*	22.75

can be integrated with two different filters to achieve a dual-band filtering response.[21]

In this work, an MTM consisting of a square waveguide (WG) with centrally loaded complementary electric SRRs (CeSRRs)[22] is used to construct a dual-band filtering horn antenna without additional filters.

MTM HORN ANTENNA CONFIGURATION

The antenna includes a coaxial feed, an MTM with six-unit cells, a WR-284 rectangular waveguide and a horn aperture (see ***Figure 1***). The MTM unit cell, which comprises a square waveguide and CeSRR, has two operating modes and is the foundation for dual-band operation and filtering. A coaxial feed ensures a good impedance match between the standard SMA connector and the MTM, which is derived from the coaxial coupler of the MTM-inspired backward wave oscillator of Tang et al.[23]

The part of the CeSRR with the cylindrical probe is inserted into the WR-284 rectangular waveguide for transformation from the TM mode of the coaxial feed to the TE mode in the WR-284 rectangular waveguide. The WR-284 rectangular waveguide, with one short end and the other end connecting to the horn aperture, serves as a bridge to connect the MTM to free space. The MTM horn antenna is optimized using CST Microwave Studio[24] and the corresponding parameters are listed in ***Table 1***. The detailed parameters of the CeSRR can be found in the work of Duan et al.[22]

RESULTS AND ANALYSIS

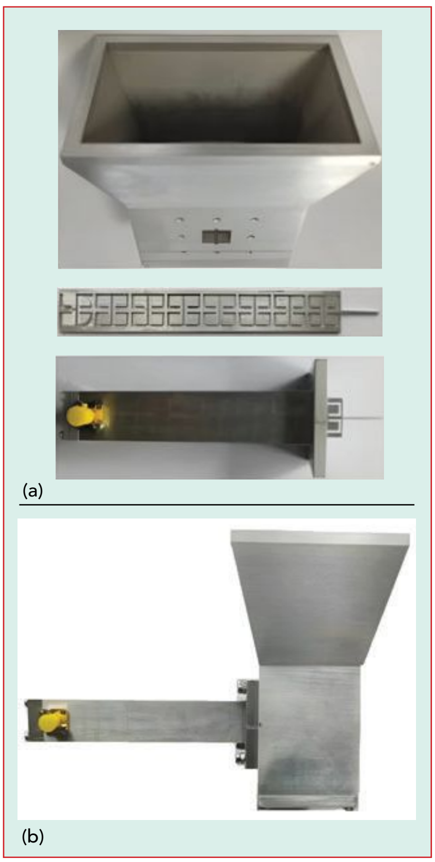
Reflection Measurements

The aluminum MTM horn antenna prototype is shown in ***Figure 2***. Low speed wire electrical discharge machining with a 0.005 mm fabrication tolerance is employed to fabricate the CeSRRs with the matched block.

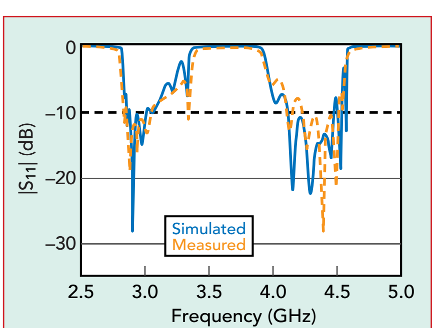
Simulated and measured $|S_{11}|$ obtained using CST Microwave Studio[24] and a vector network analyzer, respectively, exhibit good agreement and show that the antenna has two passbands centered at approximately 3 and 4.35 GHz (see ***Figure 3***). Slight discrepancies are attributed to fabrication tolerances of the CeSRRs.

Far Field Radiation Characteristics

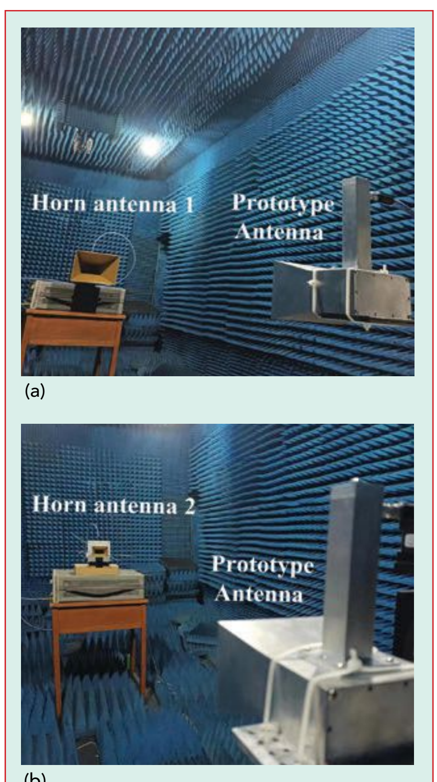
Measurement of the prototype antenna's far field radiation characteristics in a microwave anechoic chamber is shown in ***Figure 4***. Two test antennas are used; one is a 15



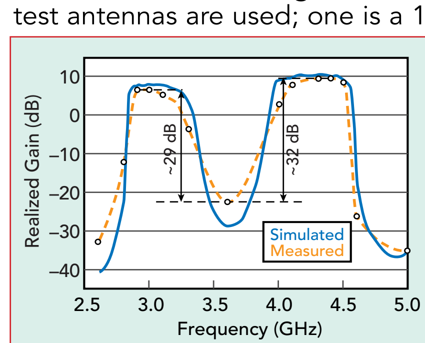
▲ Fig. 2 (a) Fabricated components and (b) assembled prototype antenna.



▲ Fig. 3 Simulated and measured $|S_{11}|$.



▲ Fig. 4 Radiation pattern measurement setup: (a) first passband and (b) second passband.



▲ Fig. 5 Simulated and measured gain.

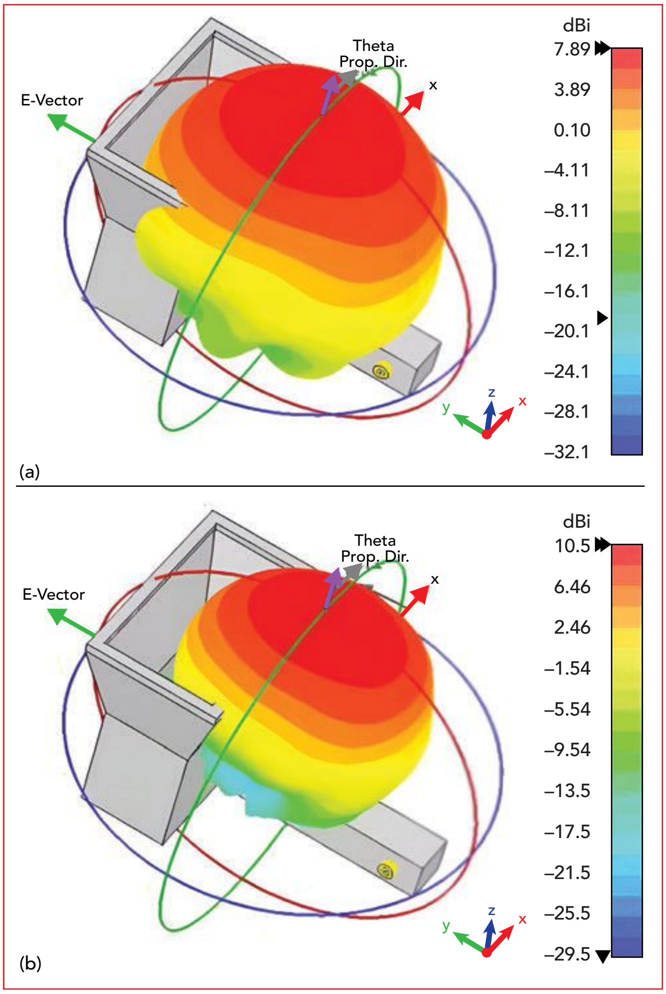


Fig. 6 Simulated 3D radiation patterns at (a) 3 and (b) 4.35 GHz.

dB standard gain horn operating from 2.6 to 3.95 GHz, and the other is a 10 dB standard gain horn operating from 3.9 to 6 GHz.

Simulated compared with measured gain is shown in ***Figure 5***. Measured results indicate that the MTM horn antenna has a maximum realized gain of approximately 6.5 dBi in the first passband around 3 GHz and approximately 9.5 dBi in the second passband around 4.35 GHz. In comparison, the gain in the stopband drops sharply to approximately -22.5 dB, indicating an out-of-band gain suppression level (OBGSL) of approximately 29 and 32 dB with respect to the maximum realized gains in the first and second passbands, respectively.

Simulated 3D far field radiation patterns are shown in ***Figure 6***, and simulated radiation patterns are compared with measured patterns at 3 and 4.35 GHz in the xoz and yoz planes (see ***Figures 7*** and ***8***), respectively. Measured results agree well with the simulation. On boresight, the x-pol is 20 dB lower than the co-pol.

Discussion

A comparison of the antenna described in this work with selected referenced antennas is presented in ***Table 2***. With respect to the horn antennas with SRRs or via holes,[16-18] this antenna provides dual-band operation as well as filtering. This MTM horn antenna without additional filters demonstrates a remarkable filtering response, resulting in a smaller size compared with the one using two different filters.[21]

Furthermore, a coaxial coupler and waveguide coupler are separately used as output structures in two kinds of backward wave oscillators.[25,26] In this work, the dual-band antenna combines the two coupling technologies; coaxial coupling and waveguide coupling are used to feed the antenna and connect to the horn aperture.

CONCLUSION

An MTM is used to construct a dual-band filtering horn antenna. The MTM antenna exhibits dual-band operation and filtering performance, as demonstrated by simulation and measurements. Maximum realized gains are approximately 6.5 and 9.5 dBi in the two passbands, respectively. The MTM horn antenna exhibits excellent filtering performance as well. This work offers a promising approach for the design of horn antennas with dual-band filtering response. ■

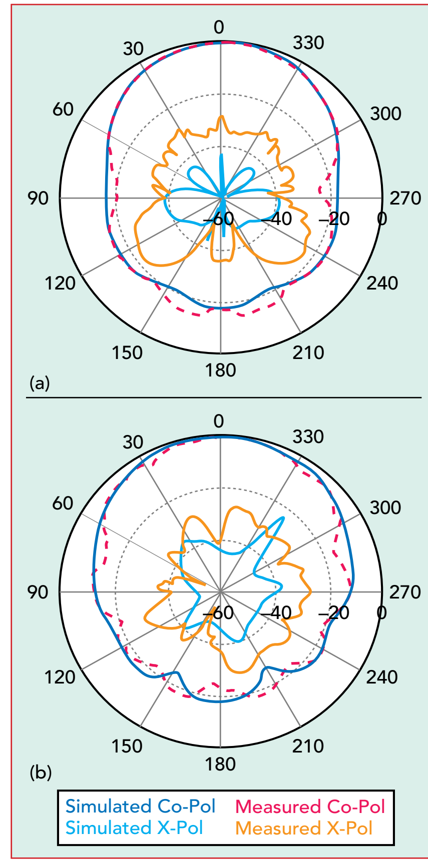


Fig. 7 Simulated and measured normalized radiation patterns at 3 GHz: (a) xoz plane and (b) yoz plane.

References

1. Y. Zhao, Z. Shen and W. Wu, "Wideband and Low-Profile H-Plane Ridged SIW Horn Antenna Mounted on a Large Conducting Plane," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 11, November 2014, pp. 5895–5900.
2. C. Wang, E. Li, Y. Zhang and G. Guo, "Ridged Horn Antenna with Adjustable Metallic Grid Sidewalls and Cross-Shaped Back Cavity," *IEEE Antennas Wireless Propagation Letters*, Vol. 15, November 2015, pp. 1221–1225.
3. Y. Pan, Y. Cheng and Y. Dong, "Dual-Polarized Directive Ultrawideband Antenna Integrated with Horn and Vivaldi Array," *IEEE Antennas and Wireless Propagation Letters*, Vol. 20, No. 1, January 2021, pp. 48–52.
4. J. S. Kang, N. W. Kang, D. G. Gentle, K. MacReynolds and M. H. Francis, "Intercomparison of Standard Gain Horn Antennas at W-Band," *IEEE Transactions on Instrumentation and Measurement*, Vol. 60, No. 7, July 2011, pp. 2627–2633.
5. A. B. Ayed, I. Jaffri, A. M. Darwish, P. Mitran and S. Boumaiza, "Proof-of-Concept of Millimeter-Wave RF Beamforming Transmitter Architecture Employing Frequency-Multiplier-Based Up-Converters," *IEEE Microwave and Wireless Components Letters*, Vol. 32, No. 6, June 2022, pp. 776–779.

Ultra Low Phase Noise Phase Locked Clock Translators

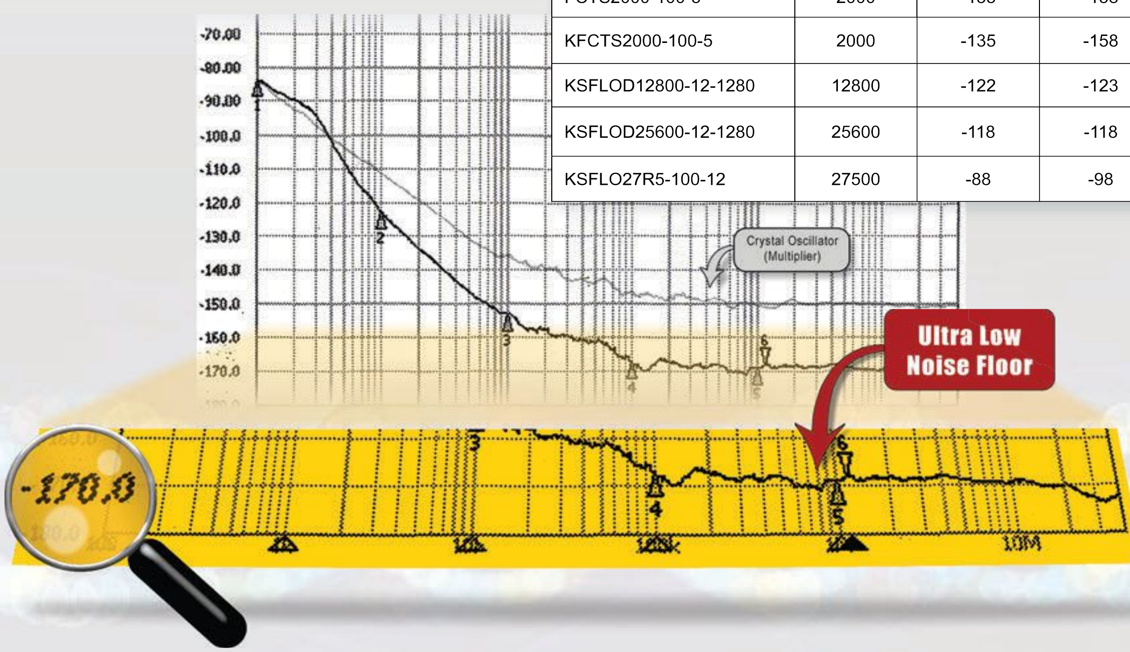
Up to 27.5 GHz

Features
- Cost Effective
- Eliminates Noisy Multipliers
- Patented Technology

Applications
- Scanning & Radar Systems
- High Frequency Network Clocking (A/D & D/A)
- Test & Measurement Equipment
- High Performance Frequency Converters
- Base Station Applications
- Agile LO Frequency Synthesis

New!

Model	Frequency (Mhz)	Typical Phase Noise		Package
		@10 kHz	@100 kHz	
VFCTS100-10	100	-156	-165	
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	
KSFLOD25600-12-1280	25600	-118	-118	
KSFLO27R5-100-12	27500	-88	-98	



Talk To Us About Your Custom Requirements.

SYNERGY® MICROWAVE CORPORATION
Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com | Web: www.synergymwave.com
Mail: 201 McLean Boulevard, Paterson, NJ 07504

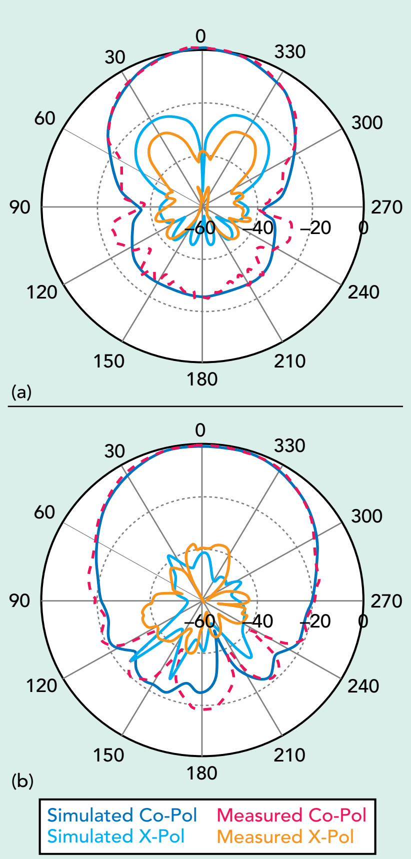


Fig. 8 **Simulated and measured normalized radiation patterns at 4.35 GHz: (a) xoz plane and (b) yoz plane.**

TABLE 2

COMPARISON WITH OTHER WORK

Reference	16	17	18	21	This Work
Antenna Type	WG	Planar	WG	WG	WG
Filtering	SRRs	Via Holes	SRRs	Filters	MTM
Dual Band	No	No	No	Yes	Yes
Center Frequency (GHz)	10	16.6	9.8	25.2/29.2	3/4.35
OBGSL (dB)	~28*	~12*	~35.4	~20/25*	~29/32
Volume (λ^2)**	4.7x3.4x5.7	6.2x3.6x0.16	3.2x2.4x5.3	2.2x4.6x3	1x1.2x1.9

*Read from figures.

** λ is the free space wavelength corresponding to the center frequency of a single band antenna or the center frequency of the lower operating band of a dual band antenna. For reference 17, it is the waveguide.

6. S. R. Zang and J. R. Bergmann, "Analysis of Omnidirectional Dual-Reflector Antenna and Feeding Horn Using Method of Moments," *IEEE Transactions on Antennas and Propagation*, Vol. 62, No. 3, March 2014, pp. 1534–1538.
7. X. C. Zhu, P. P. Zhang, Y. X. Zhang, J. X. Ge and Z. H. Gao, "A High-Gain Filtering Antenna Based on Folded Reflectarray Antenna and Polarization-Sensitive Frequency Selective Surface," *IEEE Antennas and Wireless Propagation Letters*, Vol. 19, No. 8, August 2020, pp. 1462–1465.
8. D. E. Serup, G. F. Pedersen and S. Zhang, "Dual-Band Shared Aperture Reflectarray and Patch Antenna Array for S- and Ka-Bands," *IEEE Transactions on Antennas and Propagation*, Vol. 70, No. 3, March 2022, pp. 2340–2345.
9. C. Chen, K. Huang and Y. Yang, "Microwave Transmitting System Based on Four-Way Master-Slave Injection-Locked Magnetrons and Horn Arrays with Suppressed Sidelobes," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 66, No. 5, May 2018, pp. 2416–2424.
10. N. Ashraf, A. R. Sebak and A. A. Kishk, "PMC Packaged Single-Substrate 4×4 Butler Matrix and Double-Ridge Gap Waveguide Horn Antenna Array for Multibeam Applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 69, No. 1, January 2021, pp. 248–261.
11. N. Ghassemi and K. Wu, "Millimeter-Wave Integrated Pyramidal Horn Antenna Made of Multilayer Printed Circuit Board (PCB) Process," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 9, September 2012, pp. 4432–4435.
12. M. Hamedani, H. Oraizi, A. Amini, D. Zarifi and A. U. Zaman, "Planar H-Plane Horn Antenna Based on Groove Gap Waveguide Technology," *IEEE Antennas and Wireless Propagation Letters*, Vol. 19, No. 2, February 2020, pp. 302–306.
13. M. M. Yang, L. Zhang, Y. Zhang, H. W. Yu and Y. C. Jiao, "Filtering Antenna with Quasi-Elliptic Response Based on SIW H-Plane Horn," *IEEE Antennas and Wireless Propagation Letters*, Vol. 20, No. 7, July 2021, pp. 1302–1306.
14. Y. Cheng and Y. Dong, "High-Gain All-Metal 3-D Printed Lens-Horn Antenna for Millimeter-Wave Applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 22, No. 2, February 2023, pp. 308–312.
15. J. H. Cho, K. Y. Park, C. M. Lim and H. W. Son, "Design and Implementation of an X-Band Horn Antenna with a Metamaterial Lens Using 3D Printing Technology," *IEEE Access*, Vol. 12, January 2024, pp. 17773–17781.
16. M. Barbuto, F. Trotta, F. Bilotti and A. Toscano, "Horn Antennas with Integrated Notch Filters," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 2, February 2015, pp. 781–785.
17. L. Liu, T. -L. Bai, J. -Y. Deng, D. Sun, Y. Zhang, T. Yong, S. -G. Zhou and L. -X. Guo, "Substrate Integrated Waveguide Filtering Horn Antenna Facilitated by Embedded Via-Hole Arrays," *IEEE Antennas and Wireless Propagation Letters*, Vol. 19, No. 7, July 2020, pp. 1187–1191.
18. S. S. Roy, C. Saha, N. K. Mallenahalli and D. Sarkar, "Circular Split Ring Resonator (C-SRR) Array Integrated Frequency-Notched Horn-Filtenna with Wide and Strong Rejection Band," *IEEE Access*, Vol. 9, March 2021, pp. 52664–52671.
19. Y. B. Jung and S. Y. Eom, "Dual-Band Horn Array Design Using a Helical Exciter for Mobile Satellite Communication Terminals," *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 3, March 2012, pp. 1336–1342.
20. X. Yang, X. Q. Lin, B. Wang and Y. Su, "A Dual-Wideband Structure-Shared Antenna with Self-Diplexing Property for High-Power Microwave Application," *IEEE Transactions on Antennas and Propagation*, Vol. 69, No. 7, July 2021, pp. 4201–4205.
21. S. Wu, J. Li, Y. Li, S. Yan and X. Y. Zhang, "SLM Printed Dual-Band Dual-Polarized Shared-Aperture Filtering Antenna Array for Millimeter-Wave Integrated Sensing and Communication," *IEEE Transactions on Antennas and Propagation*, Vol. 72, No. 3, March 2024, pp. 2855–2860.
22. Z. Duan, J. S. Hummelt, M. A. Shapiro and R. J. Temkin, "Sub-Wavelength Waveguide Loaded by a Complementary Electric Metamaterial for Vacuum Electron Devices," *Physics of Plasmas*, Vol. 21, No. 10, October 2014.
23. X. Tang, Y. Zhang, S. Jiang, J. Zhang, L. Zhang, Q. Wang, X. Li and Z. Duan, "Metamaterial-Inspired Backward Wave Oscillator Using a Dual Band Coaxial Coupler," *IEEE Electron Device Letters*, Vol. 44, No. 9, September 2023, pp. 1559–1562.
24. CST Studio Suite, *Dassault Systèmes*, Web: http://www.cst.com.
25. X. Tang, Z. Duan, X. Ma, S. Li, F. Wang, Y. Wang, Y. Gong and J. Feng, "Dual Band Metamaterial Cherenkov Oscillator with a Waveguide Coupler," *IEEE Transactions on Electron Devices*, Vol. 64, No. 5, May 2017, pp. 2376–2382.
26. X. Tang, X. Li, Q. Wang, J. Zhang, X. Wang, S. Li, L. Zhang and Z. Duan, "Miniature Metamaterial Backward Wave Oscillator with a Coaxial Coupler," *IEEE Transactions on Electron Devices*, Vol. 69, No. 3, March 2022, pp. 1389–1395.


MiniRF
Tiny 4x4 mm Package
MRFCP5753
5-1225 MHz, 12 dB, 75Ω Coupler
Delivers High Performance for Broadband and CATV Applications
Passives with a Passion for Performance
Couplers
Splitters
Transformers
RF Chokes
MRFCP6762
MiniRF is a proven, preferred leader in passive component supply for Broadband/CATV and Wireless Communications, with 1+ billion components shipped. MiniRF passives enable DOCSIS 4.0 & FDX system requirements, max RF output power, and have excellent repeatability and reliability with 100% RF testing. The USA-based design center supports standard and custom components, while multiple low-cost overseas manufacturing operations with no tariffs deliver competitive pricing.
RFMW®
Contact our team of experts for information, samples and sales: sales@rfmw.com | rfmw.com

Pocket Alarm for Microwave and Gamma Radiation

Ultraview
Berkeley, Calif.

Recent advances in GaN power amplifiers[1] and microwave tubes have enabled the development of portable microwave jammers and directed energy weapons (DEWs), which have the potential to pose a human health threat. Of particular concern are high-power microwave (HPM) pulse trains. Without inexpensive miniature RF alerting and recording devices that can be carried by thousands of government workers, military members and the general public, it is not possible to track the presence and potential effects of direct energy weapons.

Fig. 1 EM/Gammalert indicating HPM energy and gamma radiation.

THE NEED FOR WEARABLE ALARMS WITH LOGGING

Historically, spectrum analyzers and wideband digitizers used for monitoring HPM energy have been expensive and large, while portable RF field strength meters have been inadequate for characterizing pulsed microwaves. Hence, Ultraview developed its EM/Gammalert, a 4-ounce, 5.5 × 9 × 1.5 cm pocket/purse device, shown in ***Figure 1***, that issues visual and audible warnings of HPMs, as well as conventional radiation threats, including gamma radiation. These prompt the wearer to retreat from the threat and alert others.

In addition to providing an immediate alarm, the device records

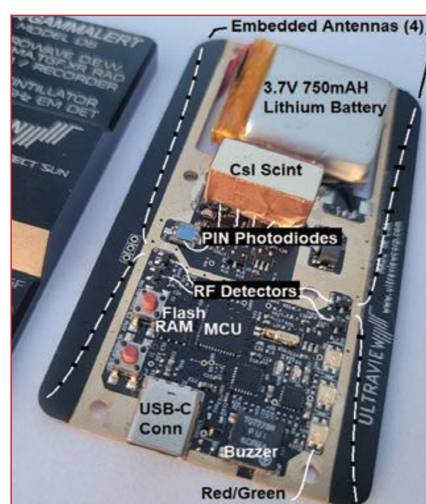


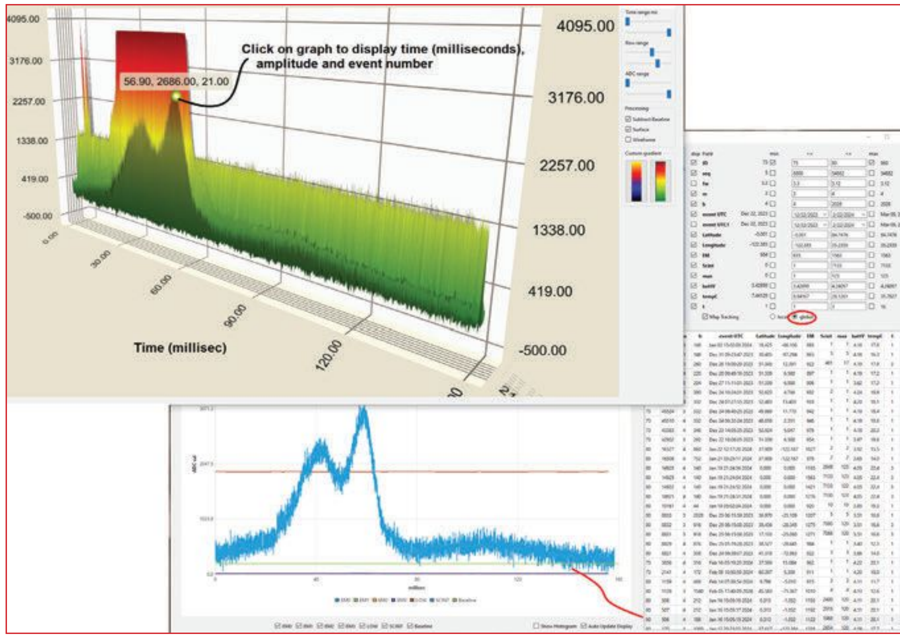
Fig. 2 PCB-embedded antennas extend outside the machined case.

each event for forensic and research purposes. Its flash RAM stores 1000 complete sets of time-aligned microwave and gamma energy envelope waveforms, each with a 1 second universal time tag for downloading. Users download via USB to a host PC, enabling viewing and waveform storage in a searchable SQL database on the computer. After examination, they can upload concerning events to a monitored global SQL database for worldwide scrutiny and near-real-time AI-assisted recognition of emerging threat patterns.

