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Microwaves&RF®

BRING AI TO BEAR ON SPECTRUM VISIBILITY

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SEPTEMBER/OCTOBER 2024 | VOLUME 63, ISSUE 5

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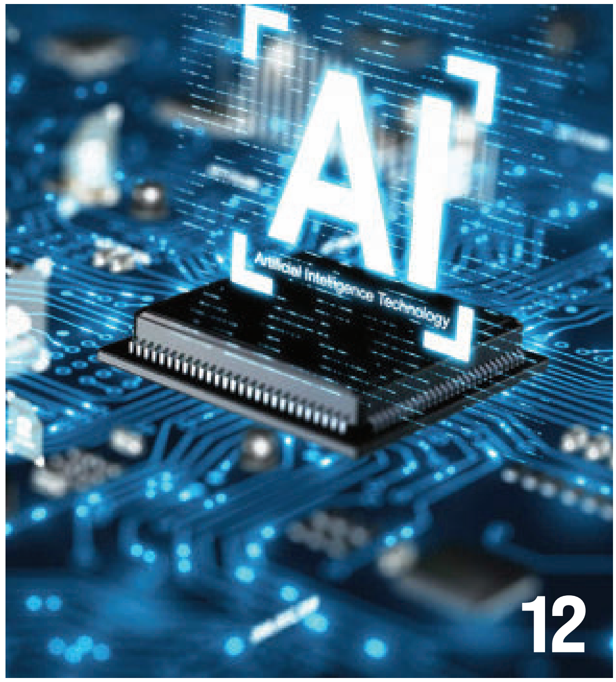

DAVID MALINIAK, Executive Editor

Let's Reflect on Making 6G Work Downtown

Reliable cellular performance in urban environments might need an assist from reconfigurable intelligent surfaces.

320405716 | Ai Â© Victor Canales Doval | Dreamstime.com

I HAPPEN TO LIVE near New York City, where I went to college and later worked for a few years. While I don't spend much time in the city these days, it's fun to occasionally head in to see a show, go to a ballgame, or visit a museum.

However, should I need to use my phone on one of my infrequent forays into the Big Apple, I'm conditioned by now to expect coverage oddities and slower-than-usual download speeds. The phone often defaults to 4G/LTE service, which, frankly, is not much slower than, say, C-band 5G data rates.

At the high frequencies and short wavelengths of low-band 5G, the density of an urban environment poses challenges for network coverage and capacity. Even as R&D forges ahead for its eventual move to 6G, the cellular industry scratches its collective head as to how it might improve the user experience in the short term.

There are possible band-aids in the form of greater deployment of non-terrestrial networks (NTNs) and more melding of Wi-Fi with cellular technologies. But one technology that's been talked up lately is reconfigurable intelligent surfaces, or RIS technology.

With reconfigurable intelligent surfaces, it's possible to literally reshape the propagation environment of a given small area on the fly. This is accomplished through manipulation of large numbers of passive meta-surface reflection units.

By intelligently controlling signal reflections and collecting scattered waves into beamformed wholes, RIS technology, which is inherently passive and requires minimal power, can optimize signal paths, reduce interference, and enable network operators to use lower levels of transmitting power.

However, several technical challenges must be overcome before RIS technology can even begin to fulfill its promise. For one, optimizations for reconfigurable intelligent surfaces are an extremely complex affair. Channel estimations are particularly compute-intensive. The optimization algorithms must accurately handle phase adjustments; failure to do so will drag down the RIS's ability to optimize signal strengths.

Companies like MathWorks are making significant progress in modeling of an RIS. In fact, we've got a Quick Poll on our site to gauge your interest in learning more about the subject.

To be sure, we've got a long way to go before 6G, or even 5G, get to the point where the technology is best positioned to serve wireless customers as well as it should. Reconfigurable intelligent surfaces may be one of the key elements to improve the situation. It's a technology to watch in coming years. ■

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Video ▶ AI/ML Software Enhances Real-Time RF Situational Awareness

Spectrum awareness is a watchword in these times of crowded airwaves, especially for 5G mobile network operators. Managing coexistence in the Citizens Broadband Radio Service (CBRS) band in the U.S. means increased vigilance through continuous spectrum monitoring as well as coordination between 4G/LTE and 5G New Radio (NR) cellular and military radar operators in shared bands. In its OmniSIG software, DeepSig brings machine learning to bear on the growing requirements for RF situational awareness. The software takes input from any radio and performs real-time detection and classification of signals.

www.mwrf.com/55143628

Video ▶ The IoT Swings at the Things Conference

The Things Network provides a set of open tools as well as a worldwide network to build ready-to-scale IoT application solutions cost-effectively, with maximum security. It leverages the Things Stack, a LoRaWAN Network Server that securely manages applications, end devices, and gateways. The Things Stack uses the LoRaWAN network protocol using LoRa modulation for long-range, low-power, and secure performance ideal for telemetry use cases. The Things Network is an open community of people, companies, governments, and universities that are learning, experimenting, and building with The Things Stack to create LoRaWAN-based IoT solutions.

www.mwrf.com/55141459

Article: Simulation Environment Empowers Auto Radar Development

Designed to effectively address test and measurement challenges, the R&S AREG-P from Rohde & Schwarz leverages the AREG800A radar target simulator and offers a highly versatile configuration and precision parameters. Its modular structure includes a base unit, up to three digital channels for independent generation of artificial objects, and has the capacity to connect up to three front ends to a single base unit.

www.mwrf.com/55143477

Article: Conquer the Challenges Facing Next-Gen Front Ends

Digitization of RF signals is an important part of modern defense systems. However, depending on the application, ensuring integrity of the signal all the way through the process to bits isn't so simple. RF segmentation, isolation, and a cascade of analog functions still govern the performance level of any direct RF solution, albeit with fewer components than traditional architectures. The next big leap in miniaturization and simplification will need to come from the RF front end.

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Backscatter Method
May Enhance Low-Power IoT Comms

ADDRESSING WIRELESS COMMUNICATION between IoT devices, researchers from Pusan National University developed a low-power backscatter communication system to replace legacy approaches. The solution leverages circuit modeling, advanced modulation techniques, and polarization diversity to deliver a spectral efficiency of 2.0 bps/Hz and an improved energy efficiency that's 40% greater than legacy techniques.

The connected devices reflect and modulate existing signals by altering their load impedance, rather than generating signals themselves, using higher-order modulation schemes such as quadrature amplitude modulation (QAM) to achieve low bit error rates and high data rates. Although based on accurately modeled reflection coefficients, discrepancies between simulations and real-world measurements make it challenging to accurately predict the optimal reflection coefficient.

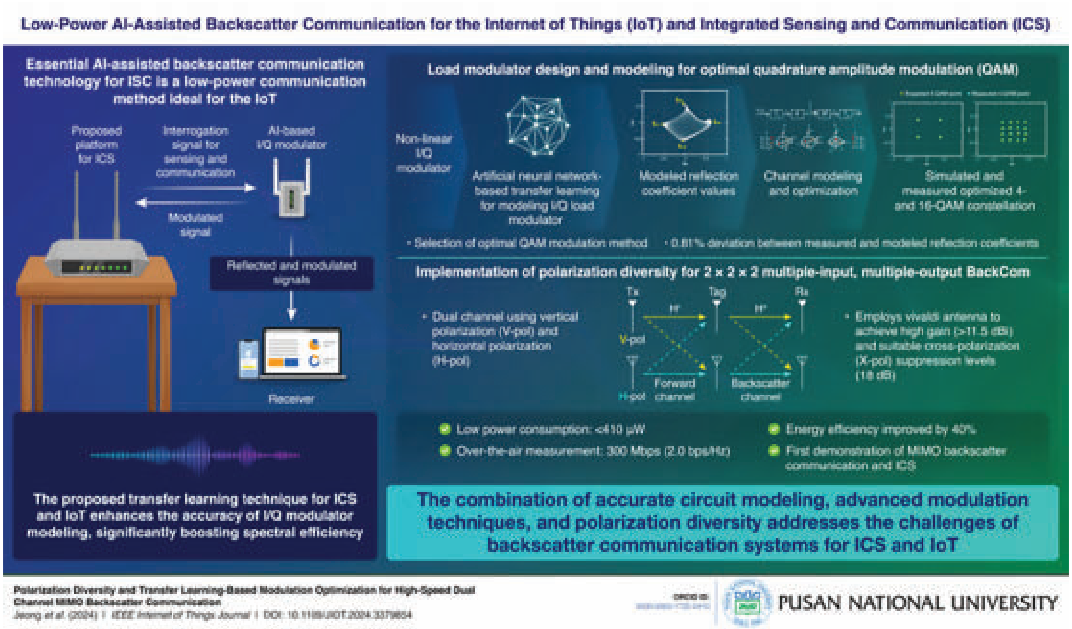
A research team led by Professor Sangkil Kim from the Department of Electronics Engineering at Pusan National University used transfer learning to accurately model the in-phase/quadrature or I/Q load modulators, introducing polarization diversity via multiple antennas for simultaneous signal transmission and reception.

By applying a transfer-learning approach, the researchers pre-trained an artificial neural network (ANN) with simulated input bias voltages to familiarize the ANN with the load modulator behaviors across varying voltage conditions. This knowledge was then employed to train the ANN using experimental data to predict reflection coefficients based on VI and VQ inputs.

This transfer of knowledge improved predictions, achieving a minimal deviation of only 0.81% between modeled and measured reflection coefficient. This enabled the researchers to select optimal 4- and 16-QAM schemes, aligning predicted reflection coefficients with specific points in the QAM constellation to ensure energy-efficient data transmission, with total consumption below 0.6 mW.

The researchers developed a 2×2×2 MIMO transceiver system featuring two transmit and two receive antennas with different polarizations to enhance signal reception, throughput, and efficiency. Using a dual-polarized Vivaldi antenna, the team achieved a gain exceeding 11.5 dBi and a cross-polarization suppression of 18 dB.

The researchers tested their algorithm and MIMO BackCom system in the 5.725- to 5.875-GHz C-band, offering a 150-MHz bandwidth with a spectral efficiency of 2.0 bps/Hz using 4-QAM modulation. Demonstrating effective bandwidth utilization, they also attained an error vector magnitude of 9.35%, indicating high reliability and efficiency. ■



Pusan National University researchers developed a high-efficiency backscatter technique to improve low-power IoT communication. Pusan National University

Dual-Mode Mesh Radar Recruited for Base Defenses

BASED ON ITS INNOVATIVE distributed dual-mode mesh radar technology, MatrixSpace has been awarded a $1.9 million tactical funding increase (TACFI) contract to develop the radar for United States Air Force (USAF) base protection. AFWERX is an arm of the USAF, within the Air Force Research Laboratory (AFRL), that connects military and commercial engineering platforms and efforts. The radar development project is expected to last 22 months.

The Phase II Sequential TACFI targets low-airspace surveillance for the USAF 87th Security Forces Squadron. The scalable mesh radar will provide base protection *(see image above)* against low-flying objects such as unmanned aerial vehicles (UAVs) and one-way attack vehicles.