MICROWAVE/EMP DETECTION AND RECORDING CIRCUITRY

The EM/Gammalert senses RF/microwave energy using four 0.5 to 10 GHz angled monopole antennas embedded in the PCB edges, which extend outside the aluminum clamshell case, as shown in ***Figure 2***. Each feeds a Schottky diode detector and a hold capacitor connected to a 12-bit analog-to-digital converter (ADC) in the embedded TI MSP430FR5969 microcontroller unit (MCU). These detectors can capture continuous wave (CW) and pulsed microwave bursts as short as 300 ns, as well as lightning or nuclear-induced electromagnetic pulses (EMPs). The hold capacitors "stretch" short bursts, allowing 40 KSPS ADC sampling.

The GUI software allows users to set separate trigger thresholds for RF, microwave, EMP and gamma events. When any threshold is exceeded, the entire set of EM



▲ Fig. 3 X-rays and background radiation recorded by EM/Gammalert.

and gamma energy waveforms, including 8 milliseconds of pre-trigger view, are stored on internal 16 MB persistent memory. Two threshold levels are programmable — one for energy levels that routinely occur and will be indicated by green LED flashes and beeps, to indicate that the device is functioning, and a higher threshold for dangerous levels, signified via a beep and continuous red LED, which may require retreat and later examination of stored waveforms.

IONIZING RADIATION DETECTION SECTION

The unit detects ionizing radiation using four parallel-connected PIN photodiodes optically coupled to a thallium-doped cesium iodide scintillator crystal. A fifth photodiode is located separately to prevent overload from high-flux pulsed radiation events, enabling, for example, enhanced research into lightning-induced terrestrial gamma flashes (TGFs) that may occasionally deliver high peak exposures to air passengers but are too short for characterization by conventional wearable radiation monitors. The photocurrents of the reverse-bias PIN diodes drive picoampere-bias amplifiers, which drive ADCs in the MCU.

Operation of this section was validated using X-rays, gamma sources and ground and airborne background radiation. ***Figure 3*** shows X-rays recorded by EM/Gammalert moving through a hand-carry baggage scanner. Spikes at the upper left of the waterfall are earlier-captured background cosmic radiation events.

VALIDATING THE UNIT USING AN EMULATED MICROWAVE DEW

There are concerns regarding the microwave auditory effect[2] (Frey Effect), which results from exposure to intense sub-millisecond microwave bursts repeating at an audio-frequency rate. The duty cycle may be too low to cause dangerous heating, but the kilohertz range may cause adverse health effects.

The unit can respond to a wide RF duty cycle range, from 300 ns single HPM events to CW. To emulate a hypothetical pulsed DEW that might evoke 1600 Hz chirps, an EM/Gammalert was placed at close range from an Ultraview Ultracomb-8G GaN 20 V 90-picosecond radar pulse generator driving a Vivaldi antenna and producing 500 million pulses per second (500 MPPS), gated on in 300 ns wide bursts, repeating 1600x per second. ***Figure 4*** shows a captured train of 300 ns microwave bursts, repeating 1600x per second. The green and blue pickets are from the antennas facing the source.

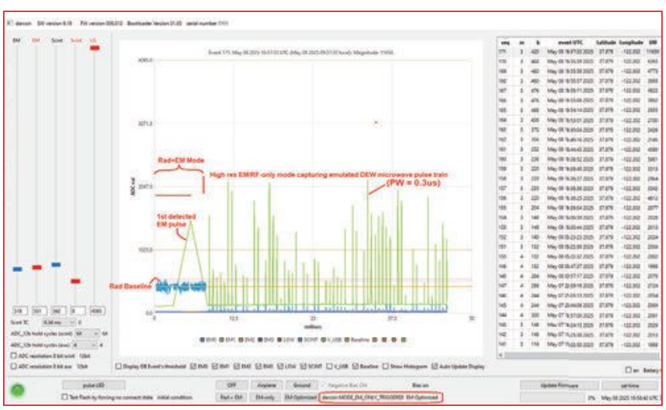


Fig. 4 **Microwave pulses recorded by the EM/Gammalert.**

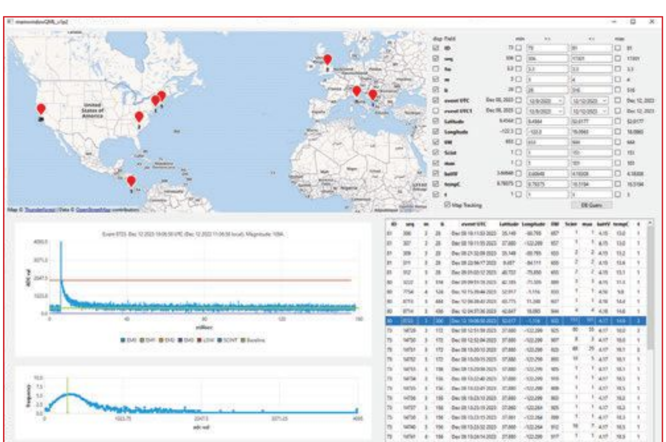


Fig. 5 **Global database map of user-uploaded events.**

EMERGING GLOBAL THREAT ANALYSIS

Data from any instrument studying new threats and sparsely-researched phenomena must be vetted by experts. Isolated alarm indications, unless correlated with concurrent health effects or readings from other instruments, may not be credible. However, if similar indications from clusters of devices are received in a global database, as in ***Figure 5***, an increased level of confidence and global knowledge could then be established.

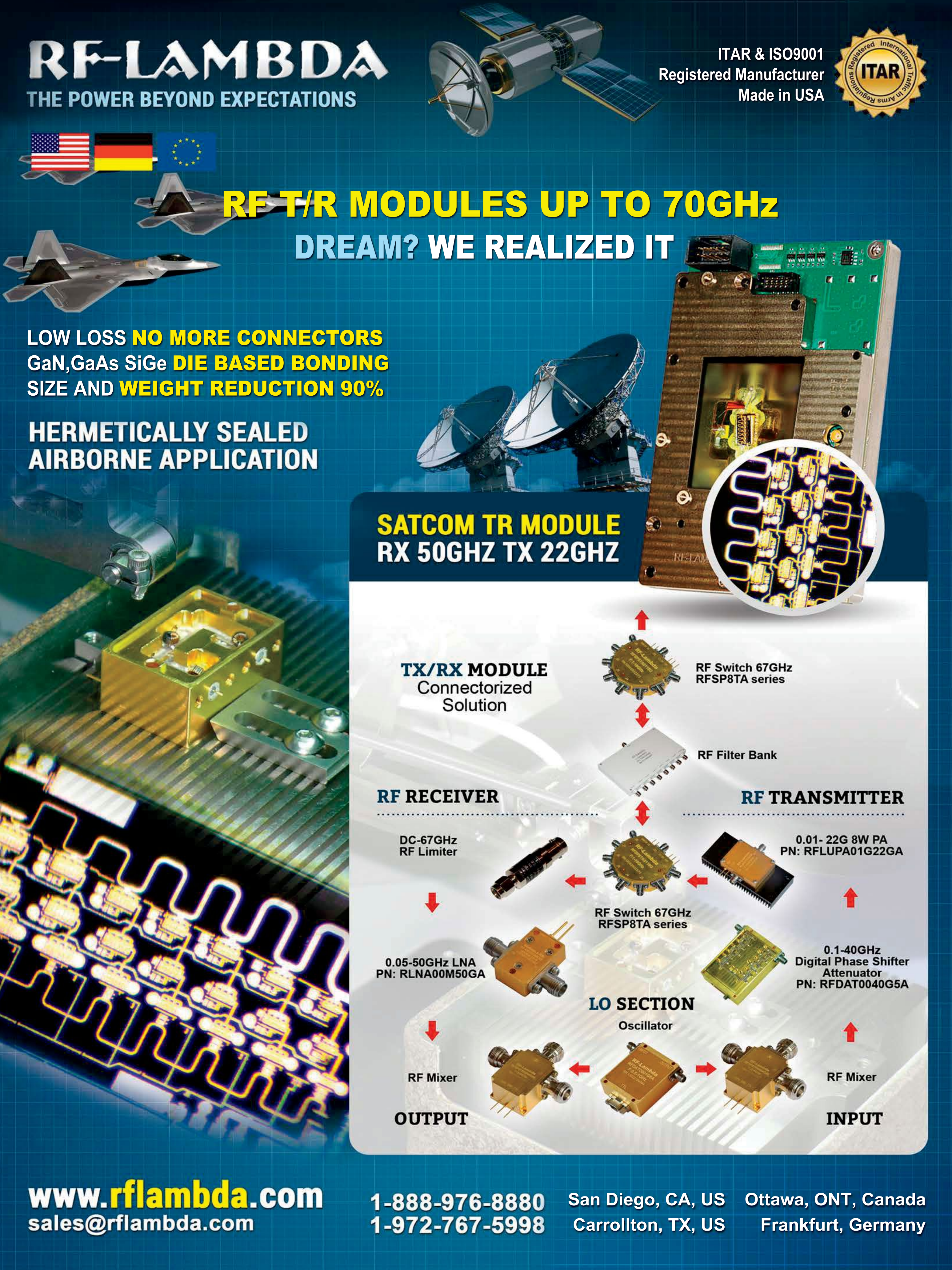
SUMMARY

A pocket device designed to warn of and record emerging threats has undergone preliminary validation using X-ray, gamma and a wide range of CW and pulsed microwaves.

Ultraview, Berkeley, Calif.
www.ultraviewcorp.com

References

1. B. Manz, "Delivering More Power – GaN Continues to Supercharge Electronic Attack," *The Journal of Electronic Dominance*, June 2025, pp. 20–30, Web: https://www.jed-digital.com/jedm/0625_june_2025/MobilePagedArticle.action?articleId=2060635.
2. K. R. Foster, D. C. Garrett and M. C. Ziskin, "Can the Microwave Auditory Effect Be "Weaponized"?," *Front Public Health*, Vol. 9, December 22, 2021, 23;9:788613. doi: 10.3389/fpubh.2021.788613. PMID: 35004589; PMCID: PMC8733248.
3. "An Assessment of Illness in U.S. Government Employees and Their Families at Overseas Embassies," *The National Academies of Sciences, Engineering and Medicine*, 2020, Washington, DC., Web: https://doi.org/10.17226/25889.
4. S. Pelley, "Havana Syndrome Mystery Continues as a Lead Military Investigator Says Bar for Proof was Set Impossibly High," *CBS News*, July 2024, Web: www.cbsnews.com/news/havana-syndrome-culprit-investigation-new-evidence-60-minutes-transcript-2024-07-07.
5. K. D. Stephan and M. L. Shmatov, "Hazards to Aircraft Crews, Passengers, and Equipment from Thunderstorm-Generated X-rays and Gamma-Rays," *Radiation*, Vol. 1, No. 3, 2021, pp. 162-173, Web: https://doi.org/10.3390/radiation1030015.


RF-LAMBDA
THE POWER BEYOND EXPECTATIONS
ITAR & ISO9001
Registered Manufacturer
Made in USA
ITAR
Registered International Traffic in Arms Regulations
RF T/R MODULES UP TO 70GHz
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTORS
GaN,GaAs SiGe DIE BASED BONDING
SIZE AND WEIGHT REDUCTION 90%
HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
TX/RX MODULE
Connectorized
Solution
RF Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
OUTPUT
INPUT
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
San Diego, CA, US
Carrollton, TX, US
Ottawa, ONT, Canada
Frankfurt, Germany

Cryogenic Circulators & Isolators for Quantum

QuinStar's QCY series cryogenic isolators and circulators are designed for mission-critical applications in quantum computing, superconducting devices, space-based systems and ultra-sensitive test environments. These passive components operate down to millikelvin with insertion loss as low as 0.15 dB and isolation up to 44 dB.

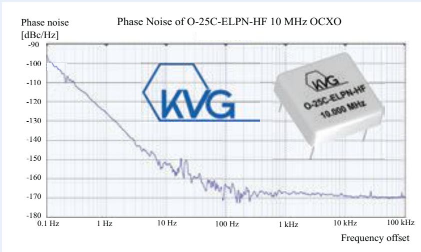
The QCY series is available in a variety of frequency bands, including 4 to 8 GHz, 4 to 12 GHz, 18 to 26.5 GHz and beyond, with single devices or multi-port array configurations. These solutions are engineered for integration into dilution refrigerators or cryostats and are compatible with a range of mechanical form factors.

QuinStar's cryogenic circulator/isolator arrays enable qubit readout pathways for today's most advanced quantum research programs. With Mμ-metal and double-shielded options available, QCY units offer magnetic isolation, minimizing interference in dense cryogenic environments.

Every QCY device is manufactured and tested in the U.S. using precision ferrite technology and proprietary magnetic assembly techniques. QuinStar's cryogenic components meet NASA EEE-INST-002 derating guidelines and are trusted by national labs, defense programs and quantum hardware startups alike. The QCY series provides signal integrity required for next-generation experimentation in quantum infrastructure and ultra-low noise environments.

QuinStar Technology Inc. has been engineering the future of modules and cryogenic components since 1993 and has expertise in mmWave products, microelectronic assembly, rapid prototyping and mass customization. QuinStar products range from standard catalog components to specialized high performance RF signal generating, amplifying and conditioning components.

QuinStar Technology, Inc.
Torrance, Calif.
https://quinstar.com



Low Phase Noise 10 MHz OCXO

KVG, a German company with over 75 years in high-end frequency control products, introduces its new 10 MHz oven-controlled crystal oscillator (OCXO). This oscillator delivers low phase noise and tight stability due to advanced optimized crystal manufacturing and sophisticated oven control design. This OCXO achieves minimal spectral spreading and superior signal integrity, including less than -90 dBc/Hz at 0.1 Hz offset, -124 dBc/Hz at 1 Hz offset, -149 dBc/Hz at 10 Hz offset and -166 dBc/Hz at 1 KHz offset. The oscillator minimizes phase jitter and drift over short averaging times and has an Allan Deviation (ADEV) of ≤ 9E-14 at T=1 second. Long-term frequency stability is controlled to ensure consistent output over extended operational lifetimes. Aging of this oscillator is less than ± 0.2 ppb per day, with a cumulative aging of less than ± 0.1 ppm over 10 years. The OCXO maintains consistent frequency output across varying environmental temperatures, specifically less than ± 2.0 ppb over the operating temperature range of -20°C to +70°C. Additionally, the OCXO has a supply voltage of +12 V and dimensions of 51 x 51 x 16 mm. KVG's OCXO can be used in metrology and calibration laboratories, scientific research equipment, high precision measurement devices, precision navigation and timing systems, radar systems, coherent communication systems and satellite communication ground stations.

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

MAKING WAVES

Analog Devices at IMS 2025

ADI's latest RF, mmWave technologies, clocking, amplifier, and power solutions come together to enable unprecedented system-level solutions for aerospace and defense, communications, and instrumentation customers.

Analog Devices

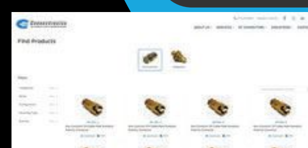
www.analog.com/en/resources/media-center/videos/6375544786112.html

Connectronics, Inc. Launches New Website Search Feature

Connectronics, Inc. announced the launch of a new search feature on the company's website. With Connectronics' new search feature, visitors can search for products by any attribute, including connector type, adapter type, series, configuration, body type, mounting type, impedance, polarity and hermetic iso ground.

Connectronics, Inc.

customrfconnectors.com



Celebrating 25 Years

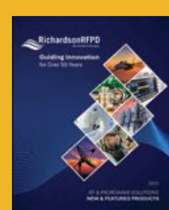
For the past 25 years, LitePoint has been leading the way in wireless testing. Wireless technology is constantly advancing, and we have an unwavering commitment to simplify test and deliver the most technologically advanced solutions.

LitePoint

www.litepoint.com

Your One-Stop RF Product Lineup Awaits

Explore high-performance RF products, components and solutions engineered for advanced RF applications.



Richardson RFPD

https://shop.richardsonrfpd.com/docs/rfpd/Featured-Products-Brochure.pdf?utm_campaign=RFPD&utm_source=MWJ&utm_medium=MakingWave-SEPT2025

Spectrum Control Drives Innovation at Philadelphia Facility

Spectrum Control's strategic investments in automation, digital manufacturing and modernized facilities, including a renovated Philadelphia RF+ SiP center, boosted assembly capacity 30 percent, throughput 50 percent, improved customer satisfaction and reinforced leadership in defense-grade RF signal management technologies.

Spectrum Control

spectrumcontrol.com

Trans-Tech Hits 70 Years!

Trans-Tech continues its 70-year legacy as the number one ferrite magnetic manufacturer in the U.S., delivering superior RF and microwave filters, circulators, radar components, patch antenna solutions and ceramic-enabled devices.

Trans-Tech

www.trans-techinc.com

NEW PRODUCTS

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

DEVICES/ COMPONENTS/MODULES

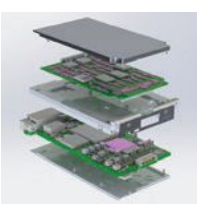
High-Power, Drop-In Circulator

3G6BEL-1 is a high-power, drop-in circulator operating within 2.5 to 6 GHz and can handle 100 W of power at CW over -40°C to +90°C. This circulator was optimized for space-constrained application and specifically designed for EW jammer applications. The design is covered under a U.S. patent and is unique for its high-power handling, wide operation band, compact size and stability over a wide temperature range.

AEM Renaissance
www.rec-usa.com

Multi-Channel RF Digitizers

VENDORVIEW



The ADSY1100 Series from Analog Devices (ADI) are multi-channel RF digitizers that operate from 0.1 to 20 GHz. These digitizers integrate the AD9084, Virtex™ UltraScale+™ FPGA and Zynq™ UltraScale+™ MPSoC, as well as optical transceivers, onboard memory, a power distribution network, clock conditioning and more. They are built around ADI's "Apollo" MXFE™ product (AD9084) featuring DAC sample rates of up to 28 GSPS and ADC sample rates of up to 20 GSPS in a 4Tx/4Rx configuration.

Analog Devices
www.analog.com

Ultra-Wideband Power Divider/ Combiner

VENDORVIEW

MIcable 1 to 26.5 GHz 5-way ultra-wideband power divider/combiner can accept and divide a 1 to 26.5 GHz signal into five output signals with equal amplitude unbalance (max. ±0.9 dB) and phase unbalance (max. ±10°). Due to extremely wide bandwidth, excellent VSWR (max. 1.6:1), insertion loss (max. 4.3 dB) and isolation (min. 16 dB), it can be widely applied in test and measurement and other wideband applications.

MIcable
www.micable.cn

High Power Limiter

VENDORVIEW

Quantic PMI Model LM-10M12G-20-10W-SFF is a high-power limiter operating in the frequency range of 0.01 to 12 GHz with 10 W of CW power handling (40 dBm) and 100 W peak. This compact housing measures 1.0 × 0.68 × 0.35 in. and is fitted with SMA female connectors.

Quantic PMI
www.quanticpmi.com

Bi-Directional Couplers

VENDORVIEW

A series of bi-directional couplers are available for operation in high frequency/very high frequency/ultra high frequency bands, with coupling values from 11 dB through 20 dB and all in small sized surface-mount packaging. These products are designed for applications in forward and reverse power sampling in routine operational monitoring of antenna amplifiers in radio transceivers and production testing reflectometers. The input power ratings are from 15 to 50 W.

Synergy
www.synergymwave.com

CABLES & CONNECTORS

Cable Assemblies

Amphenol RF introduced the SMPM to SMPM assembly on RG-178 cable into their portfolio of cable assemblies. The compact size of these assemblies makes them highly suited for use in applications where space is at a premium. With a 50 Ω impedance and the ability to operate from DC to 6 GHz, the SMPM to SMPM cable assembly on RG-178 is equipped to provide reliable RF performance in the most demanding applications.

Amphenol RF
www.amphenolrf.com

RF Cable Assemblies

VENDORVIEW

Fairview Microwave, an Infinite Electronics brand, has expanded its line of in-stock RF cable assemblies. The new products are based on the most popular custom cable designs created through Fairview's Cable Creator platform or in consultation with the company's technical support team. By turning the custom configurations into standard products, Fairview ensures that businesses in various industries have quick access to reliable RF solutions.

Fairview Microwave
www.fairviewmicrowave.com

RG Cable Assemblies

VENDORVIEW

Pasternack, an Infinite Electronics brand, has launched a new line of RG cable assemblies. Built using many types of RG (radio grade) cables, the line adds to Pasternack's already extensive portfolio and meets the requirements of numerous industries and applications. The new additions to Pasternack's cable assembly line include both 50 Ohm and 70

NewProducts

Ohm cable options, ensuring optimal signal transmission for any application.
Pasternack
www.pasternack.com

AMPLIFIERS

1.0–6.0 GHz, 300 W, 200 W Amplifier

VENDORVIEW

Exodus AMP20043 is ideal for broadband EMI-Lab, comms and EW applications. The Class A/AB linear design is for all modulations and industry standards. The amplifier covers 1.0 to 6.0 GHz, producing 300 W minimum, 200 W P1dB and 55 dB minimum gain. Excellent flatness and optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability and ruggedness. Integrated in our compact 5U chassis weighing approx. 35 kg.
Exodus Advanced Communications
www.exoduscomm.com

1000 W Broadband Amplifier

The 5129 is a 1000 W broadband amplifier that covers the 20 to 1000 MHz frequency range. This amplifier utilizes advanced power devices that provide excellent ruggedness, high gain and industry-leading P1dB performance. Due to robust engineering and employment of the most advanced devices, this amplifier achieves high efficiency operation with proven reliability. Like all OPHIR RF amplifiers, the 5129 comes with an extended multi-year warranty backed by Ophir RF's commitment to total customer satisfaction.
OPHIR RF
www.ophirrf.com

High-Efficiency UHF Power Amplifier

VENDORVIEW

Now available at RFMW, the CMX90A009 from CML Micro is a high-efficiency GaAs HBT power amplifier designed to meet the rigorous demands of professional and mission-critical communications. Delivering +40 dBm output power with over 60 percent collector efficiency at 435 MHz, it operates from a 7.4 V supply and supports both linear and saturated modes. Its wide frequency range, thermally enhanced DFN package and external matching flexibility make it ideal for LMR, public safety and mesh network transmitters.
RFMW
www.rfmw.com

High Performance Broadband Low Noise Amplifiers (LNAs)

VENDORVIEW

Quantic PMI's (Planar Monolithics) broadband LNAs offer the industry's lowest noise figure available up to 70 GHz, internal voltage regulation, internal reverse voltage protection, multichannel configurations, 2-in-1 dual-use connectorized or surface-mount designs and unconditional stability. Frequency range, gain and OP1dB values can be optimized to meet your requirements. Form, fit and function designs are our specialty, with COTS and RoHS availability. Custom amplifiers can be designed and built to your specifications at catalog prices.
Richardson RFPD
www.richardsonrfpd.com

2.0~40.0 GHz Broadband Low Noise Amplifier

Model ABL4000-05-2830 is a two-stage MMIC-based low noise amplifier module operating in the frequency range from 2.0 to 40 GHz. It offers 28 dB of linear gain and

2.5~5.0 dB of typical noise figure with excellent gain flatness and input/output return loss. The unit has a built-in voltage regulator and operates with a single DC power supply voltage. The package size of the amplifier is 1.5 × 1.0 × 0.4 in.
Wenteq Microwave Corp.
www.wenteq.com

SEMICONDUCTORS/ INTEGRATED CIRCUITS

BFICs

Qorvo's latest integrated BFICs provide a competitive edge with the lowest noise figure, enhanced temperature stability and simplified system integration. They eliminate external LNAs, reduce calibration complexity and improve cost-effectiveness. Designed for high channel efficiency, these BFICs optimize link budgets and reduce power consumption, delivering superior performance for next-generation SATCOM networks. Built on decades of RF leadership, Qorvo delivers the performance, scale and innovation trusted by top SATCOM providers worldwide.
Qorvo
www.qorvo.com

New**Products**

ANTENNAS

Patriot Antenna

Taoglas has released the Patriot series, a compact, multi-function combination roof mount antenna designed for connected vehicle fleets across emergency services, utilities and commercial sectors. Integrating up to 18 antenna elements in a single low-profile enclosure, the Patriot delivers robust multi-network connectivity while reducing vehicle roof clutter and simplifying installation. Originally developed for the Ford Interceptor, the existing vehicle OEM antenna can simply be replaced with the Patriot, while keeping the original antenna functionality, but also adding multi-radio connectivity.

Taoglas
www.taoglas.com

TEST & MEASUREMENT

Port Extender

VENDOR**VIEW**

Copper Mountain Technologies (CMT) introduced the 75 Ohm PE0312-75 port extender, which expands CMT's product portfolio for 75 Ohm test solutions. This new product enhances the flexibility of multi-port testing for broadband, telecommunications, cable and RF research and production applications in 75 Ohm environments. The PE0312-75 is a USB-controlled, 12-port extender or switch, designed specifically for 75 Ohm measurements. It enables seamless expansion from a 2-port VNA to 12 ports for multiple devices or multi-output DUTs, without the need for re-cabling, streamlining complex test configurations.

Copper Mountain Technologies
www.coppermountaintech.com

PXE EMI Receiver

VENDOR**VIEW**

Keysight Technologies, Inc. announced a major enhancement to its PXE Electromagnetic Interference (EMI) receiver, extending the wideband time domain scan (TDS) with a real-time, gapless measurement capability up to 1 GHz measurement bandwidth. The new PXE receiver enables engineers to measure from 30 MHz to 1 GHz in just one step versus the previous three-step version. This advancement provides high sensitivity, enables faster diagnostics and significantly accelerates electromagnetic compliance and certification workflows.

Keysight Technologies, Inc.
www.keysight.com

High Bandwidth Sampling Oscilloscopes

Pico Technology announced the extension of its PicoScope 9400A Series of high bandwidth sampling oscilloscopes. The products are engineered to meet the demanding needs of high speed electronics, communications, semiconductor research and high-energy physics applications. The PicoScope 9400A Series is built on Pico's SXRTO technology and, with this launch, adds three models to the previously announced 25 GHz version, giving users a choice of 6 GHz, 16 GHz, 25 GHz and a flagship 33 GHz bandwidth model.

Pico Technology
www.picotech.com

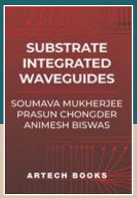
Digital Oscilloscope

RIGOL Technologies announced the launch of its eighth-generation digital oscilloscope — the DS80000 Series Real-Time Digital Oscilloscopes. Featuring up to 13 GHz analog bandwidth and a 40 GSPS sampling rate, this latest addition to RIGOL's portfolio delivers powerful high speed signal capture and analysis capabilities, providing engineers worldwide with a reliable tool for fault isolation and validation in high speed designs. The release of the DS80000 Series marks a significant milestone in RIGOL's ongoing commitment to advancing test and measurement technology.

RIGOL Technologies
www.rigolna.com

MICRO-ADS

Reviewed by
Michael Roberg



Bookend

Substrate Integrated Waveguides

Soumava Mukherjee, Prasun Chongder and Animesh Biswas

Substrate Integrated Waveguides by Mukherjee, Chongder and Biswas is an excellent reference for microwave engineers designing substrate integrated waveguide (SIW)-based circuits. The basics of SIW theory are introduced in Chapters 1 and 2, beginning with the presentation of SIW modes of operation in the context of a traditional rectangular metallic waveguide with reduced height. The working principles introduced in the first two chapters enable any microwave designer to get started with a design while accounting for SIW frequency of operation, loss and methods of transitioning from more traditional transmission lines into SIW.

Chapters 3 and 4 are more advanced, focusing on SIW antenna design. The text is focused on practical design and will be quite useful for practicing antenna designers. Several examples of cavity-backed slot antennas are provided in Chapter 3, including narrowband, dual-band, broadband and dual polarization designs. Chapter 4 covers more advanced designs, including a high gain slot antenna design as well as self-multiplexing designs which incorporate a diplexer or triplexer into the antenna. Antenna arrays using cavity-backed slot antennas are also included in the fourth chapter.

Chapter 5 covers filters implemented in SIW and is more theory-heavy than the prior chapters, with the first several pages being dedicated to filter design theory. The most basic implementation of filters using inductive metal posts and irises is first discussed, followed by more advanced cavity-based filters. As in prior chapters, there are several practical design examples, including measured data. Chapter 6 covers additional passive circuit designs in SIW. These include diplexers, triplexers and branch line couplers. Finally, Chapters 7 and 8 cover oscillators and mixers integrated with SIW, as well as antennas integrated with SIW filters and other passive components.

In summary, this book is recommended for microwave designers who are interested in designing and building SIW-based circuits. The practical examples alone are worth owning the book, as it provides reference designs for many applications and inspiration for designs outside the scope of the book.

ISBN: 9781685690458
Pages: 390
Copyright: 2024
To order this book, contact:
Artech House
us.artechouse.com

AdvertisingIndex

Advertiser	Page No.
3H Communication Systems	15
AMTA 2025	81
Artech House	86
B&Z Technologies, LLC	25
Bradford RF Sales	69
Cernex, Inc.	84
Ciao Wireless, Inc.	38
Coilcraft	23
COMSOL, Inc.	33
EDI CON Online 2025	COV 3
ES Microwave, LLC	85
ETS-Lindgren	27
EuMW 2026	87
Fairview Microwave	67
Frontlynk Technologies Inc.	63
G.T. Microwave Inc.	66
Herotek, Inc.	58
iNRCORE	55
JQL Technologies	3
Knowles Precision Devices	57
LPKF Laser & Electronics	28
Master Bond Inc.	85
Maury Microwave Corporation	35
MECA Electronics, Inc.	54
MIcable Electronic Technology Group	65
Microwave Journal	48, 80
Microwave Products Group (a Dover Company)	24
Miller MMIC	COV 2
Millimeter Wave Products Inc.	53
Mini-Circuits	4-5, 16, 42, 89
MiniRF Inc.	75
Molex	8
Nxbeam	45
Pasternack	13
Pulsar Microwave Corporation	68
QORVO	31
Qualwave	26
Quantic PMI	9
Quantic TRM	9
RapidRF AI Inc.	11
Reactel, Incorporated	41
Remcom	59
Remtec	32
RF-Lambda	6, 29, 49, 79
RFMW	31, 57, 75
Richardson Electronics	51
RLC Electronics, Inc.	21
Special Hermetic Products, Inc.	85
Spectrum Control	7
State of the Art, Inc.	62
Synergy Microwave Corporation	47, 73
Trans-Tech	44
Virginia Diodes, Inc.	19
WAVEPIA	30
Weinschel Associates	56
Wenteq Microwave Corporation	85
Werlatone, Inc.	COV 4
West Bond Inc.	83
Wright Technologies	40
Xtal Ball	37
Yun Micro Electronics	77

Sales Representatives

Eastern and Central Time Zones
Carl Sheffres
Group Director
(New England, New York, Eastern Canada)
Tel: (781) 619-1949
csheffres@mwjournal.com

Michael Hallman
Associate Publisher
(NJ, Mid-Atlantic, Southeast, Midwest, TX)
Tel: (301) 371-8830
Cell: (781) 363-0338
mhallman@mwjournal.com

Pacific and Mountain Time Zones
Brian Landy
Western Reg. Sales Mgr.
(CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada)
Tel: (831) 426-4143
Cell: (831) 713-9085
blandy@mwjournal.com

International Sales
Michael O'Kane
Tel: +44 (0) 1875 825 700
Cell: +44 (0) 7961 038 245
mokane@horizonhouse.com

Germany, Austria, and Switzerland (German-speaking)
Victoria and Norbert Hufmann
victoria@hufmann.info
norbert@hufmann.info

Korea
Jaeho Chinn
JES MEDIA, INC.
Tel: +82 2 481-3411
corres1@jesmedia.com

China
Shanghai
Linda Li
ACT International
Tel: +86 136 7154 0807
lindal@actintl.com.hk

Wuhan
Phoebe Yin
ACT International
Tel: +86 134 7707 0600
phoebey@actintl.com.hk

Shenzhen
Annie Liu
ACT International
Tel: +135 9024 6961
anniel@actintl.com.hk

Beijing
Cecily Bian
ACT International
Tel: +86 135 5262 1310
cecilyb@actintl.com.hk

Hong Kong
Floyd Chun
ACT International
Tel: +852 28386298
floydc@actintl.com.hk

Taiwan, Singapore
Simon Lee
ACT International
Tel: +852 2838 6298
simonlee@actintl.com.hk

Japan
Katsuhiro Ishii
Ace Media Service Inc.
Tel: +81 3 5691 3335
amskatsu@dream.com

Submitting ad material?
Visit: www.adshuttle.com/mwj
(866) 774-5784
outside the U.S. call
+1-414-566-6940

Ed Kiessling
(781) 619-1963
ekiessling@mwjournal.com

Corporate Headquarters: 685 Canton Street, Norwood, MA 02062 • Tel: (781) 769-9750

DC TO 86 GHz

Filter Technologies

For Every Application

LEARN MORE

CAVITY

- Passbands to 43.5 GHz
- Stopbands to 57 GHz
- Bandwidths as narrow as 1%
- 100+ dB rejection

CERAMIC RESONATOR

- Fractional bandwidths from 0.5 to 40%
- Excellent power handling, up to 20W
- High Q in miniature SMT package

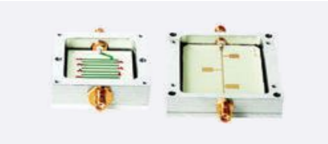
LUMPED L-C

- Wide catalog selection
- Several package options including aqueous washable
- Variety of filter topologies

LTCC

- Tiny size, as small as 0202
- Industry's widest selection of mmWave LTCC filters
- Proprietary designs with stopband rejection up to 100 dB

MICROSTRIP



- Connectorized designs with 4 to 40% fractional bandwidth
- Power handling up to 10W
- Flat group delay

MMIC REFLECTIONLESS

- Patented topology absorbs and internally terminates stopband signals
- Perfect for pairing with amplifiers, mixers, multipliers, ADC/DACs & more

RECTANGULAR WAVEGUIDE

- WR-12, WR-15 and WR-28 interfaces
- Passbands up to 87 GHz
- High stopband rejection, 40 dB

SUSPENDED SUBSTRATE

- Ultra-wide passbands up to 26 GHz
- Wide stopbands up to 40 GHz
- High Q

THIN FILM ON ALUMINA

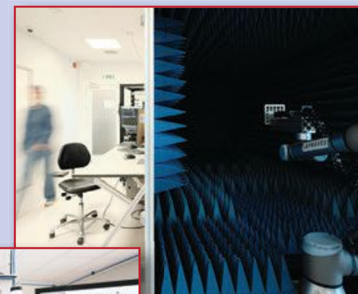
- Passbands from DC to 40 GHz
- High rejection with wide passband
- Miniature SMT package

Mini-Circuits®

FABS and LABS

Gapwaves: Tech That Sees the Human Side of Things





Gapwaves, a waveguide technology company headquartered in Gothenburg, Sweden, was founded in 2011 by Professor Per-Simon Kildal of Chalmers University. For many years, Gapwaves was considered a strong research institution and partner. However, Gapwaves has recently fostered significant growth and made a splash in the commercial market thanks to the manufacturability of its patented waveguide technology. This technology is applicable to products including slot antennas, filters, diplexers and other passive microwave components, and operates in the mmWave frequency range. As Gapwaves finds more automotive and communication applications, it continues to expand and recently opened a pilot-line facility designed for product development and testing.

Gapwaves' technology is based on artificial magnetic conductors, which create contactless, artificial waveguide structures that facilitate the propagation of the signal. By eliminating physical contact, the manufacturing specifications can be relaxed significantly while maintaining high performance, and the material choice is more lenient. This increase in manufacturability becomes more important as the technology scale grows, positioning Gapwaves to be successful in high volume manufacturing industries, including automotive. Gapwaves' technology and new facility position it for success as the self-driving car and driver safety feature industries experience rapid growth.

Gapwaves opened its pilot-line production facility in November 2024, strategically placing it near its headquarters in Gothenburg, Sweden. The facility functions as an industrialization hub where Gapwaves can validate both new products and high volume manufacturing innovations. Both steps are key during a successful new product introduction, and the facility enables Gapwaves to perfect products and systems before outsourcing them to their qualified global production partners. The facility is designed for an annual production capacity of 300,000 antennas, many of which are high volume manufacturing tests or research designs. In addition to the manufacturability benefits, this facility is pivotal to obtaining the IATF certification, a crucial certification for the automotive industry. Gapwaves recently started production at the pilot-line facility for partner Valeo's new vehicle radar. Once they optimize the production line, the product will be moved to a full-scale production facility closer to its end use. This will minimize the delivery time and cost, improving overall customer satisfaction.

In addition to automotive, Gapwaves services industries including commercial satcom, telecom and surveillance, as well as defense applications. However, automotive remains a priority not only for its success and high volume opportunity, but for the positive impact it brings. Increasing auto safety goes beyond increased convenience or speed to improved quality and preservation of life. Gapwaves values its positive contribution to automotive safety. As safety features become ubiquitous, there is a global increase in proposals to require certain features in new cars. As these pass and become law, Gapwaves' technology and manufacturability will enable the rapid implementation of safety technology without sacrificing prices.

With over 40 patent families, 14 years of experience, the new production facility and an enthusiastic team, Gapwaves will continue to positively disrupt the waveguide and automotive industries.

Gapwaves
www.gapwaves.com

eXclusive Digital Content ›››

An Inexpensive Tunable S- and X-Band RF Source for Microwave Laboratory

Manoj Kumar, Mansi Goyal and Gowrish Basavarajappa
Indian Institute of Technology Roorkee, India

RF sources are vital components in numerous scientific and engineering pursuits related to wireless communication and sensing applications. However, state-of-the-art RF sources like analog signal generators and vector signal generators are expensive for educational purposes. This article describes a low-cost electronically tunable S- and X-Band continuous wave RF source for a microwave laboratory at the undergraduate and post-graduate levels. RF signals in the unlicensed industrial, scientific and medical (ISM) band (2.4 to 2.525 GHz) are generated directly using an inexpensive commercially available nRF24L01 transceiver module. The module is configured using an Arduino Uno microcontroller through a serial peripheral interface (SPI) protocol. Active frequency multiplication (by a factor of 4) is achieved using a HMC443LP4ETR MMIC chip from Analog Devices to convert the output to X-Band.

Tunable RF sources are vital components in S-and X-Band microwave laboratory test benches (MTBs) widely used for education and teaching purposes at the undergraduate and post-graduate levels. These RF sources have typically been realized using reflex klystrons, as demonstrated in ***Figure 1a***. These are becoming obsolete and are being replaced by solid-state RF sources, as demonstrated in ***Figure 1b***.

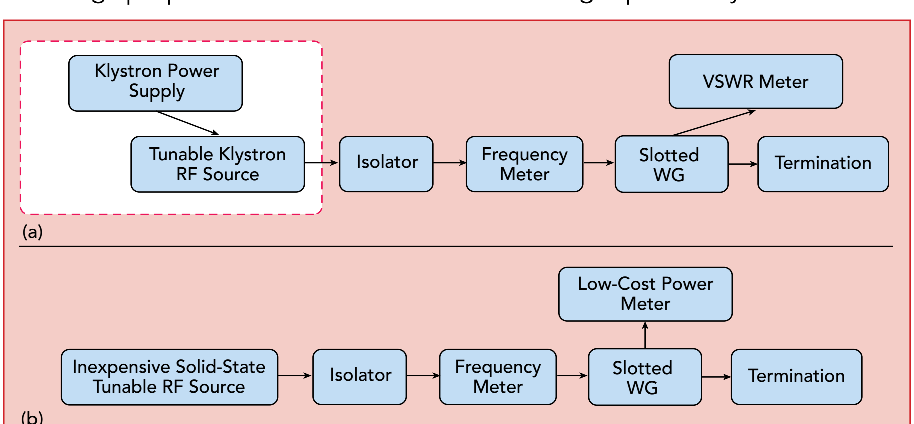
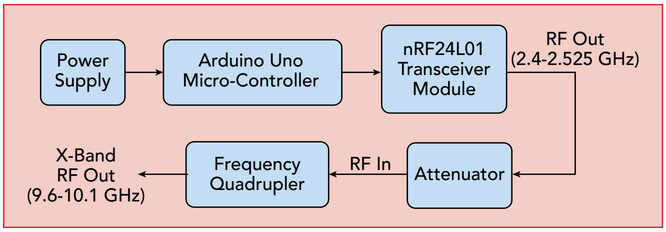


Fig. 1 **S- and X-Band MTBs for educational purposes: (a) conventional approach (b) and proposed approach.**

Various types of solid-state RF sources are available in the market, which can be categorized into three distinct categories: analog signal generators, digital signal generators and vector signal generators.[1-5] An analog RF signal generator produces a continuous wave RF signal. Analog RF signal generators are employed by educational institutions, particularly in the demonstration and investigation of the components and systems.[3,6] Methods such as direct digital synthesis are employed by digital signal generators. Compared to analog RF sources, they offer excellent precision and programmability at an increased cost.[7,8] Vector RF signal generators can generate RF signals with phase and amplitude modulation. They



▲ Fig. 2 **RF source block diagram.**

are particularly useful for testing compound modulation schemes like orthogonal frequency-division multiplexing (OFDM) and quadrature amplitude modulation (QAM), which are widely used in modern wireless communication, such as LTE and Wi-Fi. Solid-state sources are limited in their use to low-power applications.

Gunn diode-based mechanically tunable RF sources have been proposed for educational radar experimentation purposes.[9,10] One of their limitations is that they are mechanically tuned using a movable metallic short. Hindle[11] surveyed low-cost test equipment, including signal generators. However, the maximum frequency achieved was around 6 GHz, and the cost was at least 4x greater than the X-Band source proposed here. Iordachescu and M. Raducu[12] describe a low-cost Gunn diode-based fixed frequency RF source, but it has no provisions to tune the frequency. Matuszczak et al.[13] described a PLL-based X-Band RF generator for laboratory purposes. However, the prototype cost is around 12x greater than the proposed X-Band source proposed here. Note that although the reflex klystron has become obsolete for many applications, it is still being used for educational purposes solely due to its cost advantage.

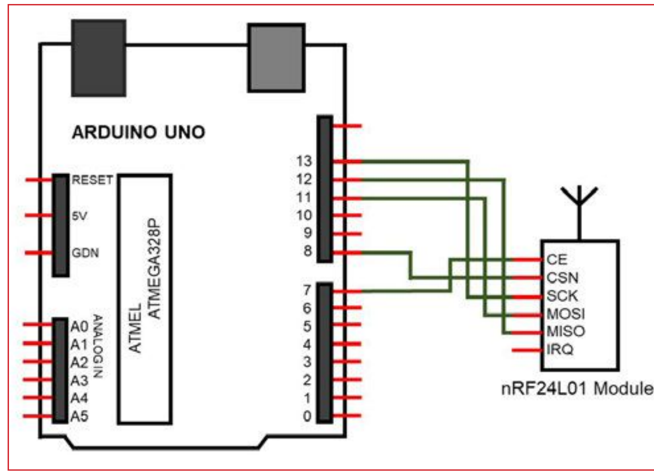
The motivation for this development activity is to replace a reflex klystron-based RF source with an inexpensive solid-state RF source for S-and X-Band MTBs. In addition to being compact, the proposed solid-state RF source has advantages such as a wide electronic tuning range and ease of use. Furthermore, the cost is much less than that of a commercially available reflex klystron and the other contemporary alternatives discussed above.

CONCEPTUAL BLOCK DIAGRAM

A simplified block diagram of the proposed tunable RF source is shown in ***Figure 2***. It consists of three main components: an nRF24L01 radio transceiver, an Arduino Uno microcontroller and a frequency quadrupler. The microcontroller provides the bias voltage and SPI control signals to the RF transceiver to select the desired frequency channel in the ISM band (2.4 to 2.525 GHz). The frequency synthesizer in the nRF24L01 radio transceiver produces a CW RF signal at the desired frequency. Since the nRF24L01 radio can provide a peak power output of 20 dBm, a 30 dB attenuator is placed in the RF signal path to protect the quadrupler. The attenuated RF signal is fed to the quadrupler to generate the desired X-Band (9.6 to 10.1 GHz) RF output.

DEVICE SELECTION

Nordic Semiconductor's nRF24L01 transceiver synthesizes 2.4 to 2.525 GHz signals. This device meets low



▲ Fig. 3 **Arduino interface to the nRF24L01 transmitter.**

power consumption requirements, is cost-effective and is compact in size. It has 125 RF channels with typically 1 MHz resolution.[14] An SPI is used for configuration and operation. The SPI provides access to the device's register map, including all configuration registers.

An Arduino Uno microcontroller unit (MCU) is chosen to program the nRF24L01 using the SPI protocol. It is a low-cost, easy-to-use and open-source microcontroller based on the ATmega328P microchip microcontroller.[15] It configures the PLL of the nRF24L01 to transmit the carrier signal continuously. Hence, the nRF24L01 is being configured to be used as a tunable RF source.

The HMC443LP4ETR MMIC chip from Analog devices[16] is used for active ×4 frequency multiplication. The RF signal generated by the nRF24L01 radio transceiver is fed to the quadrupler, which generates an X-Band RF signal at the output.

IMPLEMENTATION

The nRF24L01 radio is interfaced with Arduino Uno microcontroller. It requires an operating voltage of 3.3 V. A voltage regulator converts 5 V at the Arduino output pin to 3.3 V for the radio. The SPI provides synchronous data communication between the two devices. It has separate lines for data and clock signals. The clock ensures precise synchronization between sender and recipient. The receiver samples the data line to read the subsequent bit once it detects the clock edge.

For SPI communication, picking the right clock edge and speed is crucial. Three pins, Serial Clock (SCK), Master Out Slave In (MOSI) and Master In Slave Out (MISO) of the nRF24L01 radio must be connected to their equivalent pins on the MCU for interfacing via the SPI protocol. These pins manage data transmission and reception.

In addition, each available digital output pin on the MCU can be connected to two crucial pins: Chip Enable (CE) and Chip Select Not (CSN). The CSN pin chooses which module to use for communication, while the CE pin manages the module's power state.

The nRF24L01 radio incorporates an Optional Interrupt Request (IRQ) pin. This digital output is usually used for interrupt-driven communication and becomes active when low. In an interrupt example, the IRQ pin is

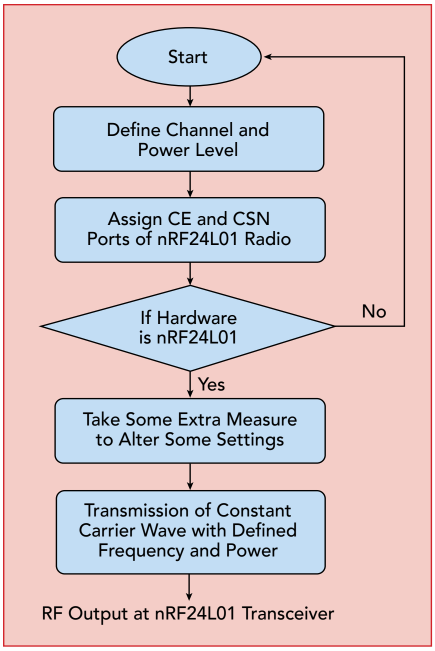


Fig. 4 **Arduino code algorithm.**

connected to a digital input pin on the MCU.

The schematic of connections between the Arduino and the nRF24L01 radio is shown in ***Figure 3***. The CE, CSN, MOSI, MISO and SCK pins of the nRF24L01 radio are connected to the Arduino Uno D7, D8, D11, D12 and D13 pins, respectively.

CODE ALGORITHM

The algorithm for the Arduino Uno code that instructs the nRF24L01 to transmit a continuous carrier signal is shown in ***Figure 4***. Two fundamental Arduino libraries, Arduino.h and SPI.h, perform SPI communication with any peripheral. Further, nRFL01 and RF24 libraries are the primary libraries required to communicate with the nRF24L01 radio module.

First, the power level and channel number are set from the specifications of the nRF24L01 module. Pins D7 and D8 of the Arduino Uno are defined as CE and CSN pins for the nRF24L01 module. Next, it identifies whether the nRF24L01 module is connected to the Arduino or not. Once it gets detected, Arduino Uno initiates the commands required for generating the unmodulated carrier. These commands perform the following tasks.

1. Setting auto acknowledgment to false, meaning the transmitting radio will always report that the payload was received (even if it was not).
2. Setting the number of retry attempts to zero and delay between retries when transmitting a payload to 250 µs.
3. Emptying all three transmit FIFO buffers.

Finally, the transmission of continuous carriers starts with the required power and frequency channel. The output of the nRF24L01 radio is measured using a spectrum analyzer (see ***Figure 5***). The power level provided by the transceiver module is around 20 dBm.

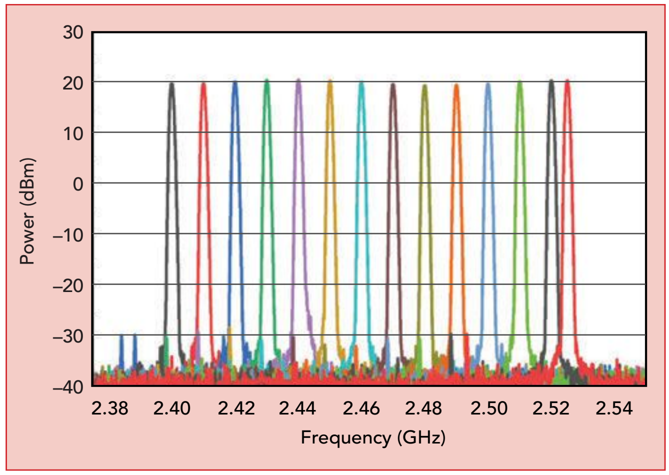


Fig. 5 **Measured nRF24L01 radio S-Band spectrum.**

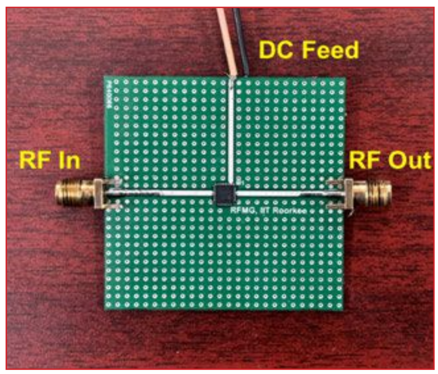


Fig. 6 **Frequency quadrupler.**

The frequency quadrupler stage plays a pivotal role in generating X-Band RF signals. The HMC443LP4ETR MMIC chip provides active frequency multiplication to the RF input fed to it. The multiplier chip can accept an RF input from -15 to +5 dBm. Hence, a 30 dB attenuator (resistive Pi circuit) is introduced before the frequency quadrupler to protect it from damage. The circuit for the HMC443LP4ETR chip is mounted on a 20 mil FR4 PCB. The signal traces for RF in, RF out and DC path are designed for 50 Ω microstrip. SMA connectors are used to interface the PCB (see ***Figure 6***) with other components.

FINAL CIRCUIT DESIGN AND PERFORMANCE

The components are connected per the block diagram (see Figure 2) and the prototype tunable X-Band source is shown in ***Figure 7***. The casing is realized using polymer 3D printing technology. Power for the quadrupler is provided by the Arduino Uno.

Spectral performance is measured using a Keysight N9020B MXA signal analyzer; the spectrum from 9.6 to 10.1 GHz in steps of 20 MHz is shown in ***Figure 8***. The source has a minimum tunability of 4 MHz at X-Band.

Phase noise is measured at 9.8 GHz. Resolution bandwidth and video bandwidth are both 10 Hz. Phase

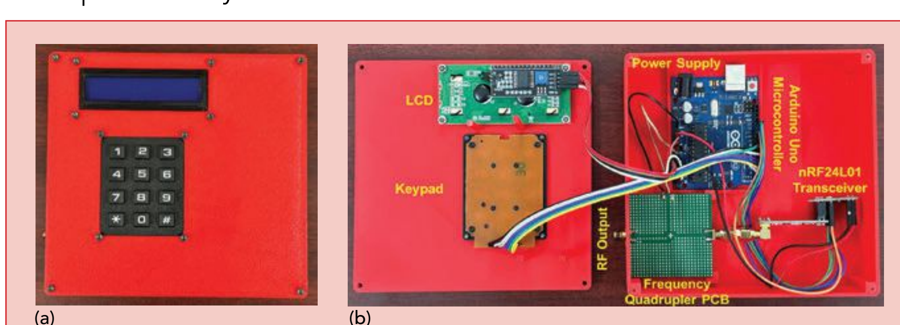


Fig. 7 **Tunable X-Band RF source: (a) assembled view (b) and opened view.**

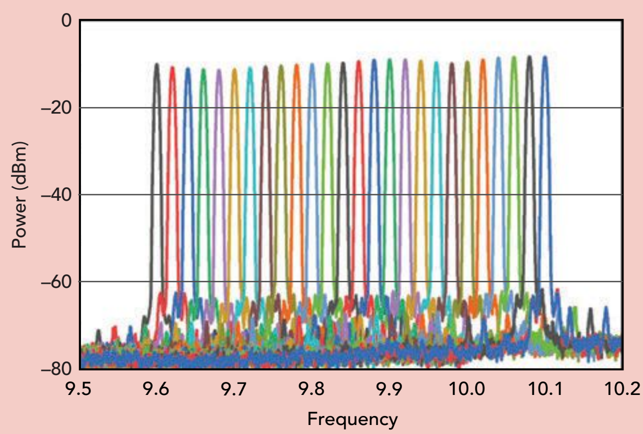


Fig. 8 Measured X-Band spectrum in 20 MHz steps (with attenuator).

noise at 1 KHz and 1 MHz offsets is -68.1 dBc/Hz and -110 dBc/Hz, respectively. The actual phase noise at S-Band is much better than -116 dBc/Hz, however, the spectrum analyzer can only measure reliably to -116 dBc/Hz. ***Table 1*** summarizes its performance in comparison with other referenced work.