Matthew Kling, vice president of Intelligent Systems at MatrixSpace, said, "This TACFI project addresses a core requirement in new force protection, which is providing an enhanced level of awareness in complex, challenging environments, quickly. A distributed radar sensor mesh has the ability to detect and identify previously undetected objects, making it essential for the new world of battlespace awareness. This project enables MatrixSpace to demonstrate our product for field use."

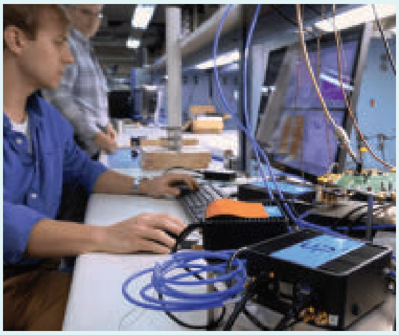
The mesh radar hardware is highly effective for and against beyond visual line-of-sight (BVLOS) uncrewed, autonomous, and tethered aircraft, and overall general airspace awareness and security.

Penn State's Applied Research Lab Aids National Security

THE U.S. DEPARTMENT OF DEFENSE (DoD) is going back to school, at least until 2029, to the Pennsylvania State University (State College, Pa.). The DoD awarded an indefinite-delivery/indefinite-quantity (ID/IQ) contract with a ceiling of $460 million to use the Penn State University Applied Research Laboratory (PSU-ARL) as a University Affiliated Research Center. No funds are obligated at the time of the contract.

The school's research facility *(see image, right)* will help examine problems affecting U.S. national security and provide analytical assessments as well as recommend solutions to senior defense leaders.

The sole-source contract to PSU-ARL provides funding for essential engineering, research, and development capability for the DoD at a research organization within a university or college. Work per the contract will be performed at the Applied Research Laboratory within the college. The estimated contract completion date is July 8, 2029. The contract is issued and managed by Washington Headquarters Services (Arlington, Va.).



The Pennsylvania State University Applied Research Laboratory

Wi-Fi HaLow Bolstered with Launch of Gateway, Sensing Camera, and People Counter

Milesight IoT and Thinkstock

The Overview: Wi-Fi HaLow Deepens Market Penetration

Morse Micro has partnered with Milesight to bring to market Wi-Fi HaLow variants of the latter's X1 sensing camera, VS135 Ultra ToF people counter, and HL31 Wi-Fi HaLow gateway. Wi-Fi HaLow functionality comes through the integration into these products of Morse Micro's MM6108 module. Together, the products enhance the market penetration of the Wi-Fi HaLow (IEEE 802.11ah) technology.

Who Needs It & Why: Multiple Smart-Everything Applications

The combination of a camera, people counter, and Wi-Fi gateway has a myriad of potential applications as an IoT/IIoT ensemble. The Milesight/Morse Micro offering lends itself to such deployments as:

- *Smart cities:* Enhancing urban living with smart lighting, parking, and waste-management systems.
- *Smart buildings:* Improving automation in buildings with accurate people counting and enhanced coverage.
- *Smart retail:* Enhancing customer experience and engagement with valuable insights.
- *Smart farming:* Revolutionizing farming with remote monitoring and precision agriculture tools.
- *Logistics and asset tracking:* Ensuring efficient and secure tracking of assets and inventory.
- *Healthcare:* Improving patient care with remote monitoring and telemedicine solutions.

Under the Hood: Wi-Fi HaLow's Long Reach and Low Power

Thanks to the addition of Wi-Fi HaLow connectivity, Milesight's new versions of its camera, people counter, and gateway can transmit images and other data at higher speeds and with low power consumption.

Wi-Fi HaLow, based on the IEEE 802.11ah standard, provides long-range, low-power connectivity for IoT applications. Wi-Fi HaLow operates in the sub-1-GHz frequency band, offering extended range and improved penetration through walls and obstructions.

According to Professor Neil Weste, Fellow at Morse Micro, "The extended range and low power consumption are particularly impressive, opening new possibilities for IoT applications that were previously out of reach. This collaboration exemplifies how advanced technology can seamlessly integrate into various industry scenarios."

Availability

The Wi-Fi HaLow versions of the X1 sensing camera, VS135 Ultra ToF people counter, and HL31 Wi-Fi HaLow gateway are available now across most regions. Contact Milesight IoT to start a design evaluation.

One IoT FEM Covers Thread, Zigbee, Wi-Fi, and Bluetooth

The Overview: An IoT FEM With Versatile Connectivity

pSemi's PE562212 is a tiny multi-protocol, 2.4-GHz front-end module (FEM) that brings versatility to makers of IoT devices. The highly integrated silicon-on-insulator FEM includes an RF power amplifier, low-noise amplifier, and control logic in a package suited for space-constrained PCBs.

Who Needs It & Why: IoT Device Makers Seeking Options

The PE562212 provides IoT designers with a bevy of options for connectivity, considering that it's designed for Thread, Zigbee, Bluetooth BDR/EDR, and Bluetooth LE applications. It's also capable of low-to-medium Wi-Fi throughput for devices that require firmware upgrades, or for applications with the need for increased data traffic.

One might use the PE562212 in an IoT device for, say, Bluetooth connectivity to a smartphone. But it also offers the ability to perform firmware upgrades over Wi-Fi. It's said to offer a balance of efficiency and linearity, enabling it to handle these disparate functions.

While also serving proprietary 2.4-GHz applications, the device links all sorts of smart devices using the Thread and Matter protocols. Smart speakers, lighting, and thermostats can be connected, as can IoT hubs, range extenders, wearables, sensors, and more. IIoT applications abound, too, such as asset tracking and industrial devices.

Under the Hood: Solid Banner Specifications

On top of its compact size and high integration, the PE562212 delivers up to +21-dBm output power and digital transmit-gain control in 1-dB steps with 15-dB range. In addition, the device offers impressive receive capabilities with a typical noise figure of 1.5 dB and a low-loss bypass path (0.9 dB typical) with a GPIO interface.

PCB routing is simplified by the PE562212 because it requires no external SMD components, such as control lines, supply lines, and RF traces. Packaged in a 14-lead, 1.8- × 1.8- × 0.7-mm LGA package, the device is now available in sample quantities.

USB Peripheral Controller Claims First 20-Gb/s Connectivity

Infineon Technologies

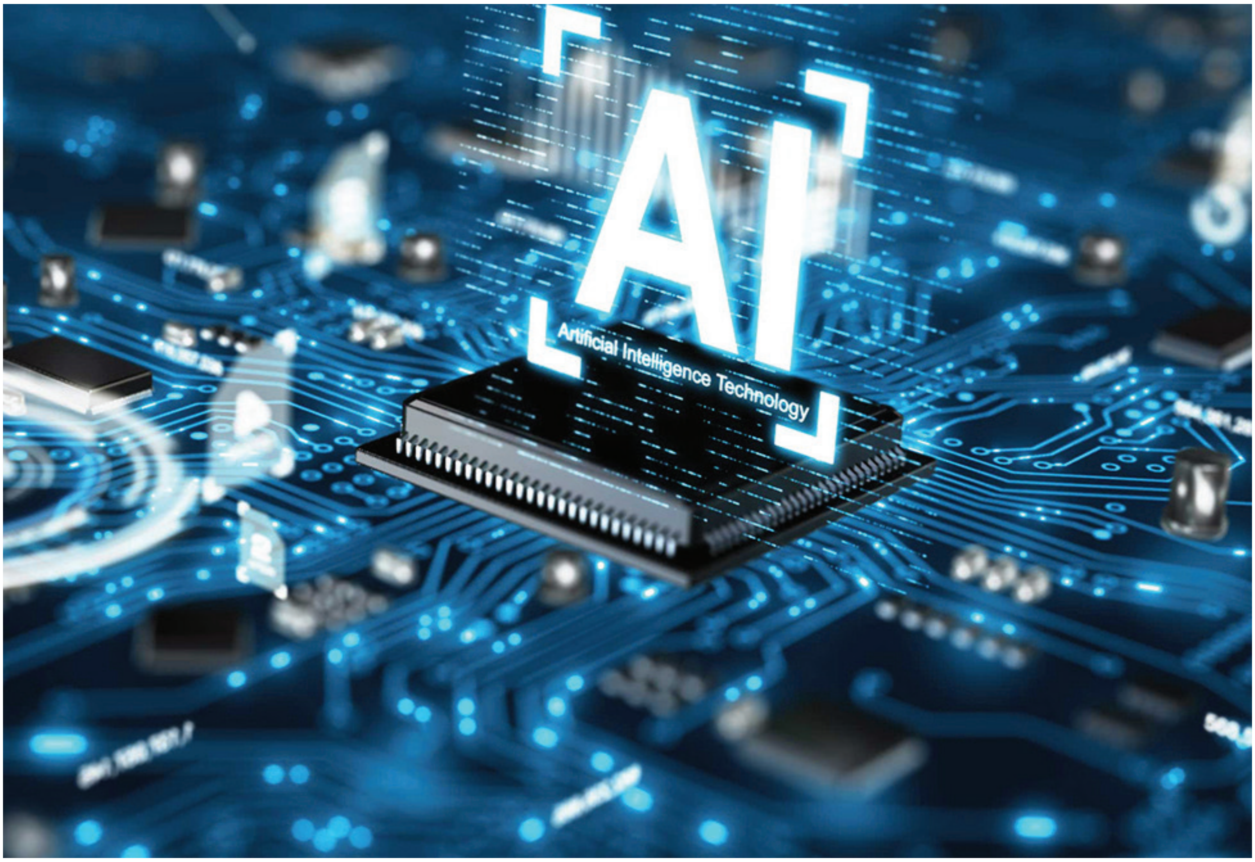
ADVANCED PORTABLE and wearable wireless devices need a good device interface for fast charging and data transfer. Addressing this demand, Infineon Technologies launched the EZ-USB FX20 programmable USB peripheral controller. It opens the door to the creation of USB devices for the demanding requirements in AI, image processing, and emerging applications.

Offering high-speed connectivity with USB 20-Gb/s and LVDS interfaces, the EZ-USB FX20 has a bandwidth up to 6X greater than legacy devices.

Well-suited for space-constrained applications, the EZ-USB FX20 comes in a 10- × 10-mm^2 BGA package. The controller enables BOM optimization and supports direct USB-C connection without a high-speed signal multiplexer.

A quick-start development kit includes firmware and there's a configuration tool for easy integration. Also in the mix is a standard FPGA Mezzanine Card connector for FPGA cards and an all-in-one programming and debugging accessory card. Furthermore, the peripheral controller offers application notes for hardware and software design to address various applications.