CONCLUSION

A low-cost electronically tunable S- and X-Band RF source for educational microwave laboratories replaces legacy reflex klystrons. At X-Band, the device generates tunable frequencies between 9.6 and 10.1 GHz in the steps of 4 MHz, which can be tuned by selecting channels between 1 and 125. Its low cost is attributed to the use of commercially available off-the-shelf components. ■

References

1. A. K. Lu and G. W. Roberts, "An Oversampling-Based Analog Multitone Signal Generator," *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, Vol. 45, No. 3, March 1998, pp. 391–394.
2. I. Chiba, H. Nakamizo, K. Tajima, T. Akiyama, R. Takahashi and E. Taniguchi, "A Flexible and Precise APAA System with RF Modules Including a Signal Generator," *IEEE International Symposium on Phased Array Systems and Technology*, October 2013.
3. B. Gao, F. Zhang, P. Zhou and S. Pan, "A Frequency-Tunable Two-tone RF Signal Generator by Polarization Multiplexed Optoelectronic Oscillator," *IEEE Microwave and Wireless Components Letters*, Vol. 27, No. 2, February 2017, pp. 192–194.
4. M. Weiß, C. Friesicke, R. Quay and O. Ambacher, "Low-Power Differential Input to Single-Ended Output GaN RF-DAC for RF-Signal Generation," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 69, No. 3, March 2021, pp. 1646–1653.
5. H. L. Lee, S. P. Park and M. -Q. Lee, "High Power Microwave Signal Generation Based on Recursive Balanced Power Amplifier," *IEEE Access*, Vol. 11, July 2023, pp. 73352–73358.
6. B. Razavi, *RF Microelectronics*, 2nd Edition, Prentice Hall, 2012.
7. H. T. Jensen and I. Galton, "A Low-Complexity Dynamic Element Matching DAC for Direct Digital Synthesis," *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, Vol. 45, No. 1, January 1998, pp. 13–27.
8. S. Arora, P. T. Balsara and D. Bhatia, "Digital Pulsewidth Modulation (DPWM) Using Direct Digital Synthesis," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, Vol. 10, No. 4, August 2022, pp. 4231–4244.
9. M.A. Solano, J. Saiz-Ipina, J. -M. Zamanillo and C. Perez-Vega, "X-band Gunn Diode Oscillator for a Multiple-Frequency Continuous-Wave Radar for Educational Purposes," *IEEE Transactions on Education*, Vol. 45, No. 4, November 2002, pp. 316–322.
10. J. -M. Zamanillo, C. Perez-Vega, J. Saiz-Ipina and M. A. Solano, "X-band Microwave Gunn Oscillator for Educational Purposes," *International Conference on Network Universities and e-Learning*, May 2003.
11. P. Hindle, "Very Low-Cost RF Test Equipment for the DIY Engineer or Student," *Microwave Journal*, Vol. 63, No. 12, December 2020.
12. G. -A. Iordachescu and M. Raducu, "Low-cost X-band Microwave Oscillator, Modulator and Detector for Educational Purposes," *14th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, July 2022.
13. P. Matuszczak, Ł. Kulas and K. Nyka, "Low-Cost Microwave X-band Generator," *2nd International Conference on Information Technology*, June 2010.
14. NRF24L01+ single chip 2.4GHz transceiver datasheet, Nordic Semiconductor, Web: https://www.sparkfun.com/datasheets/Components/SMD/nRF24L01Pluss_Preliminary_Product_Specification_v1_0.pdf.
15. Arduino Documentation, Web: https://docs.arduino.cc/.
16. "HMC443LP/443LP4E SMT GaAs HBT MMIC x4 Active Frequency Multiplier, 9.8 - 11.2 GHz Output," *Analog Devices*, Web: https://www.analog.com/media/en/technical-documentation/data-sheets/hmc443.pdf.
17. Klystron tube 2k25, *SALICON*, Web: https://www.salicontech.co.in/product/2k25-k19-k27/.

TABLE 1

COMPARISON OF LOW-COST RF SOURCES

Reference / Parameter	9, 10	11	12	13	17	TWX	TWS
RF Power (dBm)	1.8	15	NR	13	14	4	20
Frequency Tuning Range (GHz)	Mechanical 8.0 - 12.1	Electronic 0.02 - 6.4	Fixed 9.5	Electronic 9.7 - 11	Electronic 8.7 - 10.5	Electronic 9.6 - 10.1	Electronic 2.4 - 2.52
DC Power Supply (V)	14	NR	6.5	NR	-200 to 300	5	5
Relative Cost	NR	8X	X	23X	8X	2X	X
Phase Noise (dBc/Hz) (1 MHz offset)	< -160	< -115	NR	NR	NR	< -110	<< - 116*

NR: Not Reported, TWS: This Work S-Band, TWX: This Work X-Band
*Limited by test equipment capability

EW, RADAR & MILCOM 2025

A SPECIAL SUPPLEMENT TO Microwave Journal

Cover Feature

6 Countering High Frequency Surface Wave Radar
Richard L. Powers, Aerospace BD, LLC

Special Report

18 International Spectrum Supportability for Software Defined Radios: Part 2
Guenever Aldrich, Veronica Cruz-Klueber and Mark Lofquist, The Aerospace Corporation

Tutorial

32 From the Radar Equation to T/R Module Specifications
Erick Lima and Josiah Spear, Spectrum Control Limited

Product Features

46 USB-Powered VNA Brings Accuracy to Field Applications
Signal Hound

50 RF Sampling Transceiver Family
Jariet Technologies, Inc.

Tech Briefs

54 RF Coaxial Contacts for D38999 Cable Assemblies
Pasternack, an Infinite Electronics brand

54 Q/V-Band Cassegrain Antennas for Ground Systems
Eravant (Formerly Sage Millimeter Inc.)

56 High-Power Solid-State Amplifier
Exodus Advanced Communications

Company Showcase

58 Descriptions of company literature and products

Staff

Group Director: Carl Sheffres
Associate Publisher: Michael Hallman
Media Director: Patrick Hindle
Brand and Content Director: Jennifer DiMarco
Technical Editor: Del Pierson
Associate Technical Editor: Cliff Drubin
Editorial & Media Specialist: Kelley Roche
Associate Editor: Kaitlyn Joyner
Multimedia Staff Editor: Barbara Walsh
Electronic Marketing Manager: Chris Stanfa
Senior Digital Content Specialist: Lauren Tully
Director of Production & Distribution: Edward Kiessling
Art Director: Janice Levenson
Graphic Designer: Ann Pierce

EUROPE
Office Manager: Nina Plesu

CORPORATE STAFF
CEO: William M. Bazzy
President: Ivar Bazzy
Vice President: Jared Bazzy


VNA400
VECTOR NETWORK ANALYZER
40 MHz - 40 GHz
Signal Hound
PORT 1
P1
STATUS
P2
PORT 2

Countering High Frequency Surface Wave Radar

Richard L. Powers
Aerospace BD, LLC, Annapolis, Md.

Over-the-horizon high frequency surface wave radars (HFSWRs) are appearing along the coast of the People's Republic of China and in their artificial islands in the South China Sea. As the technology is seen to fruition as part of an integrated anti-access/area denial (A2AD) scheme, these radars will be capable of detecting and tracking ships well beyond 300 km, aircraft above and below the horizon, ballistic missiles and cruise missiles, with near-targeting quality azimuth and range accuracy. Robust countermeasures are needed, as they have the capability to detect and track "stealth" platforms due to the long high frequency (HF) wavelengths.

INTRODUCTION TO HFSWR

Due to the conductivity of salt water, a vertically polarized wave in the HF, 3 to 30 MHz domain will propagate along the curvature of the ocean for hundreds of kilometers without relying on an ionospheric bounce. The U.S.' HFSWR experiments provided proof of concept in the 1960s and 1970s at the Naval Research Laboratory led by James Headrick, and in the 1970s with the U.S. Air Force-sponsored TOP SEA radar developed by Leon Lewandowski and colleagues at Sanders Associates (now BAE Systems). Canada and other nations have advanced the state of the art to operational systems for over-the-horizon 200 NM Exclusive Economic Zone (EEZ) ship surveillance. China's interest in HFSWR also began in the 1960s. HFSWR installations are inherently large compared to microwave radars due to the long wavelength and need for a large receiving aperture for bearing accuracy. The open literature on the subject is substantial, as is worldwide academic, civilian and military interest for applications ranging from hydrography to EEZ enforcement to low-altitude over-the-horizon cruise missile detection and tracking.

Surface wave propagation is lossy compared to line of sight (LOS), but excellent performance can be achieved even with the inherent difficulties of operation in the HF band. Ship detection is best in the lower HF band; higher frequencies are better for aircraft and missiles. A system intended primarily for early warning of incoming sea-skimming anti-ship cruise missiles (ASCM) might be optimized around 15 to 20 MHz. To illustrate the over-the-horizon concept and performance, a relatively small conceptual shipboard system,[1] sponsored by the U.S. Navy, operating in the 10 to 18 MHz range can achieve useful tracking ranges from an aperture length of less than 185 m, as illustrated in ***Figure 1***. Larger coastal installations will achieve much longer ranges. In contrast, the enormous 1500 m Russian coastal surveillance Podsolnukh HFSWR, as shown in ***Figure 2***, tracks targets out to 500 km and has reportedly been exported to China.[2,3]

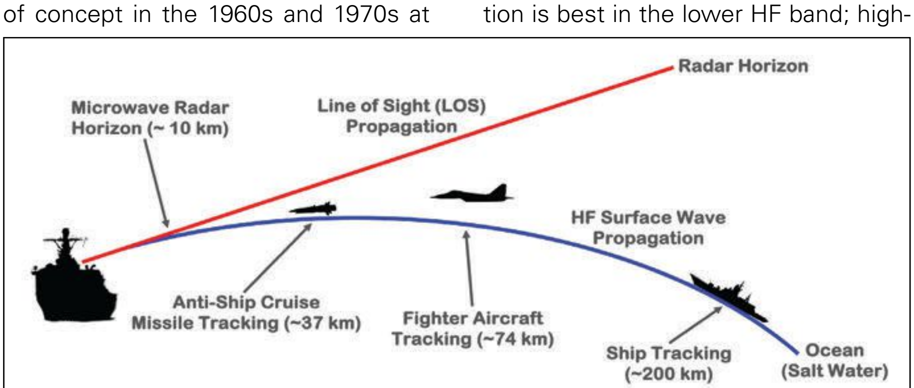


Fig. 1 A conceptual shipboard HFSWR, optimized for ASCM detection.[1]

HFSWR COMPLEXITIES AND ADVANCES

Advances in digital receivers over the last approximately 30 years have enabled the development of practical systems. Beamforming, target detection and tracking can all be done digitally with minimal operator involvement. Modern digital receivers in the HF band feature analog to digital converters and low phase noise, which enable high sub-clutter visibility necessary for detecting slow-moving targets at extended ranges. Unlike HF over-the-horizon backscatter (OTH-B) radars, sounders are not needed because HFSWR does not depend on the ionosphere. However, many of the challenges, such as external noise, man-made interference and the need for high sub-clutter visibility, are shared between these two distinct types of HF radars. HFSWR performance is different from microwave

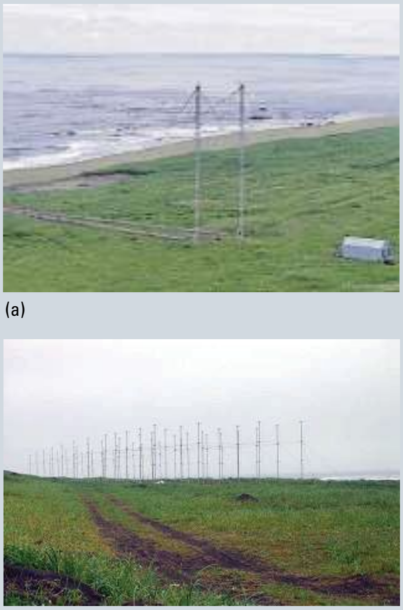

(a)
(b)

Fig. 2 Russian Podsolnukh HFSWR antennas.

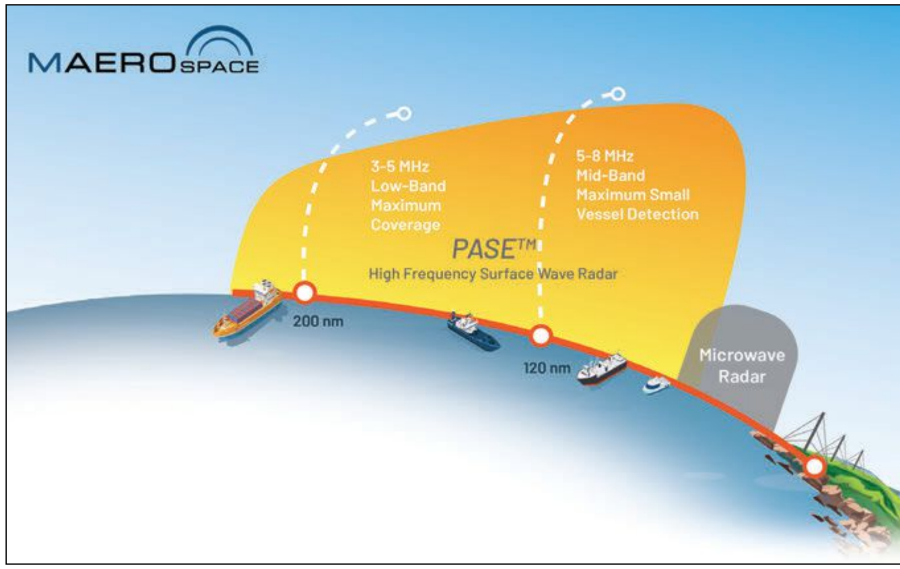


Fig. 3 Maerospace dual-band HFSWR product performance. *Source:* Maerospace Corporation.

radar due, in part, to three key factors:

1. **Receive array directivity:** Directivity rather than gain is often used for the receiving system because it is dominated by the external noise level rather than internal thermal noise. HF is almost always externally noise-limited, often by over 40 dB.
2. **Surface wave propagation loss:** Surface wave propagation loss is an additional loss that can be substantial and poses a significant challenge to the radar designer. Two-way loss varies by frequency and sea state; path loss over 200 dB is typical for long-range ship detection at the low end of the HF band and increases with frequency.
3. **External noise:** External noise is naturally occurring in the HF band and is much higher than internal kTB noise. Typically accepted planning values are 50 dB above kTB at 2 MHz, reducing to 20 dB at 30 MHz. When man-made interference is added, depending on location, time of day, etc., values of 80 dB have been observed at the low end of the band.

Canada is a leader in EEZ ship monitoring using HFSWR. Maerospace, based in Ontario, Canada, has developed a fourth-generation HFSWR with 120-degree azimuthal coverage up to 200 nm. Their radar — Persistent Active Surveillance of the EEZ (PASE) — operates from 3 to 5 MHz and is approximately 650 m in length. They own and operate one of their radars, as demonstrated in ***Figures 3*** and ***4***, on the East Coast of Canada, in Newfoundland. Maerospace's HFSWR product is representative of the state of the technology readily available today.

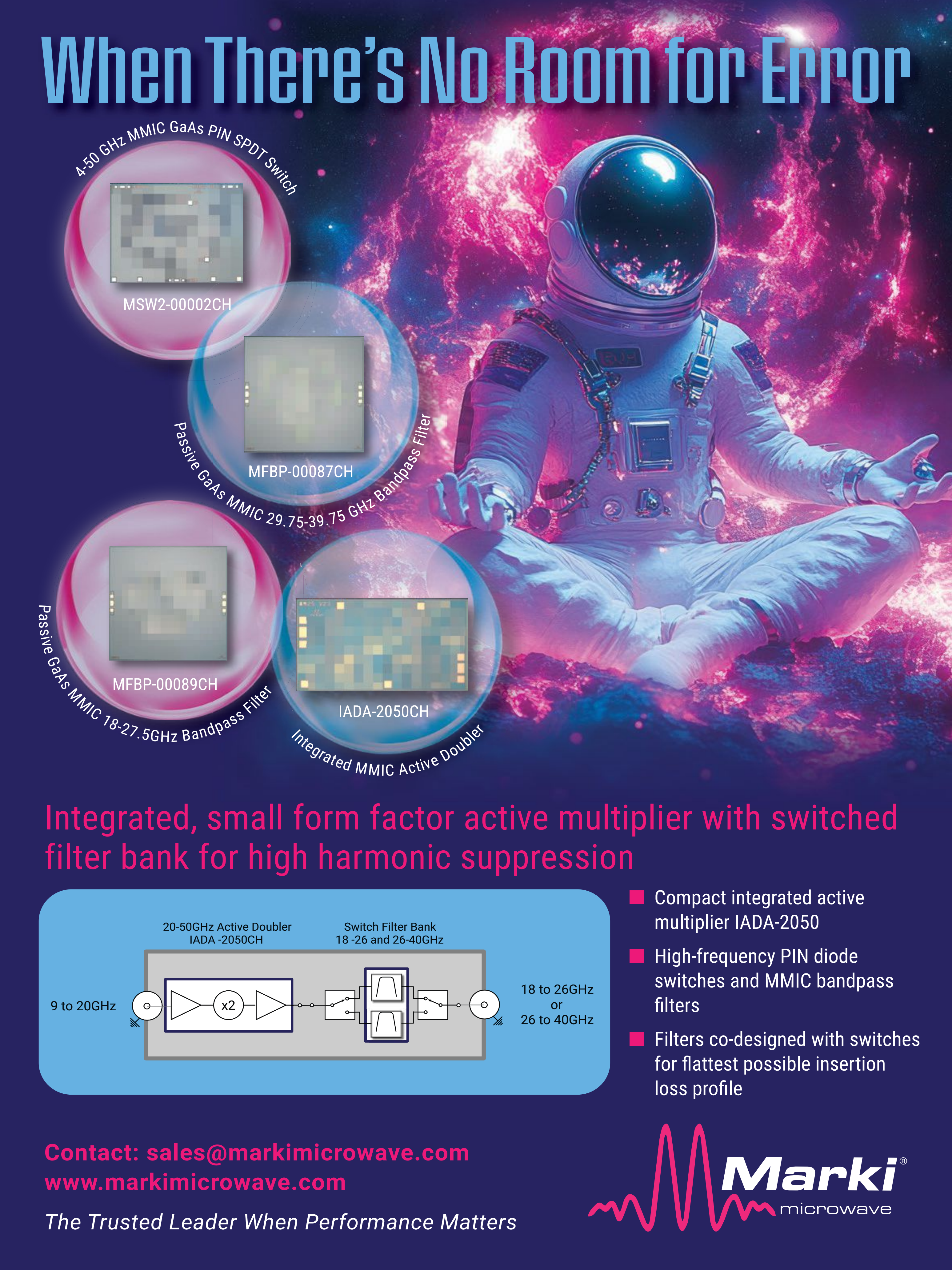
Fig. 4 Maerospace HFSWR installation, Cape Race, Newfoundland. *Source:* Maerospace Corporation.

The dual-use military potential of commercially-available HFSWR systems cannot be overlooked. The constraints on the HFSWR radar designer are substantial. Nikolic, et al.[4] describes a Serbian development of a frequency modulated continuous wave (FMCW) HFSWR for EEZ monitoring in the Gulf of Guinea and elaborates on some of the constraints they faced for this EEZ single-purpose system. It also provides excellent diagrams of a semi-bistatic EEZ ship monitoring shore-based design and likely ship detection ranges.

Since 1967, China has developed HFSWRs,[5] which have been deployed at multiple sites along its coast. Open literature suggests that HFSWR is part of their overall integrated A2AD scheme. Chinese academic literature on the subject is substantive and demonstrates a long-term commitment to advancing this technology. They are building HFSWR systems in the South China Sea within the disputed Spratly Islands, including on Cuarteron Reef, as shown in ***Figure 5***.[6] The reef is claimed by China, Taiwan, Vietnam and the Philippines.

A key advantage of operating in the HF band is that target scattering is typically in the Rayleigh and Mie (resonance) regions because the wavelength of the radar is larger or nearly equal to the target of interest. Reducing radar cross section (stealth) via shaping and radar absorbing materials becomes less effective, making HFSWR an attractive means of beyond the horizon A2AD coastal surveillance.

HFSWR systems are monostatic, semi-bistatic or truly bistatic. Monostatic systems will be the most compact and are likely modulated high-duty-cycle pulsed systems consistent with their range and Doppler resolution requirements. The operating frequency range can vary from as low as a few MHz to as high as 18 to 25 MHz, depending on the target of interest and on noise and interference conditions. Once a target breaks the radar horizon, such as a high altitude aircraft or a ballistic missile, LOS propagation comes into play and detection ranges increase accordingly.


When There's No Room for Error
4-50 GHz MMIC GaAs PIN SPDT Switch
MSW2-00002CH
MFBP-00087CH
Passive GaAs MMIC 29.75-39.75 GHz Bandpass Filter
MFBP-00089CH
Passive GaAs MMIC 18-27.5GHz Bandpass Filter
IADA-2050CH
Integrated MMIC Active Doubler
Integrated, small form factor active multiplier with switched filter bank for high harmonic suppression
20-50GHz Active Doubler
IADA -2050CH
Switch Filter Bank
18 -26 and 26-40GHz
9 to 20GHz
x2
18 to 26GHz
or
26 to 40GHz
Compact integrated active multiplier IADA-2050
High-frequency PIN diode switches and MMIC bandpass filters
Filters co-designed with switches for flattest possible insertion loss profile
Contact: sales@markimicrowave.com
www.markimicrowave.com
The Trusted Leader When Performance Matters
Marki®
microwave

Antenna choices vary with the design; a notional multi-purpose military system might include a log-periodic monopole transmitter serving as a wide-beam illuminator and multi-frequency digital receive array configurations covering a wide HF spectrum to detect a carrier strike group at a great distance, detect and track aircraft as they are launched and detect and track cruise missiles beyond the horizon to provide early cueing of engagement systems.

HFSWR challenges must be emphasized before considering countermeasures. Foremost, surface wave over-the-horizon propagation is lossy when compared to LOS propagation, an inherent opportunity for the ECM designer to exploit. Sea clutter moving in Doppler, target to clutter ratio, sea state, external noise, man-made interference (e.g., shortwave radio) and other factors will degrade detection range. The requirement for meaningful near-targeting quality range and Doppler information will limit waveform choices. Bearing accuracy is almost entirely a function of receive array size. HFSWR systems must have high sub-clutter visibility to detect moving targets in the presence of moving ocean clutter. A modern HFSWR is likely to place a high dynamic range digital receiver at every antenna element, to the degree affordable, for simultaneous digital beamforming to match the coverage of the transmit antenna, and adaptive nulling of interference (e.g. shortwave radio transmitters) and directional jamming. Frequency agility or multiple simultaneous frequencies can optimize target detection, so a multi-purpose system might be either operating in three simultaneous bands or shifting between those bands. Choosing frequencies within each band may be based on finding the quietest parts of the HF spectrum or pseudo-random to make jamming more difficult, or a combination thereof. A coherent integration time interval is needed to pull moving targets out of the ocean clutter. The clutter patch is moving, and ocean currents and sea state influence detection and false alarm rates; constant false alarm rate (CFAR) processing and target tracking are non-trivial problems for the HF radar designer.

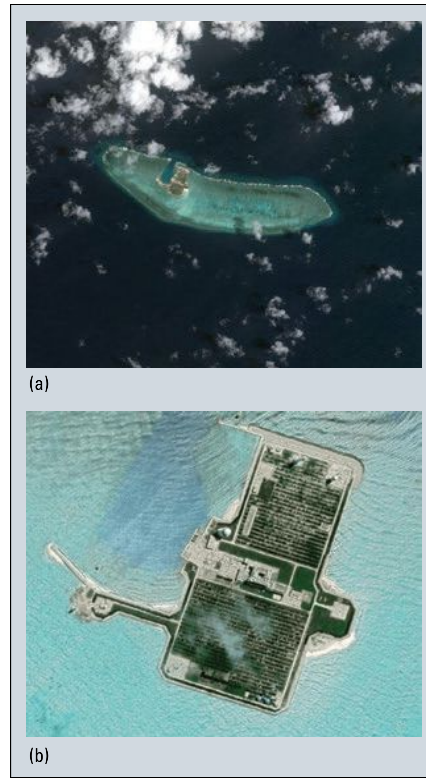

(a)
(b)

Fig. 5 Chinese HFSWR site on disputed Cuarteron Reef in the South China Sea.

© DARIN RUSSELL/LOCKHEED MARTIN

CONSIDERATIONS FOR COUNTERMEASURES DESIGNERS

Target processing and waveform optimization literature speak volumes for three intelligence needs: a constant OSINT effort, frequent ELINT collection and analysis of signals of interest and theoretical analysis of likely wartime modes. Given the complexities of operating a radar at HF, the different optimal frequencies as a function of target size, external noise, clutter and interference, frequent collection is required to build a strong understanding of how these systems operate over time and electromagnetic conditions. HF radar experts in the U.S., Canada and Australia can provide the knowledge to assist the ECM designer in understanding how these radars operate now and how they might operate in wartime and the future. The good news for the ECM designer is that the radar designers are under constraints that are perhaps more challenging than those of their microwave counterparts due to the HF electromagnetic environment and surface wave propagation loss.

A small team of HFSWR radar experts, talented ECM designers, HF equipment designers, A2AD experts and those skilled in modern autonomous payload delivery methods such as unmanned underwater vehicles (UUVs), unmanned surface vehicles (USVs), etc., if provided with visionary leadership that invites creativity, can quickly converge on a variety of flexible yet affordable solutions. With a long duration and range, and a modular payload capability, the HII REMUS autonomous underwater vehicle, as shown in ***Figure 6***, is one potential delivery example; multiple units can operate collaboratively, which may enable new countermeasure ideas.

The first consideration for the ECM designer is that of mission. Since the sites are relatively large, perhaps relocatable but not immediately mobile, and their locations fixed by imagery and HFDF, destruction of enemy air defenses (DEAD) using conventionally guided weapons is an option. Given the large site, how many weapons are required to take it down and how long will it take an adversary to reconstitute the site with spare equipment? Equipment shelters for transmitters and receivers can be hardened or underground, and the operators need not be on site.

Early warning radars are ideal candidates for denial and tactical deception rather than destruction. Causing an adversary to make bad decisions might be better than simply blinding their sensor. The degree to which this is possible against HFSWR needs analysis, but history suggests there may be several things that could be done to degrade and deceive.

Another consideration for the ECM designer is partial or full digital adaptive beamforming. A digitally beamformed HF radar may have many degrees

Fig. 6 HII REMUS can deliver electronic warfare payloads.

Fig. 7 Boeing EA-18G Growler electronic warfare aircraft.

Fig. 8 BAE Systems/L3-Harris Compass Call.

of spatial freedom, but some will be needed to null directional interference, such as skywave noise and narrowband communications overlapping with the wideband radar waveform. Digital beamforming is a potential ECCM feature, but also a vulnerability since an affordable HFSWR site may only have 32 receivers at any given time. This might imply jamming close to the radar using multiple sources over a wide angular sector, which provides significant transmit power (J/S) advantages given the higher loss of surface wave two-way propagation.

Airborne jamming from the EA-18G Growler (see ***Figure 7***) or EA-37B Compass Call (see ***Figure 8***) is challenging due to the HF antenna size when the wavelength of operation is measured in tens of meters. Clever antenna designers have created retractable, long wire, electrically small and efficient airborne HF antennas, but these are often tuned for a particular band. High altitude HFSWR jammers would have a distinct propagation advantage when above the LOS radio horizon, so there is a tradeoff to be considered.

Shipboard HF systems are likely to be adaptable to this mission, providing screening jamming for themselves and the carrier strike group, but this requires radiation from the ships, which are often in emission control (EMCON). Offboard, non-collocated jammers well in front of the strike group may make more sense and provide a significant jam-to-signal ratio (J/S) advantage. The emergence of highly capable UUVs and USVs makes this a more practical option than in the past.

ECM techniques to be considered range from simple noise to high-fidelity false targets. The high two-way path loss and the unique HF environment, and thus complex radar CFAR detection, might make for interesting twists on ECM techniques, especially if delivered much closer to the radar than the assets under protection. Overcoming adaptive beamforming will be a challenge, but understanding the actual available spatial degrees of freedom and the likely radar signal processing methodology may yield insights leading to highly flexible ECM techniques used in sequence or in combination to defeat or deceive. Jammers do not need to be overly complex and may not require high transmit power to be effective. As with other modern battlefield "throw-away" items, modern HF software-defined digital transceivers may enable simple devices in larger quantities that may be more effective than a few expensive assets.


MPG
CONNECTING & PROTECTING PEOPLE
a DOVER company
Where PERFORMANCE Meets PURPOSE
BSC
criteria labs
DowKey Microwave
Espy
K&L MICROWAVE
MPG SOLUTIONS
POLE ZERO
DSEI • Sept. 9–12 • Booth #S12-320 — EuMW • Sept. 23–25 • Booth B142 • mpgdover.com

Getting the jammer closer to the threat relative to the assets being protected appears to be an attractive approach. Close is relative, given the long ranges and lossy two-way propagation to the distant asset being protected. Close-in might be measured in 10s of kilometers, and the jammers are hidden under a vast ocean, popping up an antenna when jamming is needed. A field of these jammers may be sufficient to overwhelm the radar's digital beamforming at an affordable cost relative to the assets, such as a carrier strike group and its aircraft.

CONCLUSION

High frequency surface wave radar technology is mature and available. HFSWR poses an early warning and target acquisition threat, and countermeasures must be available to the warfighter. HFSWR countermeasures should not just be examined in isolation. The adversary's overall ISR CONOPs and capabilities must be considered in totality to establish the counter-ISR approach and coordinated electronic and DEAD strategy. Having a full understanding of HFSWR operation and its overall place in the hostile A2AD system is but one part of the puzzle. ■

Acknowledgments

Scott Marks of Aerospace BD for his assistance in understanding the challenges of operating in the HF band.

Myles Murphy of Aerospace BD for his assistance in assessing the threat.

Jeff Hassannia, David Markman and Nicole Hassannia of Aerospace BD for their material support and encouragement to write this paper. http://www.aerospacebd.com.

Dr. Samantha L. Powers of George Mason University for editing for comprehension.

Leon Lewandowski of Sanders Associates for his unhesitant knowledge transfer and mentoring.

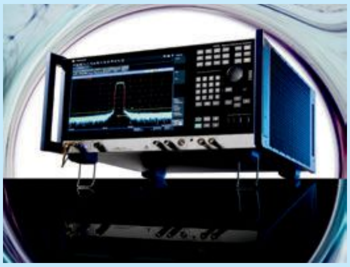
Brian Franklin, VP of Engineering and CTO of Maerospace Corporation for information on their PASE HFSWR product.

REFERENCES

1. R. L. Powers, L. M. Lewandowski and R. J. Dinger, "High Frequency Surface Wave Radar," *Sea Technology*, Vol. 37, June 1997, pp. 32–40.
2. "Russian Podsolnukh," *Global Security.Org*, Web: https://www.globalsecurity.org/wmd/world/russia/podsolnukh.htm.
3. R. Uppal, "High Frequency Surface Wave Radars (HFSWR) for Ship Detection and Tracking Far Beyond the Horizon," *International Defense Security and Technology*, July 29, 2021, Web: https://idstch.com/security/high-frequency-surface-wave-radars-hfswr-for-ship-detection-and-tracking-far-beyond-the-horizon.
4. D. Nikolic, N. Stojkovic, P. Petrovic, N. Tošic, N. Lekic, Z. Stankovic and N. Doncov, "The High Frequency Surface Wave Radar Solution for Vessel Tracking Beyond the Horizon," *Facta Universitatis Series: Electronics and Energetics*, Vol. 33, No. 1, March 2020, pp. 37–59, Web: https://www.researchgate.net/publication/339253979_The_high_frequency_surface_wave_radar_solution_for_vessel_tracking_beyond_the_horizon.
5. "Over-The-Horizon Surface Wave Radar (HFSWR)," *Global Security.Org*, Web: https://www.globalsecurity.org/wmd/world/china/oth-swr.htm.
6. K. Mizokami, "China's Putting Anti-Stealth Radar in the South China Sea," *Popular Mechanics*, February 24, 2016, Web: https://www.popularmechanics.com/military/weapons/news/a19602/china-installing-anti-stealth-radar-in-south-china-sea.

Advertorial

ROHDE&SCHWARZ



FSWX Signal and Spectrum Analyzer: Measure the Impossible

Unlock Precision in DRFM Testing with the Multi-Channel FSWX

In modern electronic warfare, Digital RF Memory (DRFM) technology is crucial for advanced radar deception and jamming systems. By capturing, digitizing, and re-transmitting RF signals with high fidelity, DRFMs enable techniques like false target generation and coherent spoofing. As radar systems become more agile, measuring DRFM performance – particularly timing, coherence, and spectral integrity – requires precision.

To achieve this level of performance verification, a sophisticated tool is necessary to analyze both input and output signals simultaneously, across wide bandwidths, with nanosecond-level timing accuracy. The multi-channel signal and spectrum analyzer FSWX from Rohde & Schwarz is an indispensable tool for this purpose.

PRECISION TESTING FOR CRITICAL INSIGHTS

The FSWX is designed for demanding RF applications, providing simultaneous, synchronized capture of its input RF channels. This capability allows engineers to directly compare a DRFM's input and output, ensuring they are perfectly matched in amplitude, phase, and timing. This architecture is essential for understanding how a DRFM processes and replays radar signals, whether they are single pulses or complex modulated streams. With analysis bandwidths up to 8 GHz for a single channel or 4 GHz per channel, the FSWX offers unmatched visibility across wide-spectrum signals.

WHAT CAN YOU MEASURE?

With the FSWX, engineers can measure critical performance parameters that define DRFM effectiveness:

- **Amplitude Fidelity:** Compare input and output power envelopes with sub-dB accuracy.
- **Phase Coherence:** Identify subtle phase shifts that could compromise deception techniques.
- **Time Delay:** Measure DRFM latency with nanosecond resolution.
- **Spectral Integrity:** Evaluate spurious emissions, harmonics, and spectral regrowth with dynamic range expansion making use of the FSWX's unique cross-correlation technology.
- **Group Delay:** Analyze signal delay across frequency, essential for chirped radar compatibility.
- **Modulation Quality:** Assess EVM and I/Q imbalance in modulated signal playback.

These capabilities provide a comprehensive view of DRFM behavior from signal reception to retransmission.

READY FOR REAL-WORLD CHALLENGES

DRFMs must operate reliably in dynamic environments with rapidly changing radar waveforms. The FSWX is built for such scenarios, featuring:

- Multi-Channel signal analysis for DRFM input/output comparison.
- Advanced measurement applications for detailed analysis of pulsed or fast-changing signals.
- Fast triggering for pulsed signals.
- Vector signal analysis (VSA) for modulation checks.
- Multi-domain view for simultaneous time, frequency, and modulation analysis.

Example of multi-channel deceptive technique analysis with Pulse Measurement Application

Whether testing frequency agility, high PRF burst modes, or advanced ECM scenarios, the FSWX captures, records, and analyzes it all.

SEGMENTED CAPTURE: UNLOCKING EXTENDED SCENARIO ANALYSIS

Radar scenarios do not always unfold in neatly defined timeframes. Scanning patterns, long-range radar, or dynamic ECM environments require extended observation windows. This is why the Segmented Capture feature of the Pulse Measurement Application (option K6) is so powerful.

Segmented Capture allows the FSWX to analyze long-duration radar signals by breaking them into individually triggered and stored segments. Instead of relying on a single continuous capture (limited by memory), the system uses event-based triggering (e.g., pulse detection, amplitude threshold, frequency jump) to collect only relevant portions of the RF activity.

ENGINEERED FOR CONFIDENCE

With its robust architecture, wideband coverage, and coherent RF inputs, the FSWX signal and spectrum analyzer from Rohde & Schwarz is more than a test instrument – it is a mission-ready validation tool for DRFM developers, system integrators, and defense labs.

When signal integrity matters and nanoseconds count, the FSWX gives the clarity, coherence, and confidence to deliver EW systems that perform under pressure.

AOC 2025 International Symposium & Convention

Visit Rohde & Schwarz at the AOC International Symposium & Convention in National Harbor, MD, at booth 423 to experience DRFM testing with the FSWX.

Find more information about the new FSWX online: www.rohde-schwarz.com/measure-the-impossible

International Spectrum Supportability for Software Defined Radios: Part 2

Guenever Aldrich, Veronica Cruz-Klueber and Mark Lofquist
The Aerospace Corporation, Chantilly, Va.

Software-defined radios (SDRs) have become the standard for both commercial and military applications around the world due to their ability to operate internationally, particularly where dynamic reconfiguration and multi-standard capabilities are essential. Where a traditional hardware-based radio requires physical touching and changing of the piece parts to reconfigure the system, an SDR allows the user to adapt to operating in different frequency bands and RF environments through software. An SDR is the younger, faster sister of the hardware-based radio, not quite "your father's brother's nephew's cousin's former" roommate's radio (We are in an argument over which is the best: Spaceballs, Star Wars, or Star Trek.)

In the DOD and the United States, spectrum supportability is part of the certification process, which examines, identifies and assesses regulatory, technical and operational spectrum issues. These have the potential to impact the required operational performance of a candidate system through the process of the Spectrum Supportability Risk Assessment (SSRA).[1,2] The U.S. DOD, however, does not typically operate within its own borders, except for testing, training and disaster relief. As such, the supportability needs to be looked at internationally through host nations and proposed operating areas. The U.S. frequency allocation chart, as shown in ***Figure 1***, and all non-U.S. frequency allocation charts must be examined.

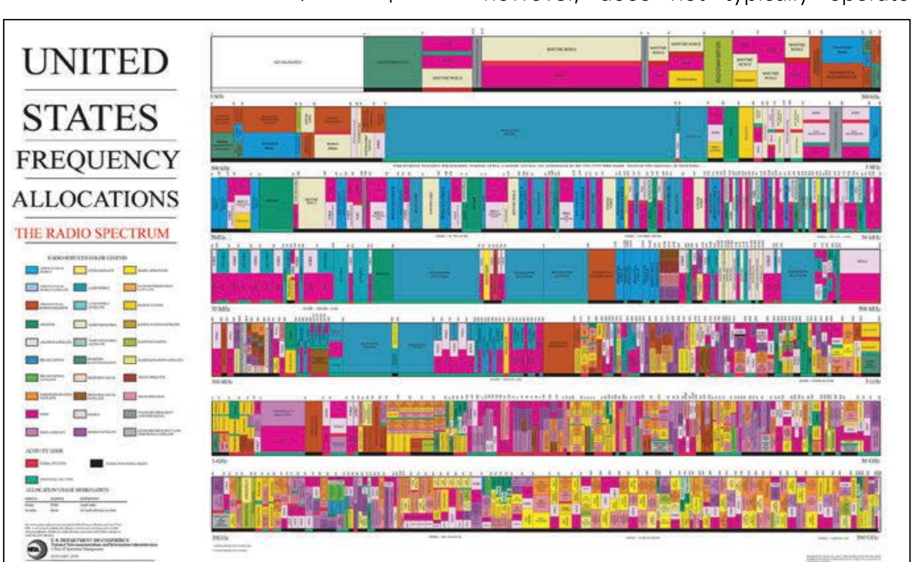


Fig. 1 United States frequency allocation chart. Source: Department of Commerce.

The African Telecommunications Union's spectrum allocation chart is shown as an example in ***Figure 2***. In comparing the two charts, there are both similarities and differences. For example, the lower 3 GHz frequency band is harmonized for radiolocation (radar), but the U.S. adds an allocation for amateur radio.

Outstanding examples of SDRs that have been ruggedized for both radiation hazards and shock and vibration, as well as being deconflicted intergalactically, are the Star Wars Commlink, the Star Trek Communicator and the Spaceballs Spaceball, which operate across the galaxy without issues. We will leave it up to the reader as to which is the best SDR, as we have our own opinions.

SDRs are inherently more flexible than traditional hardware-based radios.[3] Traditional radios are typically optimized for specific frequency bands and wireless standards, and changing those often involves physically modifying or replacing components. These differences are shown in ***Figure 3***. Unlike a traditional radio, an SDR can change wireless standards and frequencies through

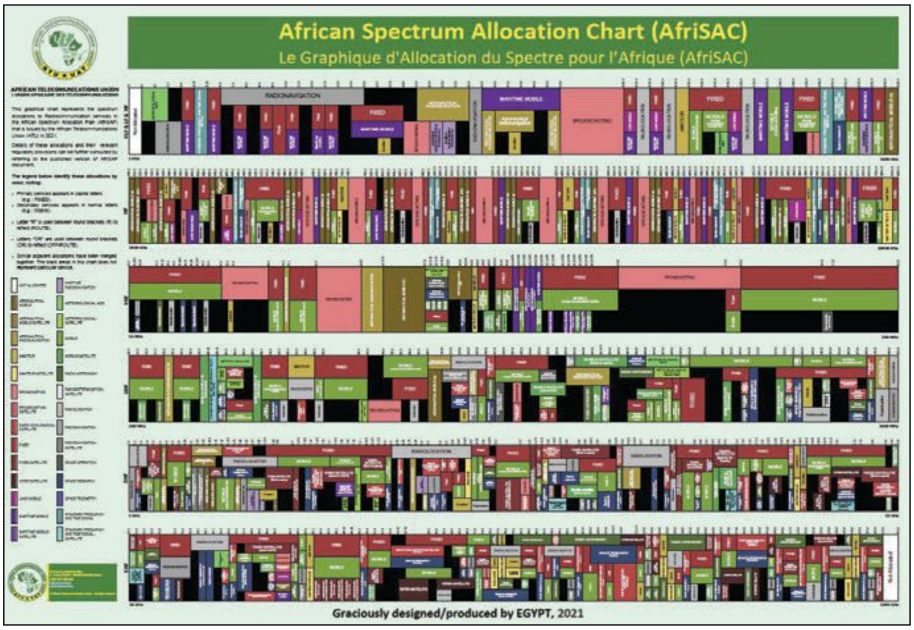


Fig. 2 African spectrum allocation chart. *Source:* African Telecommunications Union.

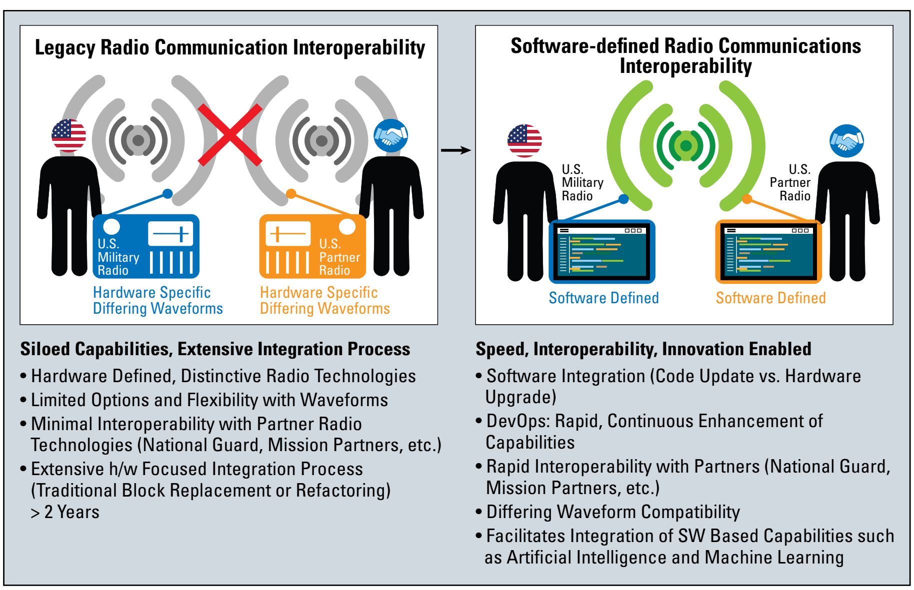


Fig. 3 Legacy radio vs. SDR interoperability. *Source:* Air Force Research Laboratory (AFRL).

software changes, allowing for support of a broader range of applications. This flexibility is achieved by utilizing programmable hardware components that can be reprogrammed to accommodate new protocols and frequencies as needed. SDRs can implement advanced signal processing algorithms that can dynamically adjust to varying signal conditions, optimizing performance in real-time.[4] This enables SDRs to support a wide array of communication standards, from legacy systems to emerging technologies, without the need for hardware changes.[5] Additionally, SDRs enable quick deployment in dynamic environments, as they can be swiftly reprogrammed to adapt to new operational requirements and innovations.

While SDRs have many advantages, they also have challenges. They typically require more power than traditional hardware-based radios, which can be a limitation in power-sensitive applications. The complexity of the software involved in SDRs necessitates sophisticated development and maintenance, often incurring higher initial development and ongoing maintenance (or sustainment) costs. Furthermore, the initial investment in SDR technology can be more expensive compared to conventional radio systems, which may be a barrier for some organizations. Additionally, the need for robust cybersecurity measures to protect against software vulnerabilities adds another layer of complexity and expense.[5]

Commercial SDRs are primarily designed to meet the needs of a broad market, focusing on flexibility and interoperability across various consumer and enterprise applications. They typically prioritize cost-effectiveness and ease of use, supporting multiple communication standards such as LTE, Wi-Fi and Bluetooth. In contrast, military SDRs are built to meet stringent requirements for durability, performance, reliability and security while operating in harsh environments and incorporating advanced encryption and anti-jamming technologies. Additionally, military radios are ruggedized to withstand extreme conditions, including shock, vibration and radiation hazards. Cybersecurity is another critical concern in military SDRs, necessitating robust protective measures to safeguard against cyber threats and ensure the integrity of communications.[6,7] While SDRs offer significant benefits, their design and implementation are tailored to meet the specific demands of their respective use cases.

Military and commercial SDRs have distinct differences in size, weight and power (SWaP), and costs driven by their specific operational requirements and use cases. A table summarizing the differences between commercial and military SDRs and the trade-offs is shown in ***Table 1***.

Looking at it in greater detail, military SDR designs have specific requirements that drive form factors:

- **Size and Weight:** Military ruggedization results in bulkier devices compared to their commercial counterparts.
- **Power:** Military requirements for encryption and anti-jamming technologies, as well as the need to support multiple, simultaneous communication channels, typically require more power to operate.
- **Reliability:** The requirement to have a single radio operate reliably in frozen worlds like Star Wars' Hoth and Earth's Southeast Asian rainforest drives design accommodations and results in higher material costs in military SDRs.

In contrast, a commercial SDR has a very different set of priorities:

- **Size and Weight:** Commercial SDRs prioritize ease of use, portability and cost-effectiveness, often resulting in more compact and lightweight designs.


ERZIA
NEWSPACE
DC CTRL
ERZIA
ERZ-HPA-0600-1800-40-E-NS
IN
OUT
COTS ready for launch
Discover it at EuMW Stand #C84
erzia.com/newspace

TABLE 1

DIFFERENCES BETWEEN SDRS AND THE DESIGN TRADE-OFFS

Design Axis	Military SDR	Commercial SDR	Primary Trade-off
Mission Environment	Contested/jamming, coalition ops	Regulated, low-threat	Anti-jam resilience vs. cost/complexity
Standards & Testing	MIL-STD-810, -461, JITC	FCC, 30PP, PTCRB	Extreme qualification vs. time-to-market
Security	Type-1/Suite-A crypto, Zeroise circuits	AES/FIPS, OS-level	High assurance vs. SWaP/battery
Waveform Flexibility	Multi-band, hopping, SCA	Few standards, optimized silicon	Interoperability vs. power/latency
SWaP	Rugged, high-power PA	Slim, battery-centred	Range & ruggedness vs. weight/size
Economics	Low volume, $$$	High volume, $	Lifecycle sustainment vs. unit cost

- **Power Costs:** Designed to be power efficient, commercial SDRs cater to consumer and enterprise applications, where battery life and energy consumption are important factors. They focus on optimizing power usage for standard communication protocols such as LTE, Wi-Fi and Bluetooth.
- **Cost Considerations:** The emphasis on affordability and accessibility for a wide range of users drives the design and manufacturing processes.

Under harsh operating conditions, military priorities of security and performance result in generally higher SDR SWaP values. In contrast, commercial SDRs focus on cost-effectiveness, portability and power efficiency, leading to lower SWaP values tailored to their respective markets. The number of production units manufactured is an order of magnitude higher than the military, which drives production costs down.

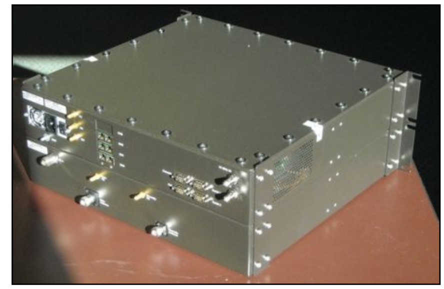


Fig. 4 Vanu Inc.'s Anywave® global system for mobile communications. *Source:* Vanu Inc.

The first commercial SDR approved by the Federal Communications Commission (FCC) was Vanu Inc.'s Anywave® global system for mobile communications (GSM) base station in November 2004, as shown in ***Figure 4***. It ran on a general-purpose processing platform and was a dual-mode cellular base station that supported both GSM and code division multiple access (CDMA). In a press release announcing the certification, Vanu stated their system consisted, "entirely of software applications that support all of the GSM cellular base station functionality running on off-the-shelf Hewlett-Packard ProLiant servers with an ADC Digiv-

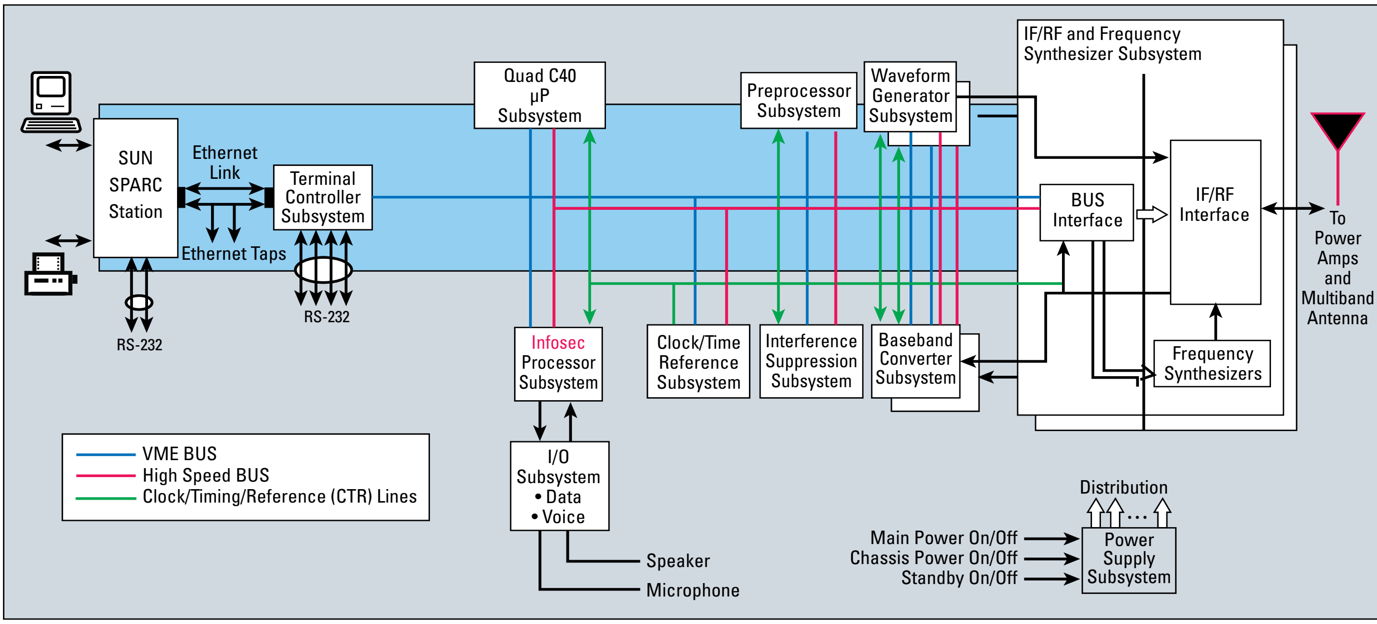


Fig. 5 SPEAKEasy Phase 1 architecture. ***Source:*** **AFRL.**

ance RF subsystem." At the time, the FCC chairman called the approval "the first step in what may prove to be a radio technology revolution."[8] And there has been, or rather, in the words of Star Wars Episode VII, The Force Awakens: "There has been an awakening. Have you felt it?"

The Joint Tactical Radio System (JTRS) was the first major military software-defined radio. The first true military SDRs were the SPEAKEasy I and II, developed at the Air Force's Rome Labs in New York.[9] Phase I was demonstrated in 1994.[10] They were proofs of a concept, research and development program, with

two programmable channels, a Texas Instruments quad-TMS 320C40 multi-chip module for digital signal processing and a SUN Sparc 10 workstation as a man-machine interface.[9] The architecture for SPEAKEasy I is shown in ***Figure 5***.

By the early 2000s, advances in radio technology had complicated communications. Ground and aviation radios were typically unable to communicate with modern satcom systems.[11]

When JTRS was initially being developed in the early 2000s, its primary goal was to be fully interoperable between the different types of radios[11], as shown in ***Figure 6***. The Army was the lead military department for the acquisition. They intended to change that with JTRS by developing and acquiring affordable, high-capacity, fully interoperable tactical radios to meet the bandwidth needs of different military areas. The JTRS program had eight common goals and a multi-billion-dollar budget. In 2012, they delivered a ground mobile radio (GMR) after having spent billions on other radios.[12] The GMR could not tolerate harsh conditions, making it unusable in the desert. The key issue with the program was that the U.S. military started with a technological advancement problem the size of a Borg Cube and decided it was the size of a short Jedi Master. And, like Yoda being underestimated because of his size, the size and complexity of the development efforts needed to create and implement ruggedized, fully interoperable multi-domain SDRs were significantly underestimated.[3] For scale, a Borg cube has an approximate volume of 27 cubic kilometers, and Yoda is 66 cm tall.

Fig. 6 The JTRS SDR was designed to use a common architecture. *Source:* U.S. Army.

SDRs are now integral to many areas, both commercial and military, due to their adaptability and advanced capabilities. In the commercial sphere, SDRs support the global economy by enabling seamless communication across different standards and frequencies, which is vital for international business operations, industrial applications, medical technology, mobile communications and space. They ensure the bleeps, sweeps and creeps all stay where they should, and do so with very low latency, and, unlike Spaceballs, with no raspberry jam.

In the military domain, radio requirements have evolved significantly beyond voice and data communications, now requiring communication systems that can run multiple waveforms simultaneously to allow communication across all warfighting domains, something that currently only SDRs can accomplish.[13] These technical breakthroughs allow radios to go where radios have never gone before. This has made them a focus of military communications development efforts for the last several years. They facilitate global military operations by providing versatile and secure communication solutions for command-and-control systems, tactical battlefield radios, satcom, radar systems and more. SDRs can be rapidly deployed

and reconfigured to meet the demands of different mission environments. This flexibility ensures that military personnel can consistently maintain reliable communications independent of location or operating conditions.

Today, SDRs are used in a wide range of applications. They play a crucial role in enabling commercial requirements across different standards and frequencies. Just as Vanu got the first one approved for a cellular base station, SDRs are now heavily used by mobile technology companies. They provide low latency, great flexibility, high interoperability and massive multiple input multiple output (MIMO) capabilities, which are useful for the 5G physical layer and the beamforming associated with 5G signal processing.[14,15] Space is the next frontier for SDRs. SDRs have an advantage over traditional radios in that they can be reconfigured from the ground, enabling one unit to be adapted for multiple applications. Furthermore, a single satellite can operate in multiple frequency bands simultaneously, as with the European Data Relay System (EDRS), shown in ***Figure 7***.

Beyond cellular technology and space purposes, SDRs have become integral to medical devices—applications that use RF, such as computed tomography (CT) scanners or magnetic resonance imaging (MRI) systems rely on SDRs. They are also used for remotely monitoring, controlling and analyzing industrial devices and processes—supervisory control and data systems, or SCADA systems. SCADA systems are used across many industries, including oil and other pipelines, utilities and water and wastewater plants.

The current military SDRs are used across all warfighting domains and have advanced encryption to ensure secure communications in contested areas. The U.S. military has moved past the JTRS system, and while it has not reached the technological level of Star Trek communicators yet, SDRs are being used across all the military departments in all the domains, from handheld radios, manpack radios for forward-deployed teams, hardened expeditionary networks, aviation radios, to space-based radios and SATCOM. The U.S. Army's new Combat Net Radio (CNR) upgrades existing radios and provides secure battlefield voice and data communications critical for success in today's battlefield.[16]

Operating a military SDR, like the Navy's Amphibious Tactical Communications Systems (ATCS) or the CNR, outside U.S. borders is fundamentally a regulatory exercise wrapped around an RF design problem. Success hinges on three pillars: regulatory alignment, technical agility and documented assurance. All three must be addressed early in the DOD's acquisition cycle using the SSRA process.