Among its other features are two Arm Cortex-M4 and M0+ core CPUs, 512-kB flash, 128-kB SRAM, 128-kB ROM, and seven serial communication blocks. A cryptography accelerator and a high-bandwidth data subsystem handles direct-memory-access data transfers between LVDS/LVCMOS and USB ports. Data transfer is also supported by an additional 1 MB of SRAM for USB data buffering. The controller integrates USB-C port orientation detection and flip-mux functionality as well, eliminating the need for external logic.



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The Intelligent Future of Spectrum Visibility (Part 1)

Discover how artificial intelligence is revolutionizing spectrum operations, offering unparalleled speed, precision, and adaptability. AI will change the way we "see" RF.

***By Alejandro Buritica,** Product Manager, RF & Wireless, Tektronix*

ON THE MORNING of December 7, 1941, radar operators at Opana Point, Hawaii, detected an unusually large blip on their radar screen: a large group of aircraft heading for Pearl Harbor. Despite this early warning, a series of miscommunications and assumptions about the blip being friendly aircraft led to a catastrophic defensive failure.

The incoming planes were, of course, Japanese fighters, launching what would become one of the most infamous surprise attacks in military history. This incident starkly highlights the perils of underestimating the value of cutting-edge radar technology and its integration with other sensors and quick-response mechanisms.

Large-scale adoption of artificial intelligence (AI) marks a revolutionary shift in the field of spectrum operations, promising to transform it with its speed, precision, and adaptability. This article, the first in a two-part series, offers a concise guide into the complexities and innovations defining the field today. We start with an overview of the current state, setting the stage for a deeper exploration into the transformative role of test and measurement tools.

Part 2 will discuss the paradigm shift brought forth by cognitive radar and AI's integral role in electromagnetic dominance.

The Current Landscape of Spectrum Operations

Military and government entities, as well as non-government actors and civilians, contend for access and control of the electromagnetic spectrum (EMS), which brings its own set of challenges and complexities to effective spectrum operations. These are outlined below.

Increased Spectrum Congestion

Commercial allocation of new frequency bands for telecommunications and other civilian uses continues to grow. Bands previously reserved for satellite communication and military radar now serve cellular services. And bands that had been reserved and sparsely used are now designated for unlicensed Wi-Fi use, while new commercial cellular services seek to take advantage of mmWave bands, operating in the vicinity of high-bandwidth satellite and radar systems.

RF designers working in this contested environment must ensure that their designs and the radio systems that they're working with stay within their allocated channels, minimizing the amount of energy that they spill on other bands.

Regulators and spectrum operations specialists must use sensitive, wideband RF receivers to monitor the spectrum continuously and ensure that all actors are respecting their allocated frequency bands. They must also detect contested use of the spectrum for pirated use, jamming, and other forms of unauthorized electromagnetic applications.

The Dynamic Nature of Spectrum Change

The pace of change of the EMS has accelerated. To achieve multiple advantages in the use of the spectrum, and to enable better decision-making, engineers and other spectrum users must maintain continuous EMS awareness through a larger number of more capable EMS sensors. Test and measurement equipment with higher dynamic range and wider instantaneous bandwidth enables them to improve their operations as well as outpace adversarial forces in the creation of EMS effects.

The Growing Sophistication of Adversarial EMS Tactics

The sophistication of jamming and spoofing techniques used by adversaries is concerning. This is particularly the case when it comes to the relative ease of acquiring and deploying software-defined radios (SDRs) with cutting-edge FPGA capabilities and wideband front ends. Researchers need high-precision waveform generators and signal analyzers to model, simulate, and replicate these RF environment threats and stay one step ahead of malicious users.

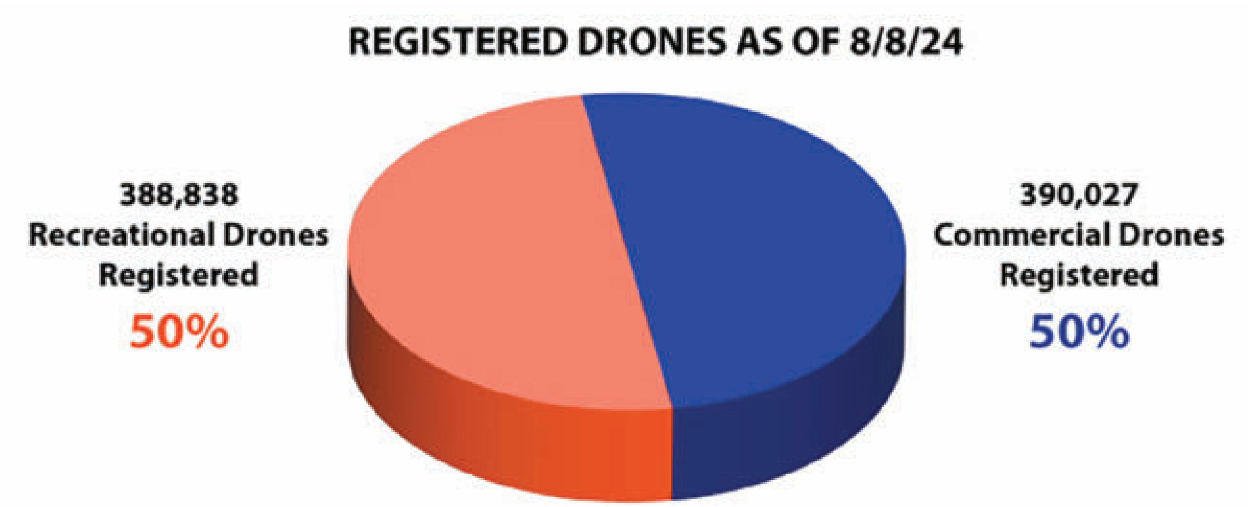
The Greater Integration in Unmanned Aerial Systems

The last 20 years have seen a proliferation of both military and commercial unmanned aerial systems (UASs), commonly referred to as drones *(Fig. 1)*. These drones have numerous legitimate and beneficial applications, but also unscrupulous and illegal uses.

UASs are readily available to consumers, which presents a challenge in managing spectrum usage and ensuring security against threats posed by swarms of these devices. RF signal analyzers and signal generators need lower noise, improved frequency selectivity, and advanced triggering to detect, identify, monitor, and take countermeasures against these threats.

Cyber-Electromagnetic Activities on the Rise

While electronic attacks rely on the physical effects of electromagnetic energy to disrupt or deceive, cyber-electromag-

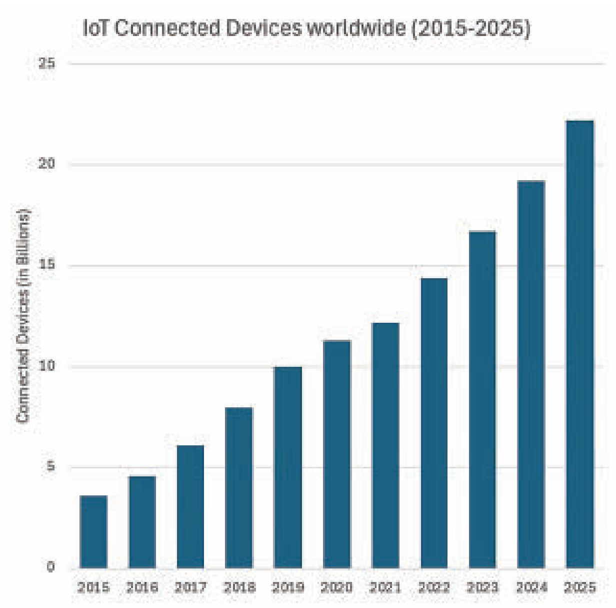


1. This graphic represents the numbers of registered UASs in the U.S., broken out by commercial and recreational. U.S. Federal Aviation Administration netic activities (CEMA) leverage cyber techniques to infiltrate, manipulate, or damage systems at a data or network level. This combination increases the effect of the attacks, allowing for more precise and targeted disruptions, often with a broader strategic scope.

The integration of cyber and electromagnetic operations tactics is a sophisticated endeavor. However, just like SDRs are commercially available and affordable, the tools for cyberattacks are increasingly accessible to users with a moderate level of technical expertise.

Increasing Density of Connected Devices

The commercial communications industry continues to drive the development and mass deployment of both high-bandwidth cellular standards and narrowband Internet of Things (IoT) services, causing the number of users and devices per area to grow exponentially *(Fig. 2)*. Arbitrating contention for RF access and improving the quality of service to all of these connected devices requires opening new bands, such as mmWave bands for 5G, and devising new radio access mechanisms.



Credit: https://iot-analytics.com/number-connected-iot-devices/

Tools for Assessing, Researching, and Advancing Spectrum Operations

Instruments such as Tektronix's arbitrary waveform generators (AWGs) and real-time spectrum analyzers (RSAs) are pivotal in navigating these complexities. High-bandwidth AWGs enable the generation of complex, real-world RF environments with precise modulation and timing characteristics, essential for testing and simulating dynamic radio behavior and electronic countermeasures.

Together with RSAs for spectrum analysis, signal interception, and environment scanning, AWGs enable researchers to replicate dense, dynamic spectral environments for developing adaptive, intelligent systems. With these advanced tools, researchers can effectively analyze spectrum usage, identify vulnerabilities, and enhance the resilience of communication, radar, guidance, and other RF systems against sophisticated denial, jamming, and spoofing techniques. As a result, they help ensure secure and efficient spectrum utilization in both military and civilian applications.

The second article of this two-part series will discuss the paradigm shift brought forth by cognitive radar and AI's integral role in electromagnetic dominance, signifying a leap toward more sophisticated and efficient spectrum management. Through examples of real-world applications, the discussion touches on the practical implications of these advances. Also addressed are the inherent technical challenges that accompany the course toward a more secure and technologically adept future in the realm of spectrum operations. ■

REFERENCES

Del Monte, L. A. (2018). Genius weapons: Artificial intelligence, autonomous weaponry, and the future of warfare. Prometheus Books.

Federal Aviation Administration. (2023). "Drones by the Numbers." Retrieved January 9, 2024.

Haigh, K. Z., Andrusenko, J. (2021). Cognitive electronic warfare: An artificial intelligence approach. Artech House.

O. M. Khodayer Al-Dulaimi, M. K. Hassan Al-Dulaimi and A. M. Khodayer Al-Dulaimi, "Cognitive Radio Technologies and Applications in Dynamic Spectrum Access Method," 2022 IEEE 9th International Conference on Problems of Infocommunications, Science and Technology (PIC S&T), Kharkiv, Ukraine, 2022, pp. 9-14, doi: 10.1109/PICST57299.2022.10238684.

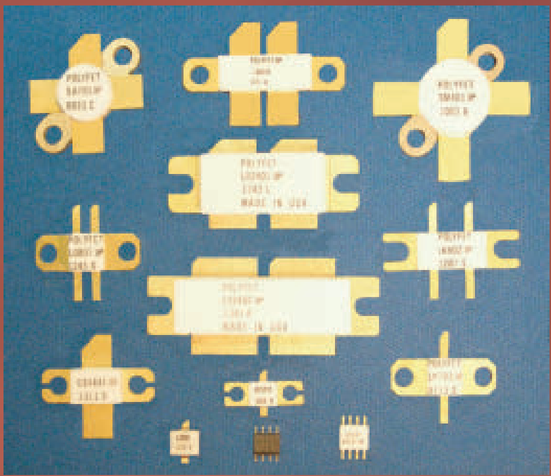
S. You, M. Diao and L. Gao, "Deep Reinforcement Learning for Target Searching in Cognitive Electronic Warfare," in IEEE Access, vol. 7, pp. 37432-37447, 2019, doi: 10.1109/ACCESS.2019.2905649.