For military systems, building a robust SSRA is essential for design and procurement decisions throughout the acquisition process.[17] They provide an early assessment for a system's potential to cause interference to, or suffer from, other military or civilian RF systems currently in use or planned for operational environments, both domestic and foreign.[2] The general process is shown in ***Figure 8***. At a minimum, it should include:

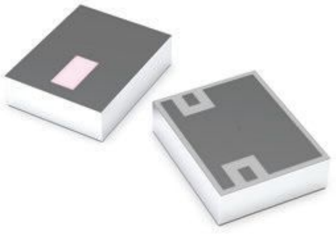
- System overview for context (MIL-STD-469G Annex A)
- Technical data sheet for power-density calculations (ITU-R Rec. SM.329)

10.7 TO 31 GHz

SATCOM Filters

Proprietary LTCC Designs

- Surface-mountable 1008 package size
- 1W power handling
- Available for space upscreening
- Wide rejection band



Model Number	Passband (MHz)	Stopband F3 (MHz)	Rejection @ F3 (dB)	Stopband F4 (MHz)	Rejection @ F4 (dB)
BFCQ-2702+	22000-31000	100-17100	42	35700-48000	43
BFCQ-2872+	27500-30000	100-22200	32	35300-55000	28.4
BFCQ-1932+	17700-21000	DC-14600	30	25600-40000	40
BFCQ-1982+	17700-20200	100-14500	55	24000-40000	45
BFCQ-1162+	10700-12700	100-8800	40	15100-27000	38

Mini-Circuits®

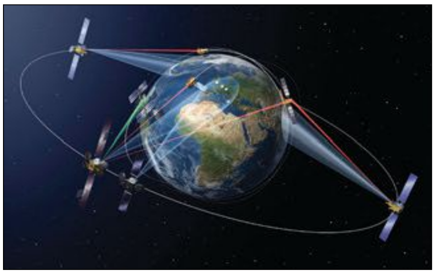


Fig. 7 The EDRS. *Source:* European Space Agency.

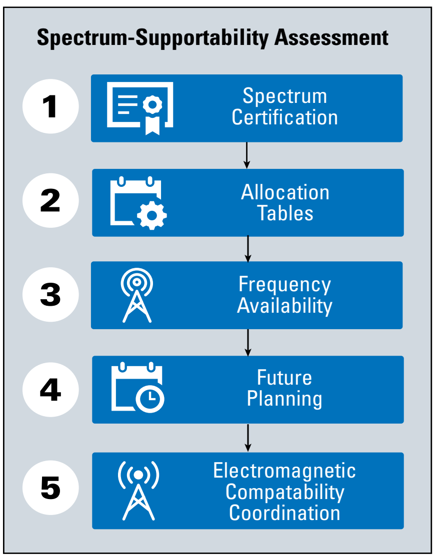


Fig. 8 General SSRA process.

- Occupied-bandwidth & out-of-band plots for compliance (CISPR 16-2-3)
- Interference-hazard analysis (ITU-R Rec. M.2101)
- Footnote cross-matrix mapping RF bands to national footnotes (ITU Radio Regulations)
- EMC/EMI test reports (MIL-STD-461G)
- Signed host-nation license or MOU.

Military host-nation approvals are critical and time-consuming. National regulators process each visiting system individually, for example, requiring filing for a spectrum license for a satellite to transmit, an application, a technical annex, reviews, approvals and sometimes on-site acceptance testing. This process can take months and involve multiple rounds of questions. It is essential to know the regulatory authority, whether it's the Ministry of Defense (MOD) frequency office in a NATO nation, or a civilian spectrum regulator like the National Communications Commission (NCC) in Nigeria.[18]

Commercial SDRs are increasingly sold and deployed worldwide, and like military SDRs, they must comply with local spectrum regulations in the country where they operate. However, the approval process for commercial equipment is generally faster and more standardized than for military systems.

Before a commercial SDR (like a cellular base station, Wi-Fi router or IoT device) can be sold in a new country, the manufacturer must obtain approval from the national regulatory authority. This ensures the device will only operate within permitted frequency bands, at allowed power levels, and in accordance with approved technical standards. Unlike military deployments, which often require detailed applications and case-by-case approvals, most commercial products follow a standardized process. This often includes submitting test results from accredited labs and complying with international norms such as those from the International Telecommunications Union (ITU), the European Telecommunications Standards Institute (ETSI) or the FCC.

Modern commercial SDRs are often designed with region-specific profiles or software-based geo-location. This enables a single device to automatically adapt to the frequency allocations and power limits specified by local regulators. When the device is powered up in a different country, it loads the appropriate configuration, sometimes based on SIM card location, GPS data or user selection, ensuring legal operation without any hardware changes. Firmware updates can add support for new markets or adapt to changing regulations, making SDRs highly flexible for global manufacturers.

For the end user, this means a commercial SDR can be sold and used globally with minimal changes, provided it passes the relevant compliance tests. In short, commercial SDR spectrum supportability is managed through a combination of international certification standards, reconfigurability and automated regional adaptation.

Both commercial and military SDR manufacturers must ensure that, as they provide systems worldwide, they accurately map frequency allocations to the corresponding footnotes in the ITU regions' frequency allocation tables, as shown in ***Figure 9***, since this plays a significant role. For example, the 225 to

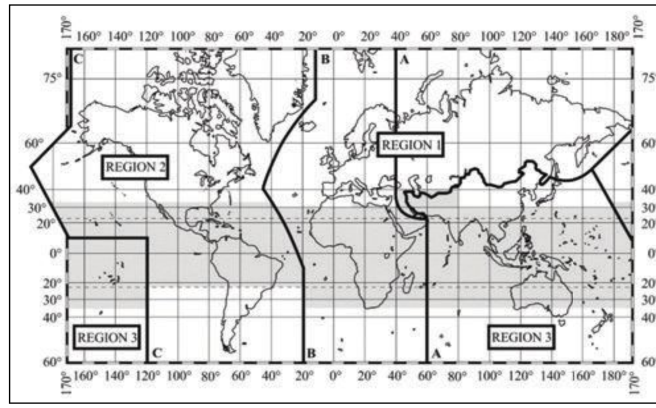


Fig. 9 ITU regions and the dividing lines between them. *Source:* ITU.

400 MHz band is allocated for aeronautical mobile use in Region 2 but has different allocations in Region 1, necessitating adjustments for commercial systems being marketed and for military systems being used during exercises. Specific national deviations also exist, such as the U.K.'s "emergency services suppression," where frequencies 380 to 446 MHz are used only for emergency services. The U.K.'s emergency band is the U.S.'s land mobile radio. Maintaining a cross-matrix of ITU table entries, regional footnotes and country-specific differences is crucial. Spectrum convergence efforts from organizations like the European Conference of Postal and Telecommunications Administrations (CEPT) and the Inter-American Telecommunication Commission (CITEL) should also be tracked to facilitate future adjustments through firmware updates.

The military has learned many lessons both operationally and through exercises such as Bold Quest 2024 and Pacific Griffin 2023. Link-16, the tactical data network used by NATO members, had emissions that impacted aircraft positioning receivers in Norway, leading to a software patch for power reduction. The NATO Tiger Meet 2022 exercise highlighted the need for narrowband frequency-hopping to overcome intermodulation issues in crowded bands. These issues were documented, and the radio equipment was updated as a result of the exercises.

By integrating documentation, regulatory, technical and real-world information streams from the outset, commercial and military SDRs remain globally usable with only minor software tweaks, avoiding costly redesigns for the different global spectrum allocations. SDRs represent a significant advancement in radio technology, offering unparalleled flexibility and adaptability. While they come with challenges, their benefits make them invaluable in both commercial and military contexts. As we continue to innovate and improve SDR technology, we can look forward to even greater capabilities and applications. Live long and prosper. ■

REFERENCES

1, B. Farmer and M. Klein, "Spectrum Supportability Risk Assessments: An Overview," *Defense Systems Information Analysis Center*, 2 November 2019. [Online]. Available: https://dsiac.dtic.mil/articles/spectrum-supportability-risk-assessments-an-overview/.

2, Defense Information Systems Agency and the Defense Spectrum Organization, "Joint Services Guide for Development of a Spectrum Supportability Risk Assessment (SSRA)," *Defense Acquisition University*, September 2011. [Online].

3. L. Goeller and P. Bronson, "Promise, Reality, and Limitations of Software Defined Radios," *Institute for Defense Analysis (IDA)*, Arlington, 2013.

4. Air Force Research Laboratory (AFRL), "Software Defined Radio: Connecting At Machine Speeds," *AFRL*, [Online]. Available: https://afresearchlab.com/technology/information-technology/successstories/software-defined-radio/.

5. R. Akeela and B. Dezfouli, "Software-defined Radios: Architecture, State-Of-The-Art, and Challenges," *Computer Communications*, Vol. 128, pp. 106–125, September 2018.

6. A. Guzman, "Why COMSEC is More Critical Than Ever: A Closer Look at the Hidden Battlefield of Communications Security," *U.S. Army*, 8 October 2024. [Online]. Available: https://www.army.mil/article/279799/why_comsec_is_more_critical_than_ever_a_closer_look_at_the_hidden_battlefield_of_communications_security#:~:text=The%20risks%20associated%20with%20poor,the%20margin%20for%20error%20smaller.

7. Global Foxcom, "The Risks of Unsecured RF Communications," *Global Foxcom*, 19 May 2025. [Online]. Available: https://foxcom.com/blog/the-importance-of-secure-rf-communications-in-modern-warfare/#:~:text=Unsecured%20RF%20channels%20are%20vulnerable,need%20for%20fortified%20communication%20infrastructure.

8. TVTechnology, "Vanu Receives FCC's First Authorization for Software-Defined Radio (SDR)," *TVTechnology.com.com*, 33 November 2004. [Online]. Available: https://www.tvtechnology.com/news/vanu-receives-fccs-first-authorization-for-softwaredefined-radio-sdr.

9. W. Bonser, "SPEAKeasy Military Software Defined Radio," in 1998 *International Symposium on Advanced Radio Technologies*.

10. V. Bose, "A Software Driven Approach to SDR Design," *COTS Journal*, January 2004. [Online]. Available: http://www.cotsjournalonline.com/articles/view/100056.

11. J. Wilson, "Military Communications Technology Makes The Switch," *Military & Aerospace Electronics*, 1 April 2002.

12. S. Gallagher, "How to Blow $6 Billion on a Tech Project," *ars Technica*, 18 June 2012.

13. D. Parsons, "Software-Defined Radios: Critical for the Military's Future Secure Communications Needs," *Avionics International*, January/February 2023.

14. R. Mohammadi, "The Future of 5G with SDR," *Microwaves and RF*, 26 February 2021.

15. A. Sayed, "Effectiveness of Beamforming Techniques on 5G," *International Journal for Multidisclipinary Research (IJFMR)*, Vol. 4, No. 6, 2022.

16. PEO C3N, "Combat Net Radio," *US Army*, [Online]. Available: https://peoc3n.army.mil/Organizations/PM-Tactical-Radios/Combat-Net-Radio/.

17. Defense Acquisition University, "J8 - Spectrum Supportability Risk Assessment SSRA," *Defense Acquisition University (DAU)*, [Online]. Available: https://www.dau.edu/cop/e3/resources/j8-spectrum-supportability-risk-assessment-ssra.

18. Elix-IRR Partners LLP, "Spectrum Management in Africa," *Elix-IRR Partners LLP*, London, 2015.

From the Radar Equation to T/R Module Specifications

Erick Lima and Josiah Spear
Spectrum Control Limited, Buckinghamshire, United Kingdom

Modern radar systems, as demonstrated in ***Figure 1***, are increasingly embedded within complex, multi-domain platforms—from airborne surveillance and automotive sensing to joint radar-communications systems. Therefore, designers must navigate a wide variety of technical trade-offs to ensure performance, efficiency, and integration.

While radar theory is well established, the challenge today is bridging the gap between high-level performance requirements and component-level design choices. The radar range equation serves as a foundational tool for making this connection. Still, its effective use demands an understanding of system-level objectives and practical limitations of real-world sub-systems and components. Originally developed during World War II to support radar performance assessment, the equation remained classified until after the war, when it became publicly available and widely adopted.

Since then, the radar equation has evolved to incorporate correction factors to enhance its accuracy and applicability for complex environments and modern radar systems. Comprehensive treatments, such as those found in (Barton, 2013), provide detailed formulations to improve range predictions and support the design of contemporary systems.

As a design tool, the radar equation enables system dimensioning and facilitates trade-off studies involving transceiver characteristics, range, and resolution. It supports informed design choices and prevents over-design and under-design, which can lead to excessive development cycles and cost increases.

An example of a technical section of a radar procurement document or request for proposal is shown in ***Table 1***. One of the most important parameters is range, typically written as "shall be able to detect a target of minimum radar cross section, $\sigma=\sigma_0$, at distance $R=R_0$ km with $Pf=Pf_0$ and $Pd=Pd_0$," where Pf and Pd are the probability of false alarm and detection, respectively. Other performance requirements can include the number of targets, range resolution and acquisition timing.

TABLE 1

FORMAL SPECIFICATION EXAMPLE

Parameter	*Requirements*
Specification at ranges	i. σ of 2 sqm up to 60 km with $Pf=1 \times 10^{-6}$ and $Pd = 0.9$
	ii. σ of 2 sqm up to 20 km with $Pf=1 \times 10^{-6}$ and $Pd = 0.9$
	iii. σ of 0.01 sqm up to 5.0 km with $Pf=1 \times 10^{-6}$ and $Pd = 0.9$

Radar Range Equation

For this evaluation, only strictly required mathematical derivations are provided, as the emphasis is on usability. Analysis is restricted to thermal noise being the dominant source of interference.

While the emphasis is on pulsed radar systems, radar waveforms and architectures vary widely, including continuous wave (CW), frequency-modulated CW (FMCW) and pulse-Doppler systems. However, this diversity does not diminish the value of a top-down systems design approach, which remains applicable across radar modalities.

To begin, consider pulse energy, peak power and pulse duration. The pulse energy E_t is equal to the integral

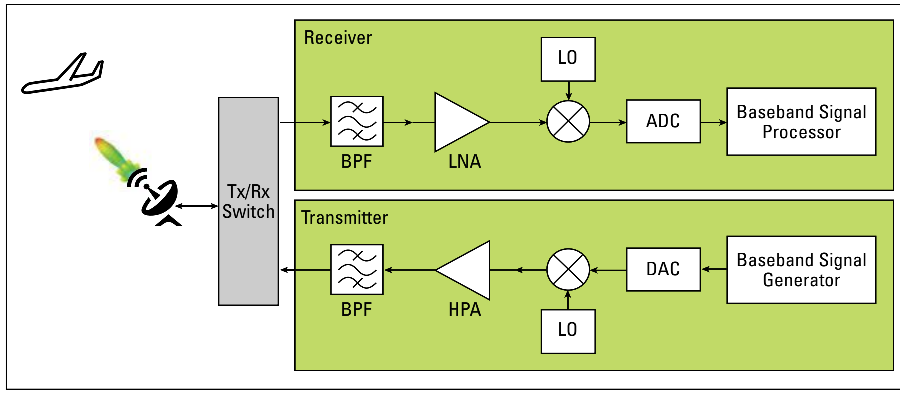


Fig. 1 Typical radar architecture.

of the instantaneous power p over the interval of time occupied by the pulse, i.e. the pulse duration:

$$E_t = \int p\,dt \qquad (J) \qquad (1)$$

For a constant transmit pulse P_t of duration τ seconds, the instantaneous power would equal the peak power P_t so the pulse energy would be:

$$E_t = \int_0^{\tau} P_t \; dt = P_t \tau \qquad (J) \qquad (2)$$

By applying E_t to the input of a matched isotropic radiator, the energy per square metre at distance R from the transmitter is given by:

$$S_0 = \frac{P_t \tau}{4\pi R^2} \qquad (J/m^2) \qquad (3)$$

G_t represents the gain of the transmit radar antenna relative to the isotropic reference, so:

$$S_t = S_0 \cdot G_t = \frac{P_t \tau G_t}{4\pi R^2} \qquad (J/m^2) \qquad (4)$$

The radar cross section (RCS), denoted by σ, quantifies the "effective echoing area" of a reflective object or target. If the target is in the direction of maximum radar antenna gain G_t at distance R, the total energy per square metre reflected by the target covering a sphere of radius R centred at the target is:

$$S_r = \frac{S_t \sigma}{4\pi R^2} = \frac{P_t \tau G_t \sigma}{(4\pi)^2 R^4} \qquad (J/m^2) \qquad (5)$$

The receiver antenna effective aperture A_e represents the ability of a receiving antenna to collect incident electromagnetic energy from a given direction:

$$A_e = \frac{G_r \lambda^2}{4\pi} \qquad (m^2) \qquad (6)$$

Thus, the total received energy referenced at the output terminal of the receiver antenna can be expressed as:

$$E_{r'} = S_r \cdot A_e = \frac{P_t \tau G_t \sigma A_e}{(4\pi)^2 R^4} \qquad (J) \qquad (7)$$

Combining Equations 6 and 7, the received energy at the output terminal of the receiver antenna can be given by:

$$E_r = \frac{P_t \tau G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4} \qquad (J) \qquad (8)$$

This expression makes explicit the dependency on the carrier frequency $\lambda_0 = \frac{c_0}{f_0}$ and the receiver antenna gain G_r. It shows that the physical size of the antenna and the transmitted waveform characteristics (pulse duration τ) contribute to the received energy.

Rearranging Equation 8 yields the range equation, expressed in terms of received energy:

$$R^4 = \frac{P_t \tau G_t G_r \sigma \lambda^2}{(4\pi)^3 E_r} \qquad (m^4) \qquad (9)$$

This form is particularly useful when evaluating radar systems based on required detection energy thresholds. If the received energy E_r is reduced to the minimum detectable level $E_{r,min}$, and the corresponding range is defined as the maximum detection range R_{max}, then Equation 9 becomes:

$$R_{max}^4 = \frac{P_t \tau G_t G_r \sigma \lambda^2}{(4\pi)^3 E_{r,min}} \qquad (m^4) \qquad (10)$$

This is the maximum radar range equation: the theoretical upper limit of detection range under ideal conditions.

The available thermal noise power generated at the input of an ideal receiver at systems equivalent temperature T_s and noise bandwidth B is:

$$P_n = k T_s B \qquad (W) \qquad (11)$$

Where k is Boltzmann's constant

TABLE 2

REQUIREMENTS FOR TRANSCEIVER PARAMETER EXAMPLE

Parameter	Requirements
Specifications at ranges	σ of 0.01 sqm up to 10 km with $Pf=1 \times 10^{-6}$ and $Pd = 0.9$

(1.38×10^{-23} $m^2.kg.s^{-2}.K^{-1}$). The bandwidth B of a superheterodyne receiver is taken to be the bandwidth of the IF amplifier or matched filter. Although the noise bandwidth is not strictly equal to the 3 dB bandwidth, in many practical applications the 3 dB bandwidth is a sufficient approximation which simplifies calculations without significantly impacting range estimations, especially for well-matched filter designs.

The signal-to-noise energy ratio (S/N) at the input of a receiver with equivalent temperature T_s and bandwidth B is then:

$$(S/N) = \frac{E_r}{P_n} = \frac{P_r \tau}{kT_s B\tau} \qquad (12)$$

And for $B=1/\tau$, the expression can be rewritten for E_r as:

$$E_r = (S/N)kT_s \quad (J) \qquad (13)$$

$$\rightarrow E_{r,min} = (S/N)_{min} kT_s \quad (J) \qquad (14)$$

Replacing the term $E_{r,min}$ in Equation 10 by 14 and rearranging to make R explicit, it is shown that the maximum achievable range $R=R_{max}$, happens for $(S/N)=(S/N)_{min}$:

$$R_{max} = \left[\frac{P_t \tau G_t G_r \sigma \lambda^2}{(4\pi)^3 (S/N)_{min} kT_s}\right]^{1/4} \quad (m) \qquad (15)$$

The equation is valid for free-space and lossless transceivers. It assumes that the beam direction is ideal, i.e. that G_t, G_r correspond to maximum gain directions for transmit and receive antenna, respectively. In a monostatic radar system, i.e. where the transmitter and receiver are co-located and share the same antenna, $G_t \cdot G_r$ becomes G^2.

It is important to note that it can be convenient to replace T_s with the equivalent system noise factor $F_s=T_s/T_0$, where T_0 = 290°K, is the standard reference. When referring to system temperature or system noise factor, not only is the receiver equivalent temperature accounted for, but also the noise contribution from the antenna. Assuming a lossless interconnect between a receiver and an antenna, when the transceiver is connected to the antenna, the relationship between the

TABLE 3

RANGE REQUIREMENTS FOR POSSIBLE SYSTEM PARAMETERS

Range Equation Input Parameters	Linear Scale	dB	
Peak transmit power, P (W)	10000	$10 \log_{10}(P_t)$	40.00
Pulse Width, τ (s)	0.2×10^{-6}	$10 \log_{10}(\tau)$	-66.99
Transmit antenna gain, G_t	10000	$10 \log_{10}(G_t)$	40
Receive antenna gain, G_r	10000	$10 \log_{10}(G_r)$	40
Central frequency, f_0 (Hz)	10×10^9	–	–
Wavelength^2,$\lambda^2=(c_0/f_0)^2$	9×10^{-4}	$10 \log_{10}(\lambda^2)$	-30.46
Radar cross section,σ (m^2)	0.1	$10 \log_{10}(\sigma)$	-10.00
$(4\pi)^3$	$(4\pi)^3$	$10 \log_{10}((4\pi)^3)$	32.98
Visibility factor, $V_0 = \left(\frac{S}{N}\right)_{min}$	10000	$10 \log_{10}(V_0)$	20.00
Noise power, kT_s (W/Hz)		$10 \log_{10}(KT_s)$	-200.97

Maximum achievable range based on these parameters can be calculated from equation 15 as follows.

$$R^4_{max}[dB] = 10\log_{10}(P_t) + 10\log_{10}(\tau) + 2G[dB] + 10\log_{10}(\lambda^2) + 10\log_{10}(\sigma)$$
$$-\left[10\log_{10}((4\pi)^3) + 10\log_{10}(k) + 10\log_{10}(T_s) + 10\log_{10}(V_0)\right]$$
$$= (40 - 66.99 + 40 + 40 - 30.46 - 10) - (32.98 + 20 - 200.97) = 160.55\ dB$$

$$R_{max} = \left(10^{\frac{160.55}{10}}\right)^{1/4} = 10.32\ km$$


TREXON
Mission Critical Connections
When it comes to solving intricate connectivity challenges, look no further than Trexon. Our cutting-edge connector and cabling solutions are meticulously designed to exceed expectations.
• Built to remain secure and reliable, in the harshest environments.
• Wide range of options to cater to your specific needs.
Discover the Trexon difference today and unlock a world of seamless connectivity solutions!
Designed for Durability. Engineered for Excellence.
trexon.com
EZ FORM CABLE
CEPA
IntelliConnect
603 MANUFACTURING
CICOIL

receiver noise factor and antenna noise temperature is given by:

$$Fs = Ts/T_0 = \frac{T_a}{T_0} + F_n - 1 \qquad (16)$$

where T_a is the antenna noise temperature and F_n is the noise factor of the receiver.

Modern versions of the original range equation usually include error correction functions to compensate for non-ideal behaviour. The authors encourage readers to consult comprehensive works such as (Barton, 2013; Pozar, 2021; Balanis, 2016; Richards, 2010; Skolnik, 1980; Omberg, 1947).

Cautions and Limitations using the Basic Range Equation

While Equation 15 is extremely useful, it is still a starting point and, therefore, must not be taken as universally applicable. It assumes free-space propagation (no ground reflection or atmospheric absorption); no multipath, clutter, or interference sources; perfect receiver matching; and a lossless transceiver.

Accounting for real-world environmental effects often renders the range equation analytically unsolvable. In such cases, numerical methods or full-wave propagation models are necessary. Improper assumptions or simplifications can lead to serious design errors, resulting in systems that are overdesigned, underperforming, or cost-prohibitive. Designers should be aware of the equation's limitations and consider detailed modelling approaches, when required.

The following examples show this equation serves as a direct bridge between performance requirements and subsystem specifications.

Example 1: Range Estimation

In this example, the goal is to use the radar Equation 15 to define a set of transceiver parameters that meet the following requirements (see ***Table 2***).

The probability of detection, *Pd*, and probability of false alarm, *Pf*, depend on the detector sub-system. They are essential in determining the minimum visibility factor, $V_0=(S/N)_{min}$: the minimum pulse energy-to-noise ratio where the pulse can be detected. Due to the complexity and probabilistic theory required to determine the visibility factor, it will be assumed that the visibility factor is a given parameter and a function of *Pd*, *Pf*, and *B* i.e. $V_0=g(Pd=0.9, Pf=0.1, B=\frac{1}{\tau})$.

Consider that V_0 [dB] = 20 dB and operating frequency f_0 =10 GHz. With these assumptions, a possible combination of system parameters to meet the range requirement is in ***Table 3***.

There are an infinite number of combinations that meet the range requirement. This enables system engineers to optimize designs based on mission-specific priorities such as SWaP and available technology. ***Table 4*** presents examples of parameters that achieve the same maximum range at which a target with $\sigma = 0.1$ m^2 can be detected for a fixed $f_0 = 10$ GHz and $V_0 = 20$ dB.

Example 1 illustrates how the radar equation can translate high-level detection requirements into quantitative subsystem specifications. By defining the desired detection range, radar cross section, and minimum visibility factor, $V_0=(S/N)_{min}$, the required transmit power, and receiver system noise temperature for a given antenna gain were calculated.

This exercise demonstrates the practicality of the top-down design thinking: not arbitrarily allocating performance budgets to individual compo-

TABLE 4

COMBINATIONS OF SYSTEM PARAMETERS WITH ANALOGOUS ANSWERS

Case	Peak Transmit Power, P_t	Pulse Width, τ	Antenna Gain, G (dB)	System Temperature Ts	Range (km)
1	10 kW	0.2 us	80 (Gt = Gr = 40 dB)	579 (NF_s = 3 dB)	10.32
2	5 kW	0.4 us	80 (Gt = Gr = 40 dB)	579 (NF_s = 3 dB)	10.32
3	10 kW	0.3 us	83.2 (Gt = Gr = 41.6 dB)	1830 (NF_s = 8 dB)	10.32
4	50 kW	0.2 us	74 (Gt = Gr = 37 dB)	1830 (NF_s = 4 dB)	10.32

nents but aligning parameters that benefit system objectives. It emphasizes the need for collaborative specification work and trade-offs across hardware designers and systems engineering teams to ensure overall feasibility and program goals.