U.S. Air Force. (2023). "Electromagnetic spectrum operations" (AFDP 3-85). Retrieved January 12, 2024.

An Overview of Cognitive Radar: Past, Present, and Future.

Statista. (2023). "Number of IoT Devices."

Broadband RF power transistors, modules, and evaluation amplifiers: Polyfet RF Devices offers them all.



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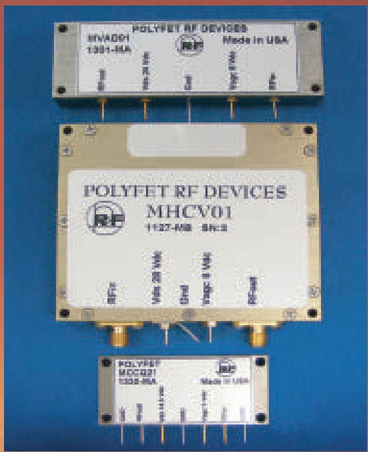

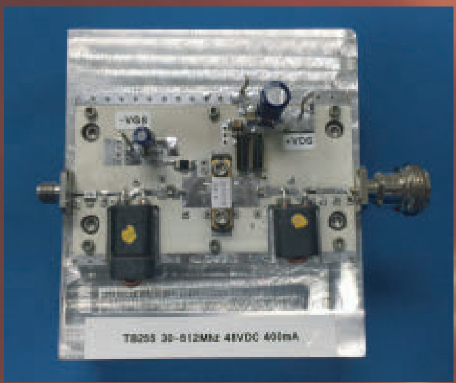

Various evaluation amplifiers available:
Displayed here is the TB255. It demonstrates the GX3442 (GaN) putting out 100W CW, 19dB across 30-512MHz with 48VDC supply.

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Design Parameters for a Wideband, Second-Harmonic **Gunn Oscillator**

Here's a simple technique for designing and building a microwave broadband oscillator based on the venerable Gunn diode.

By Saabra Deen,
Technical Staff, Osctek Ltd.

DESPITE BEING AN older, established technology, demand continues for wideband high-frequency oscillators based on the venerable Gunn diode. Sadly, designing and building such oscillators is a skill that seems to be waning these days.

Today's younger engineers turn increasingly to newer technologies when designing oscillators. In addition, they rely more on analog simulation tools to iron out the intricacies of the circuits. Meanwhile, older engineers who might have previous experience working with Gunn diodes are in the twilight of their careers, putting at risk the retention of their knowledge for the industry at large.

The Gunn diode has hung around since its invention by J.B. Gunn in the early 1960s, and for good reasons. Even though it's referred to as a "diode" because it has an anode and a cathode, it's technically not a diode because it doesn't have a conventional PN junction. Rather, it's composed of a single N-type semiconductor, which is why it's known as a transferred-electron device (TED).

A traditional PN-junction diode can perform rectification, which isn't the case with a Gunn diode since it conducts in both directions. But because its two terminals, both with negative dynamic resistance, can produce extremely high switching speeds, the Gunn diode lends itself to wideband oscillators for applications such as radar systems and sensors, communications, radiometric systems, and more. These days, Gunn diodes are typically fabricated in gallium arsenide (GaAs) with operating frequencies up to 200 GHz and gallium nitride (GaN) in frequencies of up to 3 THz.

There's a plethora of information and articles relating to Gunn-diode-based oscillators. Two notable articles offering useful insights are by W.H. Haydl[1] and J.E. Carlstrom[2]. The wideband oscillator stems from the initial work carried out by Haydl, which Carlstrom subsequently took further. Another good source of information is E.L. Holzman and R.S. Robertson's book.[3] "Solid-State Microwave Power Oscillator Design."

In this brief article, we aim to provide some guidance on considering the fundamental design parameters for such a wideband, second-harmonic Gunn oscillator.

Design Considerations for Gunn-Diode-Based Oscillators

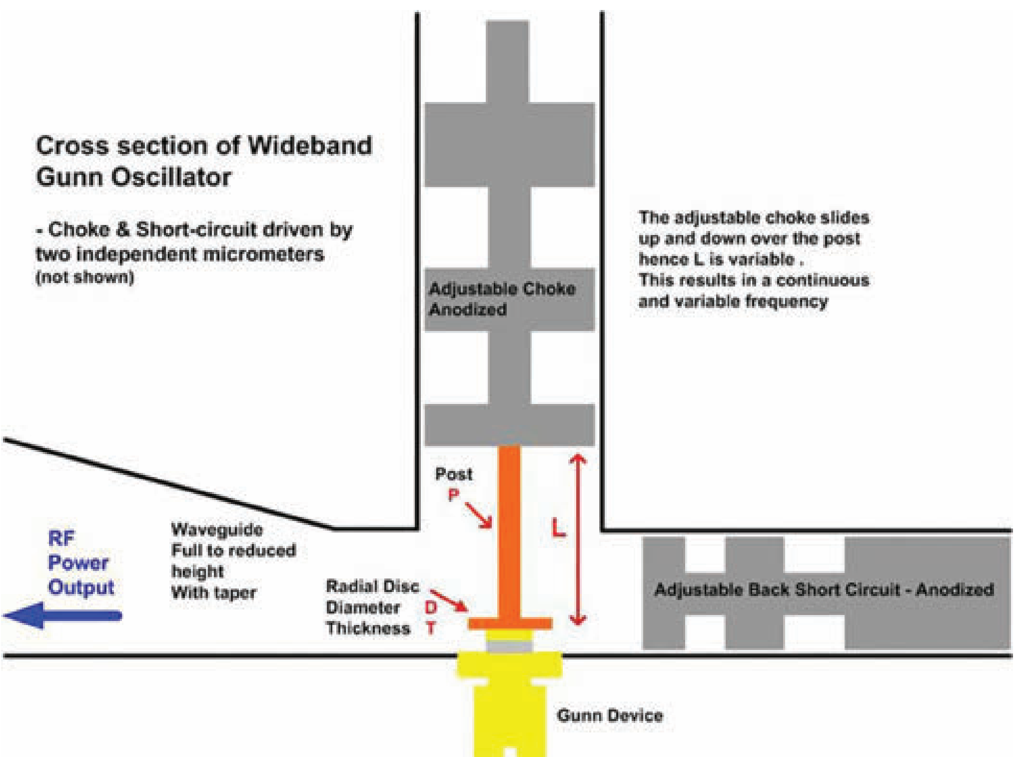
Let's consider the case of an E-band, mechanically tuned Gunn oscillator. For a waveguide, we'll go with a standard WR12 waveguide that has dimensions of 3.10 × 1.55 mm. For the circuit itself, we'll use a reduced height of 0.775 mm, which will taper out to full height.

The cutoff frequency for a WR12 waveguide is λc = 48.39 GHz. The cutoff frequency is a key parameter, because any waves at lower frequencies will not propagate. The circuit exploits this fact by using fundamental Gunn devices, which are more readily available on the commercial market.

Figure 1 shows a cross section of the mechanically dual-tuned Gunn oscillator. The Gunn diode is mounted into the base of the WR12 waveguide's cavity section with a taper to full height. The location of the Gunn diode also forms a coaxial cavity with an adjustable length.

While this coaxial cavity supports the fundamental-frequency mode of operation, only the harmonic frequency is allowed to propagate via the waveguide section (i.e., the cutoff frequency). Thus, by altering the length of the coaxial cavity, the fundamental frequency can be altered—hence, the output second-harmonic frequency.

Power is coupled out of the circuit by using the radial impedance transformer and adjusting the phase within the waveguide channel, which is accomplished by a short circuit located in the reduced height section. Because the radial impedance trans-



1. This diagram illustrates a cross section of the wideband Gunn oscillator described in the article. Images courtesy Osctek Ltd.

former isn't broadband, power will be optimum for smaller bandwidths. The dimension of the radial disc is typically half of the waveguide's length.

Parameters that have secondary effect on the oscillator performance are:

- Radial disc thickness (T)
- Post diameter (P)

The mechanism for broadband tuning is adjustment of the length, L, of a coaxial cavity *(Fig. 1, again)*. Varying the cavity's length produces very large bandwidths. Near-full bandwidth is achievable with careful attention.

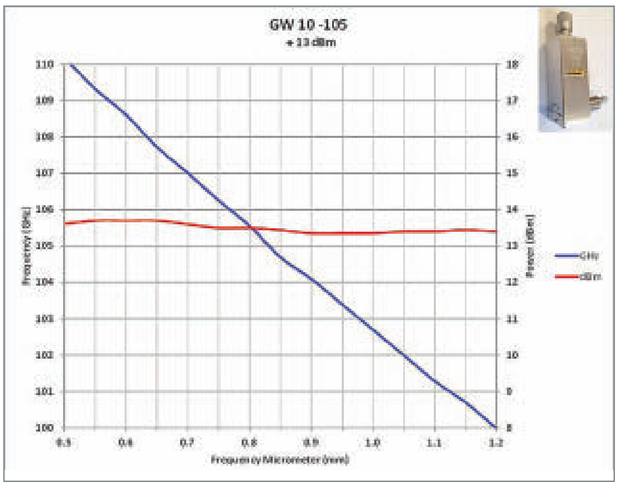
We have generated a model for prediction behavior of these dual-tuned microwave Gunn oscillators. The power output power is less predictable and usually dictated by the Gunn device in use.

The initial key parameters are as follows:

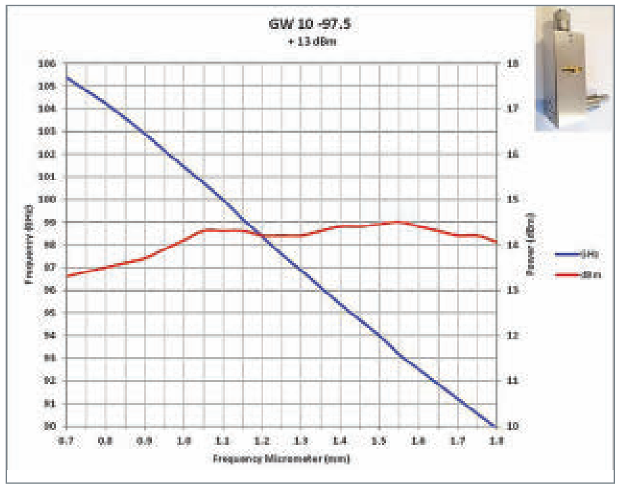
- Disc diameter (D) ~ 2.45 mm for 78-GHz operation, which is half the length of the WR12 waveguide
- Disc thickness (T) ~ 0.25 mm
- Post diameter (P) ~ 0.6 mm

Measured Data for Gunn-Diode-Based Oscillators

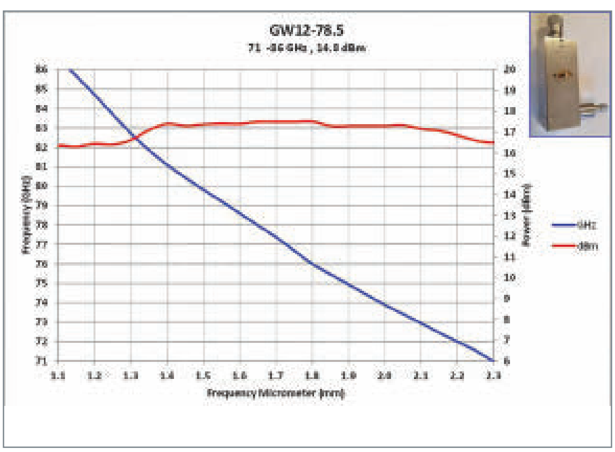
Figures 2 and 3 present typical measured data for a WR10 waveguide for bandwidths with useful power > +10 dBm. In addition, data is shown for E- and V-band units in *Figures 4 and 5*.



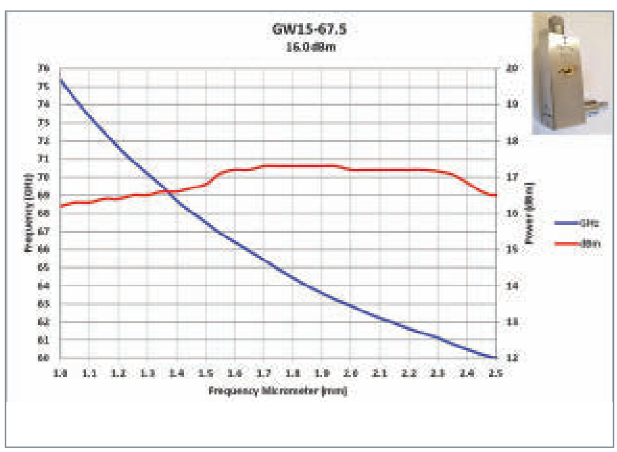
2. This graph displays typical measured data at 105 GHz with useful power > +10 dBm for a wideband Gunn oscillator with a WR10 waveguide.



3. Here's typical measured data for a Gunn oscillator with a WR10 waveguide at 97.5 GHz.

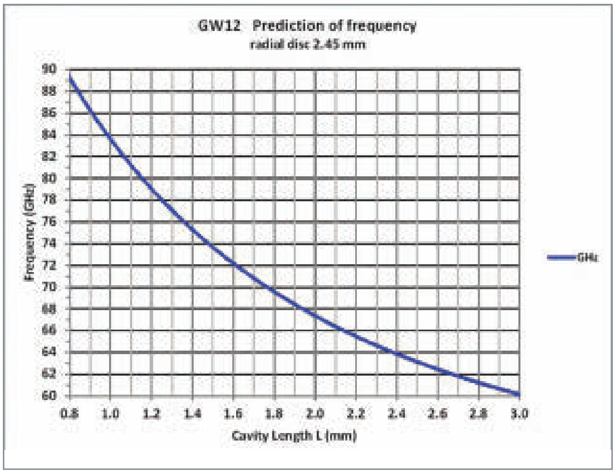


4. In this graph, we show typical measured data for a wideband Gunn oscillator with a WR12 waveguide at 78.5 GHz (E-band).



5. Shown here is typical measured data for a wideband Gunn oscillator with a WR15 waveguide at 67.5 GHz (V-band).

For the E-band case discussed in this article, *Figure 6* provides the predicted frequency behavior. There's good correlation between measured and predicted frequencies, which renders the modeling useful. And for repeatability, micrometers are fitted for both cavity frequency adjustment and power optimization as shown in *Figure 7*.



6. The graph provides predicted frequency behavior for the WR12 wideband Gunn oscillator described in this article.

7. As shown, WR12 Gunn oscillators from Osctek are fitted for both cavity frequency adjustment power optimization.

In summary, wideband, mechanically tuned Gunn oscillators can be produced to cover significant parts of the microwave spectrum. Multiple units will cover a particular waveguide with useful output power (e.g., > +10 dBm). Such oscillators offer a compact and reliable solution for high-frequency applications at a relatively lower cost when compared with upconversion or multiplier/synthesizer-based solutions. ■

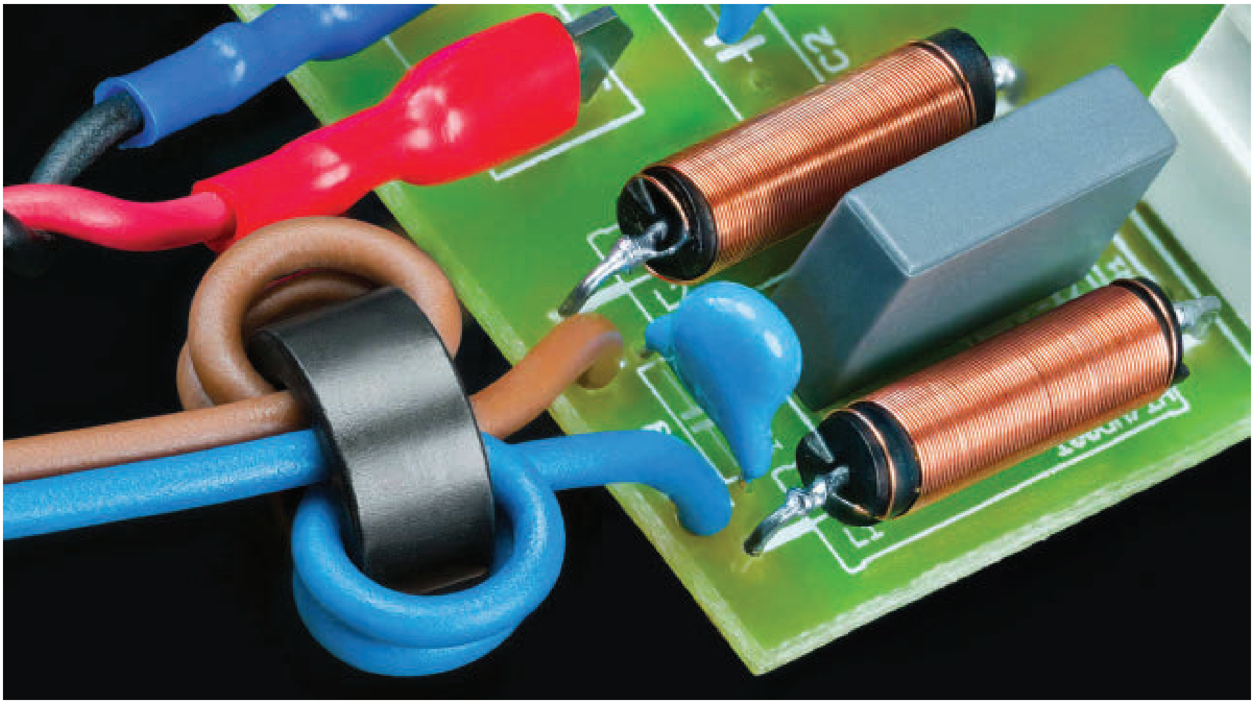
REFERENCES

1. W.H. Haydl. "Harmonic Operation of GaAs Millimeter-Wave Transferred-Electron Oscillators." *Electronics Letters*, Volume 17, Issue 22, October 1981.

2. J.E. Carlstrom, R.L. Plambeck, D.D. Thornton. "A Continuously Tunable 65-115-GHz Gunn Oscillator." *IEEE Transactions on Microwave Theory and Techniques, Vol*ume 33, No. 7, July 1985.

3. E.L. Holzman and R.S. Robertson. "Solid-State Microwave Power Oscillator Design." Artech House, Norwood, MA, 1992.

Shielding Solutions
Bring EM Isolation and Protection



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Careful attention to shielding from the earliest stages of project development will result in a better-functioning product that will sail through EMC testing.

By ***Jack Browne,***
Technical Editor

SHIELDING IN ANY FORM can protect electronic equipment by enabling sensitive circuits and devices to function closely together amidst multiple electromagnetic (EM) fields. Whether to guard against EM interference (EMI) or radio-frequency interference (RFI), shielding comes in many shapes and sizes, from raw materials to finished enclosures.

Understanding the capabilities of available EMI/RFI shielding can help when searching for a solution to suppress EM and/or RF as electronic circuits shrink, with components and interconnections being designed closer together.

EMI and RFI refer to unwanted energy fields often far apart in frequency. Both forms of interference can degrade electrical performance, although at different frequencies. EMI tends to refer to noise sources at lower frequencies, such as power supplies and lines, while RFI usually occurs at higher frequencies, e.g., RF, microwave, and millimeter-wave frequencies. Interference can include fundamental and harmonic frequencies.

EMI or RFI can travel from a source to a component or device sensitive enough to receive it via conduction, radiation, capacitive coupling, or magnetic coupling. Conduction involves physical contact with conductors, radiation through free space, and capacitive or magnetic coupling between closely spaced signal lines and EM fields.

Interference can be continuous, such as from power lines or commercial broadcast stations, or intermittent, due to random interference like pulses or power surges. EMI may be narrowband or wideband, occupying more or less than the bandwidth of the component or system it affects.

Keep EMI and RFI Under Control

As use of electronic devices expands in daily life through mobile telephones, electric vehicles (EVs), and medical devices, proximity of so many electronic devices dictate an increased need for effective EMI/RFI shielding materials and methods. Achieving electromagnetic compatibility (EMC) for any application will require designing for EMI and RFI from the device level through the circuit and system stages of a design to address the interaction of so many closely placed potential EM emitters and receivers.

Growing use of mmWave frequency bands will also result in smaller signal wavelengths and smaller circuit dimensions, with components and devices closely spaced. Forward-thinking circuit layouts can minimize the shielding foils, gaskets, and even enclosures needed to prevent interference. But in many cases, additional shielding materials provide the most effective and practical means of curbing EMI and RFI disturbances.

By understanding the capabilities of the many shielding products currently available at the device, board, and system levels, EMI and RFI can be reduced to manageable and standards-acceptable levels that enable wired and wireless electronic devices to live together.

An EMI or RFI shielding solution may require blocking the flow of energy from a source or preventing a component's reception of EMI or RFI. Surrounding a sensitive component on a printed circuit board (PCB) with a shielding structure known as a Faraday cage can stop the component from receiving external emissions and prevent the component from emitting EMI or RFI. Shielding solutions have been developed to surround components and devices on a surface-mount-technology (SMT) scale and as flexible materials. One such material is conductive foam filler, which can provide protection by absorbing unwanted EMI and RFI between PCBs in a system design.