Determining Antenna Element Number from Gain Requirements

In a phased array antenna, the total radiated field is determined by the radiation characteristics of the individual antenna elements and their spatial arrangement. According to the pattern multiplication principle, the total field E_{total} is obtained by multiplying the single-element radiation pattern $E_{element}$ by the array factor (*AF*):

$$E_{total} = E_{element} \times AF \qquad (17)$$

In logarithmic scale, this relationship becomes:

$$E_{total}(dB) = 10\log_{10}(E_{element}) + 10\log_{10}(AF) \qquad (18)$$

This rule applies under the assumption that all antenna elements are identical and equally spaced. For a rectangular (planar) array with *M* elements along the x-axis and *N* elements along the y-axis, and assuming uniform amplitude excitation, the array factor is given by:

$$AF = \left\{ \frac{\sin\left(\frac{M}{2}\psi_x\right)}{\sin\left(\frac{1}{2}\psi_x\right)} \right\} \cdot \left\{ \frac{\sin\left(\frac{N}{2}\psi_y\right)}{\sin\left(\frac{1}{2}\psi_y\right)} \right\} \qquad (19)$$

where the phase terms are defined as:

$\Psi_x = kd_x \cos\theta_0 \sin\phi_0 + \boldsymbol{\beta}_x$
$\Psi_y = kd_y \cos\theta_0 \sin\phi_0 + \boldsymbol{\beta}_y$

- $k = \lambda \cdot 2\pi$ is the wave number
- $d_x d_y$ are element spacings in the *x* and *y* directions
- θ_0 ϕ_0 define the observation angle
- $\boldsymbol{\beta}_x, \boldsymbol{\beta}_y$ are phase shifts applied for beam steering

which in logarithmic form corre-


EXODUS ADVANCED COMMUNICATIONS
Exodus-The Benchmark
Professional Grade
Feel the Power!
AMP20072
6.0-18.0 GHz, 300W
AMP20176
6.0-18.0 GHz, 1000W
AMP20160
1.0-6.0 GHz, 750W
AMP20130
80-1000 MHz, 1300W
RF & Microwave
Amplifiers CW & Pulse
10 kHz-75 GHz
LNA's & Modules
EXODUS
3674 E. Sunset Road, Suite 100, Las Vegas, Nevada 89120 USA
Tel : 1-702-534-6564 Email : sales@exoduscomm.com

sponds to:

$$AF[\mathrm{dB}] = 10\log_{10}\left\{\frac{\sin\left(\frac{M}{2}\psi_x\right)}{\sin\left(\frac{1}{2}\psi_x\right)}\right\} + 10\log_{10}\left\{\frac{\sin\left(\frac{N}{2}\psi_y\right)}{\sin\left(\frac{1}{2}\psi_y\right)}\right\} \quad (20)$$

At boresight (broadside direction, where all elements radiate in phase), the maximum value of the array factor occurs at $\psi_x=\psi_y=0$, leading to:

$$AF_{max} = M \times N \rightarrow AF_{max}[\mathrm{dB}] = 10\log_{10}(M \times N) \quad (21)$$

Resulting in:

$$G_{total}(\mathrm{dB}) = G_{element,[\mathrm{dB}]} + 10\log_{10}(M \times N) \quad (22)$$

Example 2: Array Size and Distributed Transmit Peak Power Requirement

Taking the total antenna gain determined in Example 1, and for an array antenna with element of 5 dBi,

$$G_{total} = 40\ \mathrm{dB}$$
$$G_{element} = 5\ \mathrm{dB}$$

Equation 21 can be used to calculate the total number of antenna elements required to meet the gain requirement:

$$40 = 10\,log_{10}(G_{element,max}) + 10log_{10}(M \times N)$$

$$10\,log_{10}(M \times N) = 40 - 10log_{10}(G_{element,max})$$

$$num\_elements = M \times N = 10^{\frac{40-5}{10}} = 3162.28\ \text{elements}$$

For AESA distributed power systems (1:1 ≡ amplifier:antenna element), and given that in Example 1 it was specified that the required total output peak transmit power, P_t is 10 kW, the required peak power per element can be found as:

$$unit\_Peak\_power = \frac{P_t}{nun\_channels} = \frac{1000}{3162} = 3.16W = 35\ \mathrm{dBm}$$

Example 2 demonstrates how the total transmit power in a phased array is distributed across elements, and how increasing the number of elements allows for reduced peak power per element while maintaining overall system performance. This shows an important relationship that can benefit systems design by balancing array size, element power, and thermal constraints.

Example 3: Distributed Receiver Noise Figure

In a receive array, the total thermal noise power results from the contribution of the antenna noise, low noise amplifiers (LNAs), phase shifters, attenuators, loss from passive components and other components within the RF chain. The calculation of total system noise within an RF chain is known as cascaded noise analysis. However, system performance analysis design is a backward exercise, i.e., from stakeholder requirements to component-level specifications. For simplic-

MiCable

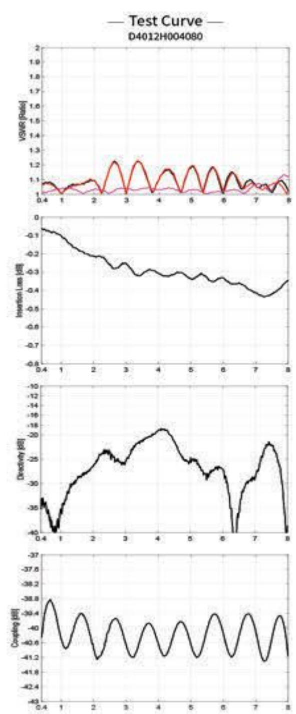
NEW

0.4-8GHz HIGH POWER Directional & Dual-Directional Coupler

- High power handling : up to **600W**
- Low VSWR & insertion loss
- Excellent coupling, flatness and directivity which will significantly improve the signal acquisition accuracy

P/N	CW Power Max.(W)	Nominal Coupling (dB)	Main Line VSWR Max.(:1)	Coupling VSWR Max.(:1)	Insertion Loss* Max.(dB)	Coupling Max.(dB)	Flatness Max.(dB)	Directivity Min.(dB)
0.4-8GHz Directional Coupler								
D3002H004080	120	30	1.3	1.3	0.8	30±1.0	±0.8	18
D4002H004080	120	40	1.3	1.3	0.8	40±1.0	±0.8	18
D3005H004080	250	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4005H004080	250	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3008H004080	400	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4008H004080	400	40	1.4	1.4	0.7	40±1.0	±1.4	14
D3012H004080	600	30	1.4	1.4	0.7	30±0.9	±1.3	14
D4012H004080	600	40	1.4	1.4	0.7	40±1.0	±1.4	14
0.4-8GHz Dual-Directional Coupler								
D3002HB004080	120	30	1.3	1.3	0.8	30±1.0	±1.0	18
D4002HB004080	120	40	1.3	1.3	0.8	40±1.0	±1.0	18
D3005HB004080	250	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4005HB004080	250	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3008HB004080	400	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4008HB004080	400	40	1.4	1.4	0.7	40±1.0	±1.6	14
D3012HB004080	600	30	1.4	1.4	0.7	30±0.9	±1.5	14
D4012HB004080	600	40	1.4	1.4	0.7	40±1.0	±1.6	14

*Theoretical I.L. Included



More Information-
Scan the QR Code

MIcable Inc.

www.micable.cn sales@micable.cn +86-591-87382856

ity, it will be considered that the receiver noise is the LNA noise.

It will be considered that the total noise, T_s, is dominated by antenna and receiver thermal noise:

$$T_s = T_a + T_n \tag{23}$$

The thermal noise contribution from the antenna is given by:

$$P_a = kT_aB \tag{24}$$

Resulting in total antenna noise (for correlated antenna noise) at the power combiner output:

$$P_{a,total} = (N \times M)kT_aBG \tag{25}$$

where $(N \times M)$ is the total number of antenna elements as presented in previous section and G is the channel gain.

The receiver noise per channel, i.e. the noise contribution, of each amplifier at the input terminal of the power combiner is:

$$P_{channel\_in} = kT_0B(F_n - 1)G \tag{26}$$

Where F_n is the amplifier (single channel) noise factor. The noise at the output of the combiner resulting from a single channel amplifier is then:

$$P_{channel\_out} = \frac{kT_0B(F_n - 1)G}{N} \tag{27}$$

The total uncorrelated noise at the output of the power combiner is:

$$P_{total\_out} = P_{channel\_out} \times N = kT_0B(F_n - 1)G \tag{28}$$

$$P_{total\_out} = kT_nBG \tag{29}$$

This equation shows that the receiver noise equivalent temperature is the same as the channel amplifier for uncorrelated noise.

Assuming a total antenna noise temperature, T_a = 75 K and using Example 1 where system temperature was specified as T_s = 579 K, the element noise temperature is:

$$T_n = T_s - T_a = 579 - 75 = 504\,K$$

$$\rightarrow F_s = \frac{T_s}{T_0} = \frac{504}{290} = 1.74$$

$$NF = 10 \times \log 10(1.74) = 2.405\ dB$$

Conclusions

The radar range equation remains a key enabler of performance-driven design. Its value lies not just in numerical computation but in its ability to align technical parameters with operational goals. When used judiciously within a top-down engineering approach, it becomes a guiding structure for navigating complexity, driving optimization, and achieving balanced, effective radar systems design. ■

References

Balanis, C. A. (2016). Antenna Theory: Analysis and Design. John Wiley & Sons.

Barton, D. K. (2013). Radar Equations for Modern Radar. Artech House.

Norton, K. A. (January 1947). The Maximum Range of a Radar Set.

Omberg, K. A. (1947). The Maximum Range of a Radar Set. Proceedings of the IRE.

Pozar, D. M. (2021). Microwave Engineering: Theory and Techniques. John Wiley & Sons.

Richards, M. A. (2010). Principles of Modern Radar: Basic Principles. SciTech Publishing Inc.

Skolnik, M. I. (1980). Introduction to Radar Systems. McGraw-Hill.

USB-Powered VNA Brings Accuracy to Field Applications

Signal Hound
Battleground, Wash.

A vector network analyzer (VNA) is a crucial instrument for designing, testing and optimizing RF components. VNAs offer the ability to characterize the magnitude and phase response of RF and microwave components across a frequency range, providing insight into how signals behave as they reflect, transmit or interact with impedance mismatches. For components such as antennas, filters, cables and amplifiers, VNAs ensure the design performs as expected from prototype to production.

The Signal Hound VNA400 brings this capability into a field-ready form factor, pushing the boundaries of what's possible in a USB-powered test instrument. Supporting up to 40 GHz, the VNA400 is engineered for RF professionals who demand lab-quality performance in any production location.

PORTABLE VNA DESIGN

Signal Hound's introduction of the VNA400 represents a step forward in compact VNA technology. Unlike traditional benchtop analyzers, which are large, power-hungry and prohibitively expensive, the VNA400 offers precision RF analysis in a package that fits in a laptop bag.

Designed for use in the lab, production line or field, the VNA400 connects to a PC via USB-C or Thunderbolt 3/4 and consumes less than 15 W of power. This makes it efficient and adaptable to mobile engineering setups, remote testing sites and constrained test benches.

The VNA400 supports simultaneous sampling of incident and reflected signals on both ports, ensuring accurate and fast S-parameter measurements across a range of frequencies. With a dynamic range of up to 135 dB, sub-Hz frequency resolution and an internal ±1 ppm TCXO, the VNA400 delivers the precision required for demanding test scenarios.

VERSATILITY FROM THE LAB TO THE FIELD

The VNA400 supports two-port and one-port measurements, making it suitable for a wide range of applications, including:

- **Filter Design and Tuning:** Measure insertion loss, group delay and return loss across the passband and stopband. Fast sweeps (up to 2000 points/sec at 30 kHz RBW) enable users to fine-tune filters in real time.
- **Antenna Testing and Matching:** Optimize return loss and VSWR in custom antenna designs or perform field verification of installed systems across a wide frequency range, including Ku- and Ka-Bands.
- **Amplifier Characterization:** Analyze gain, reverse isolation and input/output matching. The VNA400 can handle amplifiers with up to 30 dB of gain while supporting high isolation measurements beyond 120 dB.
- **Cable and Interconnect Testing:** Identify insertion loss, discontinuities or impedance mismatches in RF cables and transmission lines with time-domain analysis.
- **Component Characterization:** Evaluate SMT components, couplers, hybrids and other RF components to verify performance before integration.

The ability to support a broad selection of short-open-load-through (SOLT) calibration kits ensures the VNA400 can be calibrated accurately with commonly available standards.

Fig. 1 Example of Signal Hound software suite.

POWERFUL SOFTWARE, SEAMLESS AUTOMATION

Included with the VNA400 is Signal Hound's VNA software suite, as demonstrated in ***Figure 1***, designed to streamline test and measurement workflows. The software provides a familiar, modern interface with industry-standard presets, fixture de-embedding and time-domain analysis capabilities. Engineers can toggle between frequency and time-domain views to diagnose mismatches or locate reflections along transmission lines.

The software also supports automated measurement routines through full SCPI command control, making it easy to integrate the VNA400 into larger test systems or production lines. Engineers can script custom measurement sequences or use the instrument in conjunction with external signal routing for multi-device testing, all from a standard PC interface.

PRECISION WITHOUT COMPROMISE

Legacy VNA solutions often come with trade-offs including cost, size, complexity and a steep learning curve. The Signal Hound VNA400 delivers high performance RF measurements in a compact, USB-powered form factor that costs significantly less than comparable solutions without sacrificing speed, accuracy or reliability. With rugged design, low power draw and broad application support, the VNA400 is designed for modern RF engineers who need precision on the bench and performance in the field. For the development of radar components, optimization of satellite communications hardware or troubleshooting of a high frequency link, the VNA400 provides visibility across the signal path.

CONCLUSION

The Signal Hound VNA400 is more than a portable alternative to traditional VNAs; it is a fully capable, lab-grade analyzer designed to keep up with the pace of RF innovation. By combining a 40 GHz measurement capability, up to 135 dB dynamic range and a robust software suite in a device that fits in the palm of your hand, the VNA400 empowers RF engineers to work anywhere the job takes them.

Signal Hound
Battleground, Wash., https://signalhound.com/.

RF Sampling Transceiver Family

Jariet Technologies, Inc.
Redondo Beach, Calif.

JARIET Technologies introduces the ELECTRA family of direct RF sampling transceivers, a platform pushing the boundaries of analog-to-digital and digital-to-analog conversion. ELECTRA devices operate from very high frequency (VHF) through Ka-Band, spanning 100 MHz to 36 GHz, with sampling rates of up to 64 GSPS. This technology targets demanding applications including radar, electronic warfare (EW), satellite communication (satcom), 6G/5G cellular, test and measurement instrumentation and quantum computing platforms.

Traditional RF systems rely heavily on complex analog frequency conversion chains, including mixers, filters and local oscillators, which add size, power consumption and system complexity. ELECTRA's direct RF sampling approach eliminates these intermediate steps, providing a cleaner, more integrated solution. The result is a flexible, software-defined architecture that simplifies system design while enhancing overall performance, adaptability and scalability.

BENEFITS OF RF SAMPLING

Direct RF sampling enables the instantaneous digitization of signals across a wide frequency band, eliminating the need for multiple frequency down-conversion stages. This approach reduces system complexity and physical footprint, lowers power consumption and cuts costs by removing analog components. Additionally, the ability to digitize wide bandwidths in real time enables the implementation of advanced digital signal processing (DSP) algorithms that can be updated or optimized via software, providing flexibility for multi-mission and evolving applications.

By capturing raw RF signals directly at high sample rates, systems can achieve higher fidelity and better noise performance, facilitating the detection and processing of weak or transient signals in challenging environments. This capability is particularly critical in scenarios requiring wideband spectral awareness and rapid frequency agility.

ADVANTAGES OF DIGITAL UP/DOWN-CONVERSION

Complementing direct RF sampling, ELECTRA integrates advanced digital up-conversion (DUC) and digital down-conversion (DDC) blocks, which outperform analog frequency conversion techniques in multiple dimensions. Unlike analog mixers and filters, DUC and DDC are implemented in the digital domain, eliminating analog non-linearities, drift and calibration challenges.

These digital blocks provide precise control over frequency translation, filtering bandwidth, phase alignment and gain, all programmable through software. This flexibility is essential for modern communication and radar systems, enabling rapid adaptation to changing signal environments and standards. Moreover, DUC/DDC facilitates simplified multi-channel synchronization and calibration, which is critical in phased-array antennas and MIMO architectures where coherent signal processing across multiple channels is required.

KEY ATTRIBUTES

The ELECTRA family offers direct RF sampling from 100 MHz to 36 GHz, enabling coverage across VHF, UHF, L-, S-, C-, X-, Ku-, K- and Ka-Bands with instantaneous bandwidths of up to 6.4 GHz. The 10-bit ADCs operate at 64 GSPS. The 2T2R and 4T4R transceivers combine ADCs, DACs, PLL/VCO ultra-low jitter internal clocks per transmit/receive pair, coarse and fine DUC/DDC, multi-chip synchronization and a 16-lane JESD204C SERDES interface running 30 Gbps, as shown in ***Figure 1***. Available packages are 25 × 25 mm for dual Tx/Rx and 32.5 × 27.5 mm for quad Tx/Rx versions, enabling multi-channel system integration. Additionally, ELECTRA is offered as packaged ICs, bare die and licensed IP for board-level, MCM, SiP or ASIC development, serving a range of system design requirements.

MARKET APPLICATIONS

ELECTRA's features serve multiple cutting-edge markets, including EW, radar and phased arrays, satcom, 5G/6G wireless, test and measurement and quantum computing. ELECTRA serves the EW market through its signal digitization for rapid threat detection and


Knowledge
is Key!

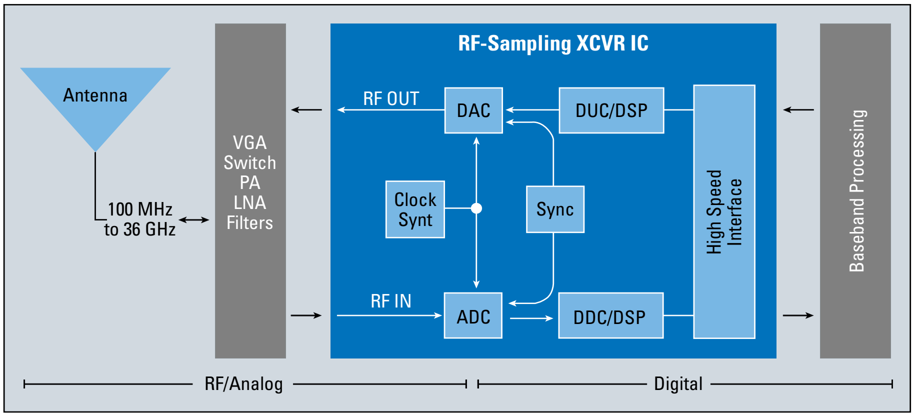


Fig. 1 Example block diagram of ELECTRA.

countermeasures. It is used in radar, which prioritizes superior resolution, target tracking and low latency processing. In the satcom market, the ELECTRA family is used in gateway links and phased-array antennas for LEO, MEO and GEO satellites. As 5G/6G wireless grows, the ELECTRA family can scale with it due to its operation into the FR2 frequency range. ELECTRA's ability to both capture and generate RF signals has made it appealing to the test and measurement industry. Finally, the precision RF readout is used in quantum computing. ELECTRA technology spans a multitude of industries.

Advantages in Radar Design

ELECTRA enhances radar system performance by enabling direct digitization of wide bandwidth signals with excellent noise spectral density and phase noise, which translates into better target discrimination. Its multi-channel 2T2R/4T4R architecture supports dense radar arrays with tight synchronization and calibration, enabling scalable solutions that can adapt to evolving operational needs. This flexibility enables radar designers to implement complex waveforms and signal processing techniques that improve situational awareness and threat detection.

Advantages in EW Design

In the demanding domain of EW, where spectral agility and rapid response are vital, ELECTRA's wideband instantaneous sampling capability captures signals across a broad spectrum in a single step. This reduces system complexity and improves time-to-acquisition. Integrated ultra-low jitter clocks and high dynamic range converters ensure sensitive detection of weak or transient signals in dense RF environments, while multi-chip synchronization supports scalable EW arrays for spatial filtering and jamming. ELECTRA's programmable DSP and software-defined nature enable rapid adaptation to emerging threats, making it an asset for modern EW systems.

Advantages in Satcom Payloads

Satcom payloads benefit from ELECTRA's ability to digitize and generate RF signals directly across a vast frequency range up to Ka-Band. This capability supports high-throughput multi-beam and frequency-agile gateway links, enabling more efficient spectrum use and enhanced data rates. By eliminating multiple frequency conversion chains, ELECTRA reduces size, weight and power consumption (SWaP), which are critical parameters in space-borne systems. Its integrated clocking and synchronization enable the coherent operation of phased-array antennas and beamforming modules, which are essential for dynamic beam steering and satellite network flexibility. Software-defined control ensures future-proofing against evolving standards and mission profiles.

Jariet Technologies is a fabless semiconductor company, headquartered in Redondo Beach, Calif. Jariet was founded in 2015 by Charles Harper (CEO) and Craig Hornbuckle (CTO) to develop world-leading RF sampling data converter and RF transceiver ICs. The ICs and IP developed by Jariet are often utilized in advanced receive and transmit hardware found in EW, radar, satellite payloads, satellite ground stations, 5G/6G communications, optical systems, quantum computing, wireless backhaul and test equipment.

Jariet Technologies, Inc.
Redondo Beach, Calif.
www.jariettech.com/

RF Coaxial Contacts for D38999 Cable Assemblies

Pasternack, an RF, microwave and mmWave provider with over 50 years of expertise, offers RF coaxial contacts for D38999 cable assemblies. These coaxial contacts are used in demanding environments that require high frequency data transmission. Pasternack's RF coaxial contacts are integral to the D38999 cables used in aerospace, military and industrial operations, helping to advance their functionality and withstand harsh conditions.

Pasternack's RF coaxial contacts for D38999 cable assemblies are designed for precise impedance matching to minimize signal reflection and maximize signal integrity. The coaxial contacts are used in military applications, reaching frequencies of up to 60 GHz and supporting the bandwidth requirements of advanced communication systems.

When D38999 cable assemblies have RF coaxial contacts, they become more compatible with a variety of connector types and sizes for integration into existing systems. Pasternack offers standard and custom length cable assemblies with a D38999 contact on one end and either an SMA connector or a D38999 contact on the other. Combinations can include BMA, BMB, BMZ, M39029, SMPM and SMPS contacts on UT047, UT086, UT141, RG174 and RG316 cables. The other end of the cable can have another 38999 pin or socket or a male or female SMA connector to interface with a different RF system.

In an industry reliant on high performance connectors, Pasternack's RF coaxial contacts for D38999 cable assemblies help military and aerospace engineers enable system reliability, durability in harsh environments, signal integrity and straightforward integration.

VENDORVIEW

Pasternack, an Infinite Electronics brand
Irvine, Calif.
www.pasternack.com

Q/V-Band Cassegrain Antennas for Ground Systems

Eravant's SAY-3735135302-22-S1-DP-WR is a dual polarized 2.4 m Q/V-Band Cassegrain antenna system engineered for next-generation LEO satellite communication ground stations. The antenna operates from 37 to 52 GHz with a transmit frequency range of 46 to 52 GHz and a receive frequency range of 37 to 42 GHz.

The system features an integrated orthomode transducer (OMT) and bandpass filters with high port isolation and signal rejection between the transmit and receive channels. The antenna also includes a linear-to-circular polarizer, allowing it to transmit and receive circularly polarized signals.

To support performance validation of this 2.4 m Q/V antenna and other electrically large high frequency antennas, Eravant now offers near-field testing services using a newly acquired 3.5 m × 3.5 m planar near-field range. Standard measurement capabilities include gain and radiation patterns up to 110 GHz. Customized test parameters, such as frequency range, polarization or step size, can also be accommodated on a case-by-case basis.

As part of its mission to make mmWave accessible, Eravant designs high performance components and systems that reduce the barriers of cost, complexity and capability — empowering engineers to innovate faster at higher frequencies.

VENDORVIEW

Eravant
(Formerly Sage Millimeter Inc.)
Torrance, Calif.
www.eravant.com

High-Power Solid-State Amplifier

The Exodus AMP20176 is a high-power, broadband solid-state amplifier designed for mission-critical applications that require reliable performance across the 6.0 to 18.0 GHz spectrum. It delivers a minimum saturated power of 1000 W, a typical power of 1200 W and a P1dB of 600 W. The AMP20176 is used for CW and pulsed operations for EMC/EMI testing, military communications, radar and advanced laboratory environments.

This ruggedized, rack-mounted system employs a Class A/AB linear architecture with cutting-edge GaN transistor technology, delivering a performance of 60 dB minimum, with ±2.5 dB gain flatness over its full operational bandwidth. Integrated protection circuitry safeguards against input overdrive, excessive VSWR (operating up to 4:1) and overtemperature, ensuring uninterrupted operation. Optional digital monitoring and control (DMC) provides real-time visualization of key parameters, including forward/reflected power, gain, VSWR, current and thermal data, accessible via a full-color touchscreen interface or remotely through Ethernet, USB, RS422/RS485 or optional GPIB connections.

The AMP20176 is housed in a standard 40U rack configuration. It weighs approximately 450 kg and includes four 8U amplifier drawers and a 3U intelligent controller. It operates from 200 to 240 VAC, has a 3-phase input and draws approximately 20 kW at full-rated power. A quiet-cool closed-loop air-liquid cooling system maintains stable thermal performance in ambient conditions from 0°C to +50°C.

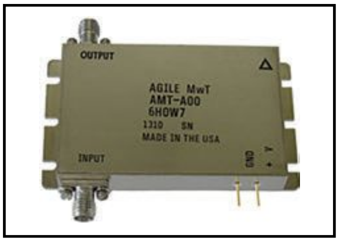
Optional features such as forward and reflected RF sample ports, calibrated power monitoring with offset correction and safety interlocks increase versatility for integration into automated systems or deployed field installations.

Exodus Advanced Communications specializes in LDMOS, GaN HEMT and GaAs technologies, manufacturing high-power amplifiers, broadband amplifiers, pulse amplifiers for radar and HIRF, as well as low-noise amplifiers and multi-band systems spanning 10 kHz to >75 GHz.

VENDORVIEW

Exodus Advanced Communications
Las Vegas, Nev.
exoduscomm.com

Signal Integrity Journal eBook March 2025
Signal Integrity Measurement and Analysis Guide
SPONSORED BY
Anritsu
Advancing beyond
Signal Integrity Journal eBook April 2025
Crosstalk Challenges and Solutions Guide
SPONSORED BY
Microwave Journal eBook April 2025
New Developments in Satellite/Space RF Technology
SPONSORED BY
RFMW
smiths interconnect
Microwave Journal SPECIALFOCUS
Satellite & Space
Microwave Journal eBook May 2025
Sub-THz Technology Advancements
SPONSORED BY
Microwave Journal eBook March 2025
Cable and Connector Guide to Accurate and Reliable Measurements
SPONSORED BY
Maury Microwave
Signal Integrity Journal eBook January 2025
Latest Trends in Power Integrity
SPONSORED BY
Microwave Journal eBook April 2025
Advancements in Phased Array Technologies
SPONSORED BY
IR HiRel
Over 100 eBooks Available
Knowledge Is Power
Download Now at mwjournal.com



New Broadband 20 W PA

AgileMwT's new broadband 20 W power amplifier (PA) operating from 2 to 18 GHz is offered in an ultra-compact size of 3.5 x 2 x 0.4 in. AMT-A0590 provides Psat of 20 W typical with flat small signal gain of 45 dB typical, ± 1 dB typical gain flatness with VSWR of 1.8:1 typical. Family of these PAs are competitively priced and ship from stock or short lead time.

Agile Microwave Technology Inc.
www.agilemwt.com

ADRF5238

VENDORVIEW

The ADRF5238 is a high isolation, non-reflective, 0.1 to 13 GHz, silicon, SPDT switch in the silicon process. This device operates from 0.1 to 13 GHz with an insertion loss lower than 1.3 dB and an isolation higher than 41 dB at 13 GHz. The ADRF5238 has a non-reflective design, and the RF ports are internally terminated to 50 Ω. Applications for the ADRF5238 include military radios, radars and electronic counter measures.

Analog Devices, Inc.
www.analog.com/en/products/adrf5238.html

Compact Microwave Synthesizer Module – Portable/ Integrated Source

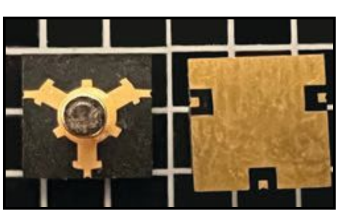
EcoSyn™ Lite MG36021A covers 10 MHz to 20 GHz and offers outstanding signal purity, +18 dBm output power at 20 GHz and ultra-fast 50 µs switching speed in a very small 4 x 4 x 0.8 in. package. Powered via external 12 VDC and controlled through USB or SPI interfaces supporting SCPI and QuickSyn commands. Ideal source solution for use as LO, system clock and other embedded applications.

Anritsu Company
www.anritsu.com/en-us/test-measurement/products/mg36021a

Next-Generation Antenna and Radome Solutions for the EW Spectrum

Axillon Aerospace (Baltimore) is an industry leader that specializes in the design, development, production, testing and repair of high performance antennas and radomes. Their products are utilized for various electronic warfare, satellite communications, signals intelligence and communication, navigation and identification applications. The facility is located in Baltimore, Md., in a modern 75,000+ square foot facility that houses an integrated fully vertical operation including design, engineering, test, production staff and manufacturing equipment.

Axillon Aerospace
www.axillonbaltimore.com



SMT Microstrip Circulators and Isolators

VENDORVIEW

Cernexwave's SMT Microstrip Circulators and Isolators are an ideal solution for broadband or narrowband signal control in a very small package. They are tailored to the exact frequency you need while maintaining low insertion loss and high isolation. Cernexwave can also customize the size, shape and port locations to fit perfectly in your system. They can operate from as low as 2 GHz to as high as 30 GHz and handle power levels of 20 W or higher.