Part of developing an effective EMI/RFI shielding solution is understanding the nature of an electronic design's radiated or conducted EMI and RFI, as well as how susceptible the design is to EMI and RFI from other sources. Test equipment for understanding the EMI/RFI characteristics of a device under test (DUT) includes an EMI receiver, spectrum analyzer, near-field EM probes, and a line impedance stabilization network (LISN) to isolate a DUT from its own power supply (which could be the source of EMI or RFI).

Testing usually occurs in two different forms during an electronic product's development cycle: as pre-compliance testing performed early during a DUT's development, to discover any circuit or system EMI/RFI issues, and during the latter stages of a product's development, in keeping with the regulatory compliance requirements for the product's application area.

A design's EMC can be determined according to regulations established by national and international standards organizations, such as the Federal Communications Commission (FCC) in the U.S., the European Union (EU) in Europe, and the International Special Committee on Radio Interference (CISPR) for global coverage.

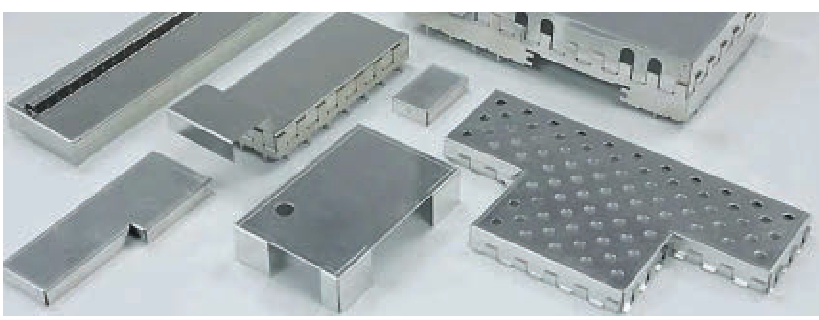
Standards such as the FCC's Part 15 regulations for most commercial electronic products and the FCC's Part 18 rules for industrial-scientific-medical (ISM) electronic equipment are examples of standards that help establish compliance and compatibility among electronic devices in everyday life. The numbers of these electronic products, which are transmitting and receiving EM and RF energy, continue to rise, requiring efficient and effective shielding solutions whether as small as Faraday cages or as large as full equipment enclosures.

Shielding Encompasses Tiny Enclosures to Room-Sized Containers

Shielding solutions range from tiny, component-sized enclosures to room-sized housings, with the item or items to be shielded and design strategy determining the type of shielding to be used. Ongoing miniaturization of electronic designs in portable devices and greater use of higher wireless frequencies lead to more densely packed circuits in smaller designs and create more difficult EMI/RFI shielding challenges.

When PCBs tested for EMI and RFI exhibit problems, layout designers often consider changes in signal paths prior to adding shielding materials—even additional circuit layers and ground planes. However, failing to solve a small EMI/RFI problem can lead to a more expensive, enclosure-sized solution.

Among the shielding solutions are Faraday cages that make it possible to surround a component on six sides (including the PCB ground plane), grounding contacts, gaskets, conductive foam, and conductive adhesives such as epoxy. Shielding is typically implemented at the circuit, board,



1. The CBS Series of EMI shields are supplied in two pieces, with a fence and removable cover, for ease of maintenance and testing of components on PCBs. Leader Tech or enclosure level with costs minimized by adding shielding as close to the noise source as possible.

Shielding individual components and devices at the circuit level is essential when the radiation from that device may interfere with nearby components in the same circuit. The Faraday cage or shield has long been a means of EMI and RFI containment. It surrounds a component or device in an enclosure that prevents EM/RF energy from escaping the device or reaching it from outside the enclosure.

Leader Tech offers a wide range of board-level shielding solutions based on the Faraday cage, such as its CBS Series. Available in standard sizes from 0.5 × 0.5 in. to 12 × 24 in., the two-part EMI shields consist of a fence and removable cover *(Fig. 1)*.

An Array of Shielding Materials

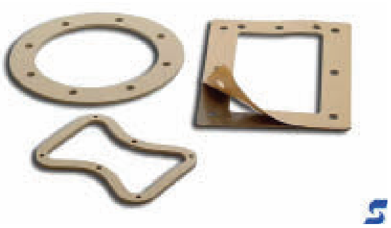
Laird, a DuPont Business, produces microwave and millimeter-wave absorbing materials, including low-loss dielectric materials. Its conductive elastomers help block EMI and RFI over wide temperature ranges, while form-in-place gaskets meet the shielding needs of portable electronic products in plastic enclosures. They have been found effective in many automotive electronic applications, including for collision-avoidance radar systems operating at mmWave frequencies.

The company also features two-piece shields that simplify the repair of shielded components and devices without rebuilding major sections of a circuit board. Its Ecofoam material provides three-axis conductivity with conductive tape on one side for ease of forming odd-shaped gaskets.

Boyd is a supplier of EMI/RFI shielding foam such as its 5770 series conductive foam, which can be used to surround an emitter and absorb its excess conducted energy. MAST Technologies offers tuned frequency absorbers; thin, magnetically loaded sheet stock optimized for attenuation at discrete frequencies. Depending on frequency, they can provide as much as 20-dB attenuation of a component's EM emissions. In addition, PPG Engineering Materials and its Cuming Microwave Corp.'s MicroGrid microwave absorber foils form thin EMI shields, including for anechoic chambers.

EMI shielding circuit- and board-level solutions come in many forms, including as adhesives and foams. Conductive epoxy such as G6-EPOXY from Graphene Laboratories, can replace solder joints acting as unwanted antennas. It adheres to a variety of materials, including plastics, metals, glass, and ceramics, and is beneficial for heat-sensitive designs like those for medical devices. When thermal management is part of the problem, Master Bond Inc. provides thermally conductive, heat-resistant epoxy.

When sections of circuits must be isolated, EMI/RFI solutions are often best implemented as some form of gasket. EMI/RFI gaskets come in a wide range of composite materials, including the conductive silicone or rubber gaskets from Stockwell Elastomerics that can manage radiant and conductive EMI *(Fig. 2)*. The gaskets are formulated to provide high EMI attenuation as well as environmental sealing, such as from rain, smoke, and dust, for several application areas ranging from residential and industrial to military environments.



2. Conductive silicone gaskets aid management of radiant and conductive EMI along with reliable environmental protection. Stockwell Elastomerics

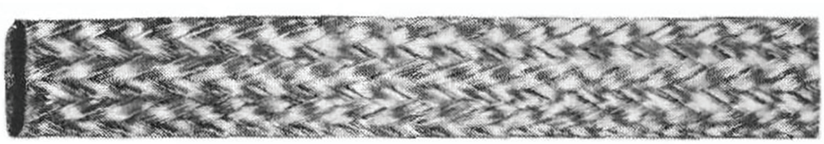
Similarly, Zippertubing has fabricated a rubberized form of conductive plastic film with a wide temperature range for EMI shielding that needs flexible gaskets.

Electronic leaks through signal paths often occur within cables and connectors, requiring the use of shielded cables and cable assemblies. For example, shielded cables from Alpha Wire surround cables for various applications with shielding foil or braids to prevent the reception or transmission from EM/RF energy from the cables.

Also on that front, ShowMeCables offers a variety of EMI-shielded cables and cable assemblies for fiber-optic, power, and RF/microwave interconnections.

Brim Electronics Inc. employs braiding on its EMI shielded and instrument-grade cables for high isolation even in dense circuit architectures. The firm's 1110 series shielded braiding *(Fig. 3)*, for instance, employs tinned copper conductors for grounding in vehicles to eliminate interference from ignition. The latest addition to the 1110 series is the model 1115 flat tinned copper braid; conductors are formed with annealed tinned copper to provide significant reduction of EMI and RFI even in automotive environments.

EMI/RFI shields provide protection for entire circuits and designs. When specific noise sources must be blocked, EMI/RFI filters can attenuate the flow of noise at fundamental and harmonic frequencies and help achieve electromagnetic compatibility (EMC) for a circuit or system without adding extensive shielding materials. EMI/RFI filters are available from a number of suppliers, including CTS Corp., Electrocube, EMI Filter Co., Murata, and TE Connectivity.



3. This shielded braiding uses tinned copper conductors to guard against ignition noise in motor vehicles. Brim Electronics

Shielded Enclosures Swallow EMI Emissions

When entire circuits or subsystems must be surrounded to prevent EM/RF leakage or exposure to nearby EM/RF energy fields, especially circuits that may contain unintentional antennas, they're usually encased in a conductive enclosure. Such an enclosure typically includes a housing, lid, and conductive gasket. For example, the 1457-EMI Series enclosures from Hammond Manufacturing Ltd., available with wall-mounting flanges, provide EMI shielding with reliable environmental protection *(Fig. 4)*.

4. Compact EMI shielding enclosures such as this one typically include a housing, lid, and conductive gasket. Hammond Manufacturing

Emcor Enclosures produces EMI/RFI shielded cabinets, cages, and enclosures such as its PROTECTOR server cabinets, which are also designed to provide data security. The enclosures feature horizontally split locking side panels for ease of access and cabinet designs with high ventilation rates (above 80%). Additional suppliers of EMI/RFI shielded enclosures include Phoenix Mecano, Polycase, and Takachi Electronics Enclosure Co. Ltd.

The importance of EMI/RFI shielding continues to rise due to the growing number of electronic devices in constant use. Challenges will be in providing adequate shielding for the rapidly shrinking dimensions of portable and mobile electronic devices, as well as developing effective but affordable shielding materials that fit the newest designs in many ways. ■

Companies Controlling EMI/RFI

Company	URL	Example product/service
AAroniaUSA	www.aaroniausa.com	RF shielding fabrics
Alpha Wire Co.	www.alphawire.com	shielded wire and cable
Altium	www.altium.com	EMI circuit layout software
Boyd Corp.	www.boydcorp.com	EMI/RFI shielded foam
Brim Electronics	www.brimelectronics	shielded braiding, cables
Coilcraft	www.coilcraft.com	EMI chokes for filtering
CTS Corp.	www.ctscorp.com	SMT EMI filters
Ecofoil	www.ecofoil.com	RF shielding foil
Electri-Flex Co.	www.electriflex.com	flexible electrical conduit
Electrocube	www.electrocube.com	custom EMI and RFI filters
Emcor Enclosures	www.emcorenclosures.com	EMI/RFI shielded enclosures
EMF Academy	www.emfacademy.com	shielding fabrics
EMI Filter Co.	www.emifiltercompany.com	EMI filters
EMI Solutions, Inc.	www.4emi.com	RF shielding foil
Graphene Laboratories	www.g6-materials.com	conductive epoxy
Hammond Manufacturing Co.	www.hammfg.com	rack-mount enclosures
Insulated Wire	www.insulatedwire.com	cables for EMC testing
JBC Technologies	www.jbc-tech.com	die-cutting of EMI shields
Krieger Specialty Products	www.kriegerproducts.com	RF-shielded doors
Laird	www.laird.com	two-piece shields
Leader Tech, Inc.	www.leadertechinc.com	board-level shielding
Masterbond	www.masterbond.com	shielding adhesives
MAST Technologies	www.masttechnologies.com	frequency absorbers
Modus Advanced	www.modusadvanced.com	RF shielding materials
Mouser Electronics	www.mouser.com	distributor for enclosures
Murata	www.murata.com	EMI suppression filters
MWT Materials	www.mwtmaterials.com	RF shielding, isolation materials
Omega Shielding Products, Inc.	www.omegashielding.com	fingerstock shielding components
Parker Hannifin Corp.	www.parker.com	board-level EMI shielding,
Chomerics Div.		shielding paints
Phoenix Mecano	www.phoenixmecano.com	shielded enclosures
Polycase	www.polycase.com	shielded enclosures
PPG Engineering Materials	www.ppg.com	EMI shielding foils
RFMW	www.rfmw.com	distributor for EMI shielding
Richardson RFPD	www.richardsonrfpd.com	distributor for gaskets
Rolec USA	www.rolec-usa.com	plastic enclosures
RS Components	www.us.rs-online.com	distributor for wire, cable, enclosures
Slipmate	www.slipmate.com	EMI shielding coatings
ShowMeCables	www.showmecables.com	EMI-shielded cables
Stockwell Elastomerics	www.stockwell.com	EMI shielding gaskets
Strouse	www.strouse.com	EMI shielding gaskets
Syscom Advanced Materials, Inc.	www.metalcladfibers.com	conductive fiber
Takachi Electronics Enclosure Co., Ltd.	www.takachi-enclosure.com	EMI shielding enclosures
Tech-Etch	www.tech-etch.com	
TE Connectivity	www.te.com	
TekPak	www.tekpak.com	
Zippertubing	www.zippertubing.com	EMI/heat shielding

Jack Browne/Microwaves & RF

The Basics of **Radar Technology** (Part 1)

By Peter Matthews, *Senior Technical Marketing Manager, Knowles Precision Devices*

Explore the foundational principles behind radar technology and how these systems are engineered to meet the demanding needs of modern applications. This article sets the stage for a deeper look at radar's evolution and its impact on RF components.

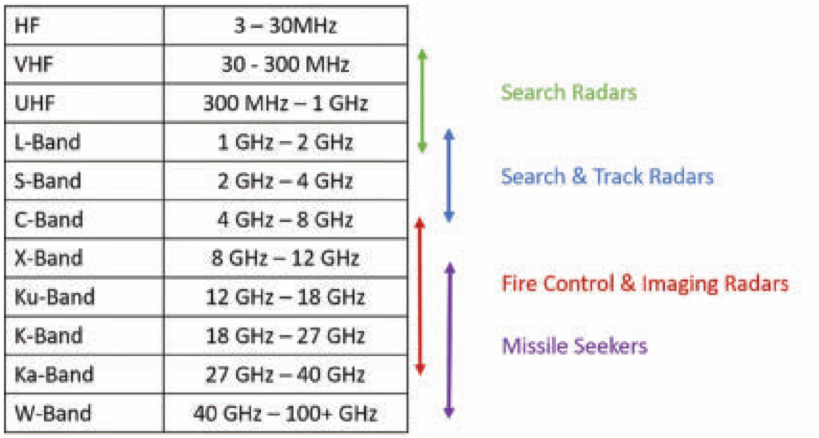
WITH A STRONG grasp of radar fundamentals comes a foundation for understanding the significance and implications of current trends and innovations in radar technology. Here we'll cover what radar systems do, what information they can yield, and review their functional components. This includes range equations and variable considerations for searching, tracking, fire control, and imaging radar.

Radar Functions and Design Parameters

Radar systems detect objects and find their locations in space by transmitting electromagnetic waves in the radio-frequency (RF) and microwave ranges. The system emits short bursts of energy and detects the echo signal returned by objects of interest. That echo signal can provide information on target detection, range, angles, size, speed, and object features.

While ranges differ by application, radar applications span VHF (30 to 300 MHz) to the Ka-band (26.5 to 40 GHz) *(Fig. 1)*.

The radar range equation is used to calculate the maximum range for target detection. Critically, it can be manipulated to understand how different factors are interrelated in the radar system and to implement application-specific design requirements. For example, to find signal-to-noise ratio (SNR), factor in system noise and how the function of interest impacts gain.



HF	3 – 30MHz
VHF	30 - 300 MHz
UHF	300 MHz – 1 GHz
L-Band	1 GHz – 2 GHz
S-Band	2 GHz – 4 GHz
C-Band	4 GHz – 8 GHz
X-Band	8 GHz – 12 GHz
Ku-Band	12 GHz – 18 GHz
K-Band	18 GHz – 27 GHz
Ka-Band	27 GHz – 40 GHz
W-Band	40 GHz – 100+ GHz

1. Radar applications span a wide range of frequency bands, from VHF to Ka-band. Images courtesy Knowles Precision Devices

The basic form of the radar equation is:

$$S/_N = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 R^4 k T_s B_n L}$$

Where:

- P_t = power transmitted by the radar
- G_t = gain of the transmitting antenna
- G_r = gain of the receiving antenna
- σ = radar cross-section (RCS) of the target, which represents the target's reflectivity
- λ = wavelength of the radar signal
- R = range to the target
- k = Boltzmann's constant
- T_s = system temperature
- B_n = noise bandwidth of receiver
- L = representation of the system losses due to both the transmitting and receiving processes and the medium through which the radar signal travels

What follows is how we can apply elements of this equation to contextualize different types of radar systems and their requirements by understanding what drives gain under various mission scenarios.

What Drives Gain in Search Radar Systems?

Search radar is designed for object detection. SNR plays a significant role in ensuring the radar system can "hear" the signal reflected by an object regardless of background noise, like picking out a conversation in a crowded room. For search-related applications, the radar system is directed around a space to explore and determine what's there. SNR must factor in the size of the space and how long the system "looks" in any one direction.

$$S/_N = \frac{P_{av} A_e t_s \sigma}{4\pi \Omega R^4 k T_s L}$$

Where:

- P_{av} = average power
- A_e = antenna area
- t_s = scan time for Ω
- σ = radar cross-section
- Ω = solid angle searched
- R = target range
- k = Boltzmann's constant
- T_s = system temperature
- L = system loss

To enhance the SNR in search applications, increase average power, antenna size, scan time, and/or target cross-section. SNR is negatively impacted by increasing the solid scan angle of the search area, target range, system temperature, and/or system losses.

Drivers of Gain in Search-and-Track Radar Systems

Search-and-track radar systems incorporate search; however, they continue to follow the target and offer location updates over time. With this form of the radar equation, it's safe to assume the target was located using search, so scan time and scan angle are less important:

$$S/_N = \frac{P_t A^2 \sigma}{4\pi R^4 \lambda^2 k T_s B_n L}$$

Where:

- P_t = transmitted power
- A = antenna size
- λ = wavelength
- σ = radar cross-section
- R = range
- k = Boltzmann's constant
- T_s = system temperature
- B_n = noise bandwidth of receiver
- L = system losses

To enhance the SNR in tracking applications, increase transmitted power, antenna size, and/or target cross-section. SNR is negatively impacted by increasing target range, wavelength system temperature, receiver noise bandwidth, and/or system losses.

What Drives Gain in Fire Control-and-Imaging Radar Systems?

Because it's akin to tracking radar in principle and in concept, fire control-and-tracking radar systems are often combined. The main difference is that fire-control radar places additional emphasis on increasing performance via range resolution, angular resolution, and/or velocity resolution.

Increasing Radar Performance Through Range Resolution

The range-resolution variable helps us understand the system's ability to distinguish between objects. It's the minimum distance between two objects while still identifying them separately. For a continuous-wave (CW) pulsed radar, for example, range resolution depends on pulse length.

The shorter the pulse length, the smaller the distance the system can distinguish. Pulse length is inversely proportional to pulse bandwidth.

Range resolution can be defined as:

$$\Delta r = \frac{cT}{2}$$

$$\Delta r = \frac{c}{2B}$$

Where:

- Δr = range resolution
- c = velocity of wave (e.g., the speed of light)
- T = pulse length in seconds
- B = pulse bandwidth in hertz

Increasing Radar Performance Through Angular Resolution

The angular-resolution variable helps us understand the system's ability to distinguish the distance between two objects at the same range.

Angular resolution can be defined as:

$$S_A \geq 2R \cdot sin\frac{\theta}{2}$$

Where:

- S_A = the angular resolution (i.e., the resolvable gap between two objects)
- R = range to target
- Θ = beamwidth

To reduce antenna beamwidth and resolve smaller distances in a dish array, for example, approximate using:

$$\theta_B \sim \frac{\lambda}{D} \cdot \frac{180}{\pi}$$

Where:

- Θ_B = beamwidth
- λ = wavelength
- D = antenna size

Alternatively, for phased arrays, this can be approximated using:

$$\theta_B \sim \frac{0.886\lambda}{Ndcos\theta}$$

Where:

- Θ_B = beamwidth
- λ = wavelength
- Θ = scan angle of our phased array

Reducing beamwidth and, by extension, improving angular resolution, can be accomplished by reducing wavelength (i.e., increasing frequency), increasing the number of elements in an array, increasing the distance between elements in an array, and by pointing the beam more precisely.

Increasing Radar Performance Through Velocity Resolution

Radar systems can measure velocity via the Doppler effect, which shifts the frequency of the received signal up or down by an amount that's proportional to the radial velocity of the target. Accurate velocity data requires careful waveform processing and canceling signals reflected from objects that aren't of interest and might be in the way.

Velocity resolution in a Doppler radar can be defined as:

$$f_d = \frac{2v_r}{\lambda}$$

Where:

- f_d = Doppler frequency
- v_r = radial velocity
- λ = wavelength

One technique for improving a radar's detection ability is through pulse integration conducted by means of fast Fourier transform (FFT), where integration time can drive velocity resolution via the following:

$$\Delta v_r \sim \frac{\lambda}{\Delta t}$$

Where:

- Δ_{vr} = velocity resolution
- λ = wavelength
- Δ_t = integration time

You can improve velocity resolution by increasing integration time or decreasing the wavelength of the transmitted waves by increasing frequency.

Effectiveness is considered a combination of resolution and accuracy. Changing some of these parameters *(Fig. 2)* may improve resolution but decrease SNR or vice versa. The role of bandwidth changes depending on the radar application.

Missile-Seeking Radar Systems

Radar systems can direct missiles using semi-active or active radar homing. With semi-active radar homing, a platform-based radar system illuminates the target, and the missile radar receiver interprets the echoes to find it. In active radar homing, the missile contains both the transmitter and receiver.

Whether active or semi-active, missile seekers have SNR needs like those of tracking radar systems and high-resolution requirements like those of fire-control radar systems.