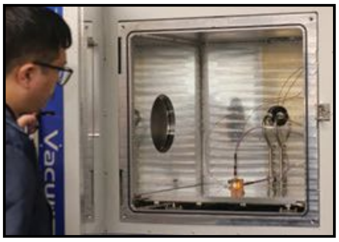
Cernexwave
www.cernexwave.com

Empower RF Model 2180

VENDORVIEW

The Empower RF Model 2180 is a field-proven, reliable solid-state 2 KW CW amplifier (1 to 2.5 GHz) ideal for GPS denial, satcom jamming and uplink communications. Boasting high linearity, selectable AGC/ALC modes and an intuitive web GUI, it delivers unmatched performance and reliability in mission-critical environments.

Empower RF
www.empowerrf.com/products/display_amplifier.php?sku=2180&source=MWJ



mmWave Thermal Vacuum Testing Services

VENDORVIEW

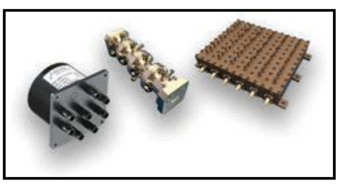
Introducing Eravant's mmWave Thermal Vacuum Component Testing Services. Simulate the extreme temperature ranges and vacuum conditions required for mmWave component testing for space qualification. The 24 × 24 × 24 in. chamber allows for testing from -160°C to +250°C with an operating vacuum pressure up to 1×10^{-6} torr. In addition, a variety of in-house test equipment and components from DC to 110 GHz are available for customer use, including specialized coaxial vacuum RF feedthroughs from SMA to 1 mm.

Eravant
www.eravant.com/products/services/chamber-testing

Ka-Band High Power Amplifier from ERZIA

The ERZ-HPA-2000-4000-39 is a high performance Ka-Band high power amplifier designed for demanding RF applications. Operating across a wide frequency range of 20.00 to 40.00 GHz, it delivers a robust output power of 39 dBm. With a small signal gain of 52 dB, this amplifier ensures excellent signal amplification and stability. Its compact design and high power output make it ideal for satellite communications, radar systems and electronic warfare.

ERZIA
www.erzia.com/products/hpa/777



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.

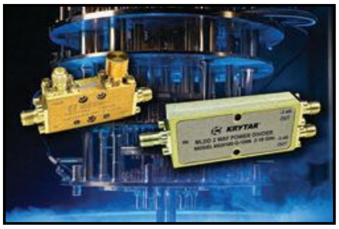
Exceed Microwave
www.exceedmicrowave.com

Exodus 18.0 - 40.0 GHz, 80 W SSPA AMP20167

VENDORVIEW

Exodus AMP20167, 18.0 to 40.0 GHz, 80 W solid-state amplifier and 49 dB gain. Ideal for broadband EMC and lab testing, MIL-STD 461(RS103) and other high-power applications. The 6U design provides outstanding power/gain flatness with forward/reflected power monitoring in dBm and watts. Other features include VSWR, voltage, current and temperature sensing.

Exodus
www.exoduscomm.com



50 Years of Cutting Edge MIL-SPEC Components: DC-110 GHz

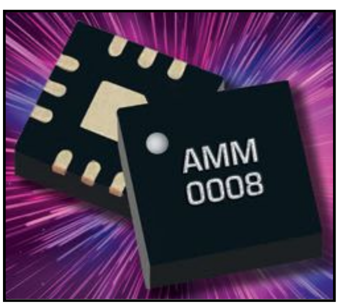
KRYTAR focuses on designing and producing ultra-broadband MIL-SPEC components catering to a wide range of defense electronic applications, including test equipment, simulation systems, satcom and SOTM, radar and IED jammers, radar systems, electronic warfare (ECM, ECCM and ESM) and quantum/cryogenic. KRYTAR products are designed and manufactured in the U.S. Whether perfecting wireless networks, satellite communications, advancing defense systems or exploring space, KRYTAR delivers off-the-shelf and custom solutions designed to meet your specific needs with unparalleled precision, quality and reliability.

KRYTAR
www.krytar.com

New Connector Options for the LB5944A 44 GHz Power Sensor

The LB5944A 1 MHz to 44 GHz True-RMS power sensor can now be ordered with its standard 2.4 mm male connector or optional 2.92 mm, male or female connectors. The 2.92 mm connector offers compatibility with commonly used 3.5 mm and SMA connectors, providing a wide array of RF connectivity. These same options are available on the 9 kHz to 44 GHz LB5944L power sensor. The power sensors offer optional HiSLIP LAN/Ethernet with Power over Ethernet. The LB59XX series features Tier 1 traceability, frequency coverage up to 75 GHz, an 86 dB dynamic range, and data security options including secure erase and option MIL.

LadyBug Technologies
www.ladybug-tech.com/product/the-lb5944a-1-mhz-to-44-ghz-true-rms-power-sensor/



DC - 20 GHz Wideband Low Noise Amplifier

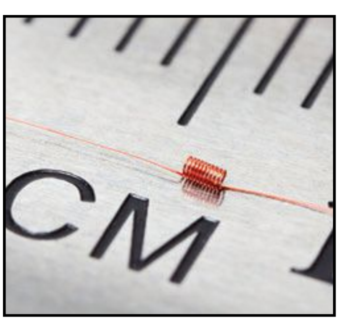
The AMM-9853PSM is a wideband low noise amplifier capable of providing 16 dB gain and +27 dBm OIP3 with a low 1.8 dB typical noise figure. It is an ideal linear signal amplifier for applications requiring low power consumption and small formfactors, featuring exceptionally flat response across its entire operating bandwidth. Available in a compact 3 mm QFN.

Marki Microwave
https://markimicrowave.com/products/surface-mount/amplifiers/amm-9853psm/

0.6-7.25 GHz High Accuracy Butler Matrices

MIcable 0.617 to 7.25 GHz 4×4 and 8×8 butler matrices can transfer the signal reciprocally from any of four or eight ports to any of other four or eight ports. Because the high performance passive components and cables are used inside, the system has super phase accuracy, amplitude balance, stability and repeatability. They cover the world's mainstream 5G NR (FR1) Wi-Fi 6E bands, making them an ideal choice for 5G testing, Wi-Fi 6E testing, MIMO testing, multipath simulation and performance evaluation, antenna array beamforming and other applications.

MIcable Inc.
www.micable.cn



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

Fast. Agile. Unstoppable: MPG's EW Tuner

MPG's Electronic Warfare (EW) Tuner delivers rapid, agile tuning across wide frequency ranges, empowering mission-critical systems with precision signal capture and interference mitigation. Designed for high performance EW environments, it offers low latency, high dynamic range and robust packaging options for airborne, ground and naval platforms. Whether integrated into radar warning receivers or spectrum monitoring systems, MPG's EW tuner ensures reliable, responsive performance in complex threat scenarios — supporting decisive action in today's contested electromagnetic spectrum.

MPG
https://bit.ly/4odfYpX

New e-Vibe™ Series of Electronically Compensated OCXO, XO5503-100 MHz

Mtron announces the launch of the XO5503 product line of e-Vibe™ OCXOs, featuring excellent vibration compensation in a small, lightweight package. The family incorporates a SC-cut quartz resonator and electronic vibration compensation resulting in 0.02 ppb/g G-sensitivity. The e-Vibe™ OCXO replaces bulkier mechanically vibration compensated products and improves system performance while reducing size to 2.0″x 1.5″ x 0.8″ and weight to 70 grams. Other features: a wide temperature range (-45°C to +85°C) and stability down to +/-200ppb.

Mtron
www.mtron.com

Drone Localization with SignalShark and ADFA DF Antenna

Narda Safety Test Solutions' SignalShark and ADFA DF antenna enable precise detection and geolocation of hostile drone signals. The system delivers high sensitivity, fast direction finding and accurate bearings — even in congested RF environments. Ideal for mobile units, perimeter security and EW missions. Compact, rugged and reliable — a trusted tool for armed forces and integrators worldwide for mission-critical spectrum dominance.

Narda Safety Test Solutions
www.narda-sts.com/signalshark

9750 MHz Surface Mount Cavity Filter

Introducing the NIC X-Band Surface Mount Cavity Filter, built with high-temperature (Sn95Sb05) solder to endure standard PCB reflow profiles of up to 215°C. This advanced filter delivers impressive performance with a passband insertion loss of less than 1 dB and exceptional out-of-band rejection greater than 60 dB, even up to 3x the center frequency. Its compact and durable SMT design makes it the ideal choice for demanding applications in radar, electronic warfare and space missions.

Networks International
www.nickc.com

Broadband Amplifier

The 5294E is a 100 W broadband amplifier that covers the 700 to 6000 MHz frequency range. Power levels available in this range are from 15 to 500 W. Pure solid-state and linear. Perfect for EW, EMC, CW/Pulse and other lab applications. All are 100 percent made in the U.S. and come with a multiyear warranty backed by Ophir RF's commitment to customer satisfaction. Contact us for more information.

Ophir RF
www.ophirrf.com

New SOSA Aligned ATR Enclosures

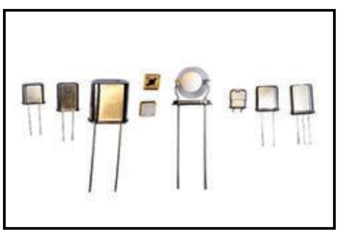
Utilizing the 3U OpenVPX form factor, the various chassis platforms typically support 100GbE or higher speeds. The new ARINC 404 5/8 size ATRs from Pixus features customized I/O options and various SOSA slot profile options, including RF and optical interfaces through the backplane. For chassis management, the ATR has the option of implementing Pixus' SOSA aligned Tier 3 mezzanine-based solution that sits behind the backplane. This saves a slot of space while acting as a health monitor and control module for the system.

Pixus Technologies
www.pixustechnologies.com

Q-Tech and AXTAL Crystal Oscillators, Delivering the Best for Defense Applications for Over 50 Years

Q-Tech and AXTAL offer a full line of crystal oscillators designed for use in critical military and defense applications where precise timing, reliability, durability and performance are essential to meet the extreme operating conditions. Oscillators may be screened to MIL-PRF-55310, Level B as required. Combined, Q-Tech and its subsidiary AXTAL offer a full range of military/defense devices including crystal oscillators (XOs), voltage controlled (VCXOs), temperature compensated (TCXOs), oven controlled (OCXOs), microcomputer compensated (MCXOs) and surface acoustic wave oscillators (SAWs).

Q-Tech
www.q-tech.com

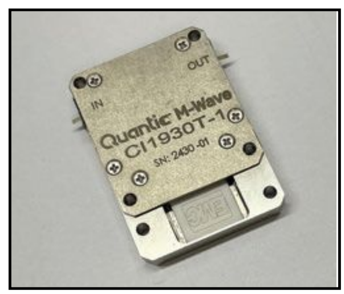


Quartz Crystal Resonators Built to MIL-Spec, Ready for Any Mission

VENDORVIEW

Quantic Croven's MIL-PRF-3098 QPL crystals enable low phase noise frequency control and timing performance from 2.4 to 125 MHz. Qualified through full Group B testing and supplied with 100 percent Group A screening, these AT-cut resonators offer excellent frequency-temperature stability (±20 to 50 ppm), minimal aging (~±5 ppm/year) and robust operation from –55°C to +105°C across CR55/U through CR141/U series. Available in HC-35 and HC-43 enclosures, they deliver precision and reliability for space, aerospace and military platforms.

Quantic Croven
www.quanticcroven.com/products/qpl-crystals/



Mil-Aero and Space-Qualified Passive Components

For over 35 years, M-Wave Design (now part of the Quantic portfolio), has delivered solutions for aerospace and defense systems. We offer a vast library of high-power, low loss passive components in connectorized, stripline and wave-guide topologies. Contact our sales team and learn how we can support your specific application needs!

Quantic M-Wave
www.quanticmwave.com

QPP Series Pulsed GaN SSPAs

VENDORVIEW

QuinStar's QPP Series Pulsed GaN SSPAs deliver high peak power, fast rise/fall times and low droop for instrumentation radar, including weather and RCS testing. Engineered for pulsed/CW modes, they outperform tube amplifiers with higher reliability, smaller footprints and no warm-up time. Available at 94 GHz and ~35 GHz, these compact, U.S.-built, military-qualified SSPAs are trusted in defense and lab environments where performance, uptime and precision matter most.

Quinstar Technology
www.quinstar.com

RF and Microwave Filters and Integrated Assemblies

VENDORVIEW

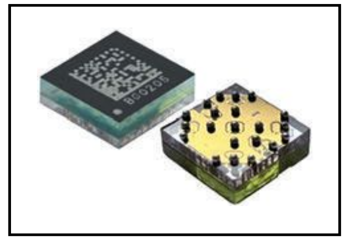
Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 67 GHz. From small, lightweight units suitable for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface-mount — their talented engineers can design a unit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

Reactel, Inc.
www.reactel.com

NEW Renaissance Converters Deliver Precision and Power for LEOS Networks

Renaissance Electronics introduces broadband converters for the LEO satellite market: the HBUC34187-192 Block Up-Converter (1 to 6 GHz input, 26 to 31 GHz output) and the HBDC34187-193 Block Down-Converter (16 to 21 GHz or 26 to 31 GHz input, 1 to 6 GHz output). Designed for flexible band tuning within operating frequencies, these compact 6 x 8 in. units deliver high performance for satellite communications. Ideal for next-gen systems where signal clarity, size and speed are mission-critical.

Renaissance Electronics
www.aeminc.com/en-us/custom-ka-band



MM5230 26 GHz High-power SP4T RF Ideal Switch

VENDORVIEW

Menlo Micro's MM5230 high-power SP4T Ideal Switch® operates from DC to 18 GHz and to 26 GHz in Super-Port mode. It delivers 25 W CW and 150 W pulsed power handling with excellent linearity (IIP3 95 dBm) and low insertion loss (0.3 dB at 6 GHz). Housed in a 2.5 × 2.5 mm BGA, it supports over 3 billion switching cycles. Ideal for replacing bulky RF relays and lossy solid-state switches in test, defense, wireless and medical systems. Available now from RFMW.

RFMW
www.RFMW.com

SMP Solutions with True 40 GHz Performance

Samtec's enhanced SMP solutions deliver true high frequency performance through 40 GHz, supporting Ka-Band requirements in military applications. SMP stack heights align with Samtec's digital high speed board-to-board connectors, simplifying system design where mixed signal (analog and digital) integration is needed. The push-on design enables quick, easy mating while the bullet adaptor compensates for misalignment. True 40 GHz SMP solutions are available as board-to-board and cable-to-board mated sets.

Samtec
www.samtec.com

High Performance Coaxial Connectors and Cable Assemblies

San-tron is a U.S.-based manufacturer of RF/microwave coaxial connectors and cable assemblies with over 70 years of experience. Located in Ipswich, Mass., the company is vertically integrated to design, machine and assemble high performance products up to 110 GHz. Core product offerings include SMA, 2.92 mm, 2.4 mm and 1.85 mm field replaceable connectors in addition to custom designs for a variety of connector interfaces. Primary markets served are telecommunication, test and measurement, aerospace, defense, medical and quantum computing.

San-tron
www.santron.com

23 GHz RF Signal Source

The SC5531A is an RF source covering the frequency range of 500 kHz to 23 GHz with fast frequency switching, 1 Hertz tuning resolution and low phase noise. It accepts 10 MHz, 100 MHz and 1.6 GHz reference signals and outputs its internal 1.6 GHz reference signal that could be used to synchronize multiple SC5531A devices, greatly improving their relative phase stability. The product features fine amplitude adjustment in the range of -40 to 15 dBm.

Signal Core
www.signalcore.com

One-Stop Shop for Your Test & Measurement Needs

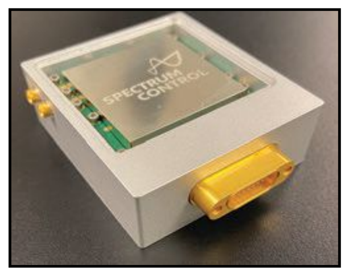
Signal Hound now offers a comprehensive suite of high performance test and measurement equipment. Find spectrum analyzers with ultra-low phase noise and sweep speeds up to 1 TB/sec. Measure phase noise with precision using the PN400 test system. Make S-parameter measurements in the field with the new USB-powered, 40 GHz, 2-port VNA400. Switch from LF through Ka-Band at lightning-fast speeds with the RFS44 antenna switch. Download the new product catalog to learn more about our premium accessible test equipment.

Signal Hound
www.signalhound.com

Spacek Labs Amplifier SLKaQ-38-15

Spacek Labs' amplifier, Model SLKaQ-38-15, has excellent performance characteristics from 26.5 to 50 GHz. Ideal for 5G frequency range 2 applications. With a NF of 3.8 dB and output P1dB of 15 dBm typical, the unit has a nominal gain of 38 dB min., 43 dB typical. VSWR is 1.5:1 typical using 2.4 mm connectors. Bias voltage +8 to +12 VDC at 0.3A. Without a heatsink, overall amplifier size is 1.13 x 0.93 x 0.31 in.

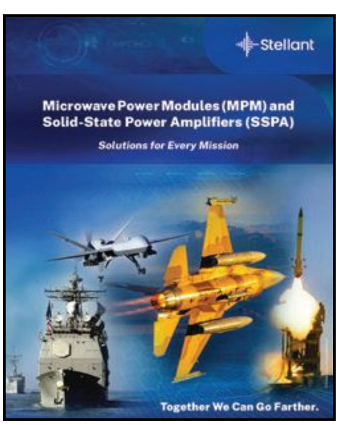
Spacek Labs, Inc.
www.spaceklabs.com



Hermetically Packaged mmWave Up/down-converter for Easy Retrofit of Existing Systems

Engineered for defense and rugged applications, this compact 2.0 x 2.1 x 0.6 in. up/down-converter enables conversion between 18 to 40 GHz and standard 2 to 18 GHz EW bands. Housed in a hermetically sealed package, it's ideal for rapidly upgrading existing systems to extend spectral coverage to 40 GHz. The unit features SMPM connectors, a single Micro-D interface and supports SPI, I2C and digital I/O. Operates from a single voltage supply with a wide input range of +12 to +48 V.

Spectrum Control
www.spectrumcontrol.com/products/rf-digital-blocks/rf-sips



Leading Provider of MPMs and SSPAs

Stellant Systems is a leading provider of microwave power modules (MPMs) and solid-state power amplifiers (SSPAs), offering a range of frequency bands and power levels to meet diverse mission requirements. Our MPMs and SSPAs deliver proven performance across aerospace and defense applications. Qualified for space, ground, sea and airborne platforms, these compact, lightweight and highly reliable high-power amplifiers drive next-generation advancements in communication, electronic warfare, radar and other microwave and mmWave systems.

Stellant Systems
www.stellantsystems.com

Teledyne Aerospace & Defense Electronics

Teledyne Aerospace & Defense Electronics provides advanced RF and microwave technologies supporting electronic warfare, radar, military communications and satellite systems. Engineered for mission-critical applications, Teledyne's solutions deliver exceptional reliability, performance and redundancy in the most demanding operational environments. With a comprehensive portfolio and a legacy of innovation, Teledyne enables defense and aerospace platforms to operate with precision and resilience. Its commitment to quality and technological excellence makes it a trusted partner in safeguarding global security and mission success.

Teledyne Aerospace & Defense Electronics
Teledyne-ade.com

Designed for Durability. Engineered for Excellence

Trexon solves the world's most challenging connectivity problems with relentless innovation, industry expertise and constant collaboration. Formed from the combination of top wire and cable companies, Trexon provides an expanding range of specialized products and solutions designed for rugged and specific conditions. The Trexon Engineered Products Group consists of the following industry-leading companies; Cicoil, EZ Form Cable, The First Electronics Corporation, Hydro Group, Integrated Cable Systems and Power Connector Inc.

Trexon Company
https://youtu.be/n9ufNoBtJ9M
https://trexonglobal.com/engineered-products/

Hand Formable Solution Providing SI

The original alternative to semi-rigid and conformable cable assemblies – Re-Flex! Using IW's proprietary laminated Teflon dielectric and double shield construction, Re-Flex provides a unique, hand formable solution providing signal integrity for inside enclosure applications. The solder free outer braid enables repeated flexure without micro-fracturing or cracks at the connector solder joint. Performing to 60 GHz, and available with a wide range industry standard interconnect options (threaded and push-on) for 085 and 141 line sizes, Re-Flex simplifies design and aids manufacturability.

Insulated Wire
https://insulatedwire.com/flexible-coaxial-cables-3/

This A&D Electronics Special Supplement eBook covers topics such as applications for RF over fiber technology, international spectrum supportability for software defined radios, troubleshooting AESA T/R modules and test stations, liquid cooled SSPAs for SATCOM uplinks, SMT mmWave converters with digital control, fiber optic cables for harsh environments, high-power solid-state amplifiers and power MOSFETs/ICs.

microwavejournal.com/articles/44287

Advertiser	Page No.
Aaronia AG	33
Agile Microwave Technology Inc.	34
Analog Devices	COV 2
Anritsu Company	38
Association of Old Crows	COV 3
Axillon Aerospace	48
Cernex, Inc.	36
CPI Electron Device Business	22
EDI CON Online 2025	55
Empower RF Systems, Inc.	16
ERAVANT	13
ERZIA Technologies S.L.	21
Exceed Microwave	42
Exodus Advanced Communications, Corp.	41
Greenray Industries, Inc.	31
Insulated Wire, Inc.	45
KRYTAR	12
KVG Quartz Crystal Technology GmbH	42
LadyBug Technologies LLC	52
Marki Microwave, Inc.	9
Menlo Micro	19
MIcable Electronic Technology Group	43
Micro Coax	11
Microwave Components Inc.	44
Microwave Journal	51, 53, 57, 65
Microwave Products Group (a Dover Company)	15
Mini-Circuits	29, 39, 49
Mtron	61
Narda Safety Test Solutions GmbH	28
Networks International Corporation	25
Ophir RF	35
Pixus Technologies	63
Q-Tech Corporation	59
Quantic Croven	14
Quantic M Wave	24
QuinStar Technology, Inc.	47
Reactel, Incorporated	7
Renaissance Electronics	10
RFMW	19
Rohde & Schwarz GmbH	17
Safran Electronics & Defense	40
Samtec USA	23
San-tron Inc.	27
SignalCore, Inc.	65
Signal Hound	5
Spacek Labs Inc.	26
Spectrum Control	COV 4
Stellant Systems	56
Teledyne ADE	3
Trexon	37

Sales Representatives

Eastern and Central Time Zones
Carl Sheffres
Group Director
(New England, New York, Eastern Canada)
Tel: (781) 619-1949
csheffres@mwjournal.com

Michael Hallman
Associate Publisher
(NJ, Mid-Atlantic, Southeast, Midwest, TX)
Tel: (301) 371-8830
Cell: (781) 363-0338
mhallman@mwjournal.com

Pacific and Mountain Time Zones
Brian Landy
Western Reg. Sales Mgr.
(CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada)
Tel: (831) 426-4143
Cell: (831) 713-9085
blandy@mwjournal.com

International Sales
Michael O'Kane
Tel: +44 (0) 1875 825 700
Cell: +44 (0) 7961 038 245
mokane@horizonhouse.com

Germany, Austria, and Switzerland (German-speaking)
Victoria and Norbert Hufmann
victoria@hufmann.info
norbert@hufmann.info

Korea
Jaeho Chinn
JES MEDIA, INC.
Tel: +82 2 481-3411
corres1@jesmedia.com

China
Shanghai
Linda Li
ACT International
Tel: +86 136 7154 0807
lindal@actintl.com.hk

Wuhan
Phoebe Yin
ACT International
Tel: +86 134 7707 0600
phoebey@actintl.com.hk

Shenzhen
Annie Liu
ACT International
Tel: +135 9024 6961
anniel@actintl.com.hk

Beijing
Cecily Bian
ACT International
Tel: +86 135 5262 1310
cecilyb@actintl.com.hk

Hong Kong
Floyd Chun
ACT International
Tel: +852 28386298
floydc@actintl.com.hk

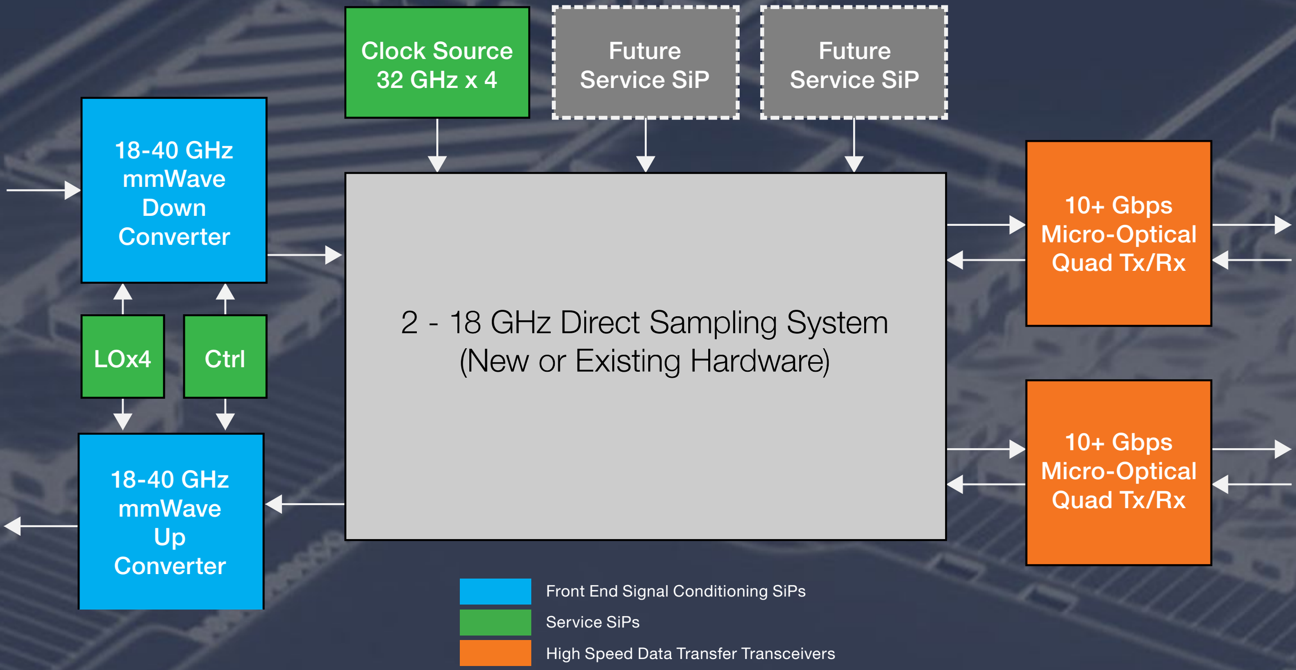
Taiwan, Singapore
Simon Lee
ACT International
Tel: +852 2838 6298
simonlee@actintl.com.hk

Japan
Katsuhiro Ishii
Ace Media Service Inc.
Tel: +81 3 5691 3335
amskatsu@dream.com

Corporate Headquarters: 685 Canton Street, Norwood, MA 02062 • Tel: (781) 769-9750

Develop the EW Future

Integrated, miniaturized RF+Digital solutions for rapid development and deployment of high-precision systems



Use our SiP platform to upgrade to 40 GHz or add a custom RF personality to your front end

- Highly integrated RF, digital, power
- Software-instrumented for tuning & control
- Single or multi-channel
- Surface-mount for rapid production
- Cost-effective and volume-ready
- Standard and custom solutions available

Get high speed optical transmission for extreme environments

- Multi-mode optical wavelength (850nm).
- Quad channel Tx/Rx from 20Mbps to >10Gbps.
- -50°C to +125°C
- Pluggable optical connector interface
- BGA solder ball contacts or LGA with interposer
- Hermetic enclosure

To learn more visit **spectrumcontrol.com/sci-blocks**

SPECTRUM CONTROL™