Whether active or semi-active, missile seekers have SNR needs like those of tracking radar systems and high-resolution requirements like those of fire-control radar systems. That said, it's important to increase angular resolution without increasing antenna size, which requires increasing the operating frequency from Ku-band to Ka-band.

Functional Blocks of Radar Systems

One approach to understanding radar design is to look at the system as a combination of functional blocks that perform key roles *(Fig. 3)*. These functions may be combined or separated across circuits.

The following are the main functional blocks in a radar system:

Waveform generators produce low-power waveforms that can be pulsed or altered in frequency or phase when necessary. Modern waveform generators leverage digital waveform generation (DWG) technology and closely resemble arbitrary waveform generators (AWGs) in function. Here, waveforms are defined by a mathematical model. Using direct digital synthesis (DDS), a digital-to-analog converter (DAC) can generate analog waveforms from digital inputs.

Amplifiers/transmitters take the signal from the waveform generator and increase its power (e.g., hundreds of watts to megawatts).

Duplexers take the high-power signal from the transmitter, ensuring that transmitted and received signals don't collide.

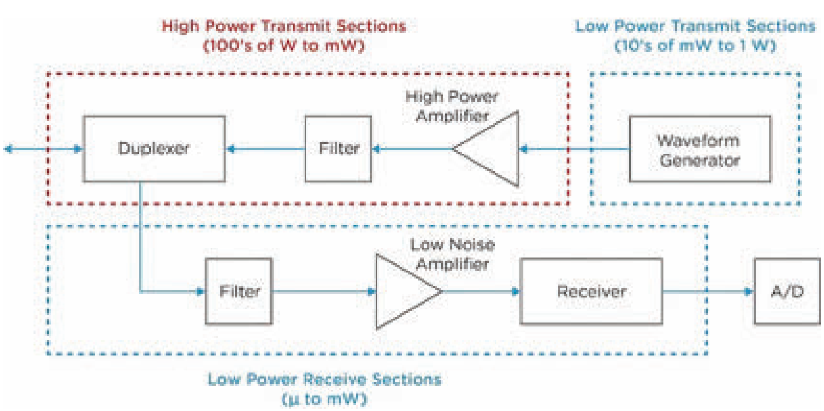
The signal leaves the antenna, finds the target, and is reflected. The antenna is excited by the incoming reflected radiation, and the received signal passes from the duplexer to the *receiver*. The receiver amplifies and cleans up the signal before passing it to the digital domain. Depending on the frequencies and sensitivity requirements of the application, different mathematical models can be applied to best serve the system.

The Evolutionary Path of Radar Technology

Here, we've laid a foundation for understanding the development path of radar technologies. The advancement of RF and digital electronics plus the desire to improve on key metrics have played significant roles in forging that path. In the next segment of this series, we'll take a closer look at the ways the evolution of radar has impacted RF components and component selection. ■

Parameter	Resolution	Key Characteristics
Range	1/BW	Bandwidth
Angle	λ/D	Wavelength, Antenna Size
Velocity (Doppler)	λ/Δt	Wavelength, Coherent Integration Time

2. When it comes to fire-control and imaging radar, primary metric parameters include range, angle, and Doppler velocity.



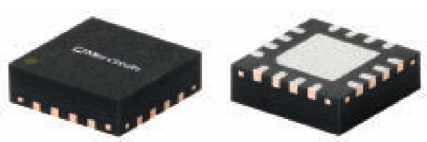
3. These are some of the major functional blocks that play key roles in a radar system.

Waveguide Amplifier Boosts 40 to 60 GHz

Mini-Circuits' model WVA-40603GX+ is a medium-power WR19 waveguide amplifier with +23-dBm output power at 1-dB compression and +24-dBm saturated output power from 40 to 60 GHz. It provides 34-dB typical gain with ±1.5-dB gain flatness across the frequency range and operates from a single voltage supply of +10 to +15 V DC. Ideal for satcom and millimeter-wave test applications, the amplifier features over-voltage and reverse-voltage protection and exhibits 13-dB typical input and output return loss.

MINI-CIRCUITS

https://tinyurl.com/ynljhhb9



Surface-Mount LNA Spans 5.5 to 12.5 GHz

Mini-Circuits' model PMA3-5123+ is a surface-mount-technology (SMT), low-noise amplifier (LNA) with 21.6-dB typical gain from 5.5 to 12.5 GHz. Its typical 1-dB noise figure, +16.8-dBm output power at 1-dB compression (P1dB), and +28.1-dBm output third-order-intercept point (OIP3) combine for wide dynamic range across its wide frequency range. The 50-Ω pHEMT-based MMIC LNA draws only 72 mA from a single +4-V DC supply and is supplied in a QFN-style SMT package measuring 3 × 3 mm.

MINI-CIRCUITS

https://tinyurl.com/yqo94b65

Spring-Loaded Adapters Enhance Connectivity and RF Performance

Offering enhanced performance and connectivity, Pasternack launched a line of spring-loaded adapters, designed for the SMP, SMPM, and SMPS connector series, available in various lengths. The adapters' low voltage standing wave ratio ensures minimal signal reflection, improving the efficiency of RF systems. The range of available lengths provides flexibility for various applications and design configurations, with operation across a frequency range from DC to 65 GHz. Performance is guaranteed under compression, for stable connections even under pressure. Eliminating gaps between the adapter and receptacle optimizes RF performance and accommodates tolerance variations within PCBs, providing a stable and reliable connection that ensures optimal signal integrity and efficiency.

PASTERNACK

https://tinyurl.com/ypjekrvd

Band-Reject Filters Cover from 6 to 20 GHz

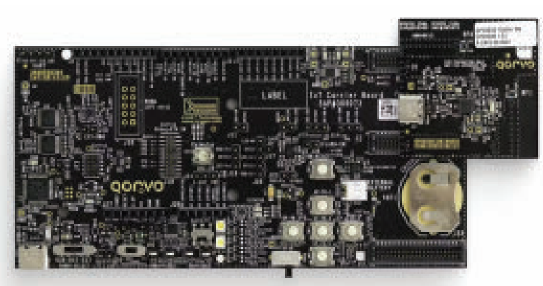
Micro Lambda Wireless released the 120 series of band-reject filters, with standard frequency models available covering 6 to 18 GHz, 8 to 20 GHz, and 6 to 20 GHz. Able to meet the most stringent requirements, they address notch depth and bandwidth requirements. For example, a 6- to 20-GHz unit that has 80-MHz bandwidth will have a notch depth of 40 dBc, and a unit with 40 MHz of bandwidth will have a notch depth of 80 dBc. The operating temperature range is from 0 to +65°C, with extended temperature versions covering from -20 to +70°C and -40 to +85°C available. Package dimensions are 1.4 x 1.4 x 1.4 in., and integrated drivers are available for all models using analog, 16-bit serial, or 12-bit TTL.

MICRO LAMBDA WIRELESS

https://tinyurl.com/yuentyg4

Matter-Compatible SoC Enhances Smart-Home Efficiency

Qorvo introduced the QPG6200L SoC for smart-home IoT devices, leveraging the company's ConcurrentConnect technology with multi-network support for Matter, Zigbee, and Bluetooth Low Energy. With a sleep current of less than 1 µA, it offers high energy efficiency in a scalable turnkey solution, and uses Qorvo's novel low-power wireless connectivity platform to ensure seamless communication and interoperability across multiple wireless standards. It supports multiple protocols on separate channels simultaneously, with a built-in secure element and PSA Level 2 Certification for enhanced IoT security.



QORVO

https://tinyurl.com/ysa4r2we

Source Generates 0.1 to 44.0 GHz

Mini-Circuits' model SSG-44GHP-RC is a wideband signal generator with 1-Hz tuning resolution from 100 MHz to 44 GHz. It delivers output levels from -40 to +23 dBm for CW and pulsed signals (pulse widths as narrow as 0.5 μs) at a 2.92-mm female connector. Harmonics are typically -15 dBc while spurious levels are typically -40 dBc or better. The generator features full software support, with USB and Ethernet interfaces, and operates in swept-frequency and frequency-hopped modes.

MINI-CIRCUITS

https://tinyurl.com/yss9kz77

Wilkinson Power Dividers Designed for FirstNet Applications

Model series 152-305-XXX 50-Ω Wilkinson power dividers from BroadWave are designed for First Responder Network Authority (FirstNet) applications. Available in 2-, 3-, 4-, and 8-way configurations, these power dividers have a typical isolation of 25 dB over a frequency range from 380 to 960 MHz. Nominal insertion loss (above theoretical split) of the 2-way is 0.4 dB, the 3-way is 0.6 dB, the 4-way is 0.7 dB, and the 8-way is 1.0 dB, with an input power of 5 W average at 25°C. The RF connectors are N female; weather-resistant models are also available.

BROADWAVE

https://tinyurl.com/yo52968v

GaAs Sub-GHz Linear Power Amplifier Eases UHF System Development

CML Micro extended its SμRF range of sub-GHz MMICs with a 2-W power amplifier. Optimized for linear performance and high reliability, the CMX90A006 can be used as a final-stage ISM (915 MHz) and SRD (868 MHz) band power amplifier in wireless transmitter applications. Delivering +33-dBm output power at 1-dB gain compression over the 860- to 930-MHz frequency range, the two-stage indium-gallium-phosphide (InGaP) devices are suitable for multi-market applications operating in the license-free bands. Operated from a 2.5- to 5.25-V supply voltage, the CMX90A006 enables system-level optimization using a single-cell lithium battery for portable applications. Fabricated with advanced InGaP HBT process technology, the device attains 52% PAE, 33 dB of small signal gain, and +42-dBm output third order intercept (OIP3) at 26 dBm per tone. Housed in a 4- x 4-mm thermally enhanced VQFN package for space-constrained designs, the RF input port of the device is internally matched to 50 Ω to reduce component count. The EV90A006 evaluation board has an output matching network to optimize performance for a given application.

CML MICRO

https://tinyurl.com/ystqvt6xystqvt6x

Voltage-Controlled SAW Oscillators Target Radar Applications

Addressing mission-critical applications like radar and test & measurement requires specialized components with precise frequency control and ultra-low phase noise. Offering the aerospace and defense market specialized technology for generating precise signals and frequencies, Microchip Technology released the 101765 family of voltage-vontrolled SAW oscillators (VCSOs) designed to deliver ultra-low phase noise. Operating at 320 and 400 MHz, the 101765-320-A VCSO delivers phase noise performance of 166 dBc at 10 kHz offset and a 182 dBc floor. Optimal for radar and instrumentation systems such as active electronically scanned arrays, the 1- × 1-in. hermetic Kovar packaged VCSOs come in supply voltages from 4.75–15.75 V and a supply current of 111 mA. The 101765 VCSOs are also available with MIL-PRF-38534 screening for critical applications where failure is not an option. The 101765-320-A-N-S-TB and 101765-400-B-N-S-TB test boards enable customers to test the parts during the design phase.

MICROCHIP TECHNOLOGY

https://tinyurl.com/yt5qggvq