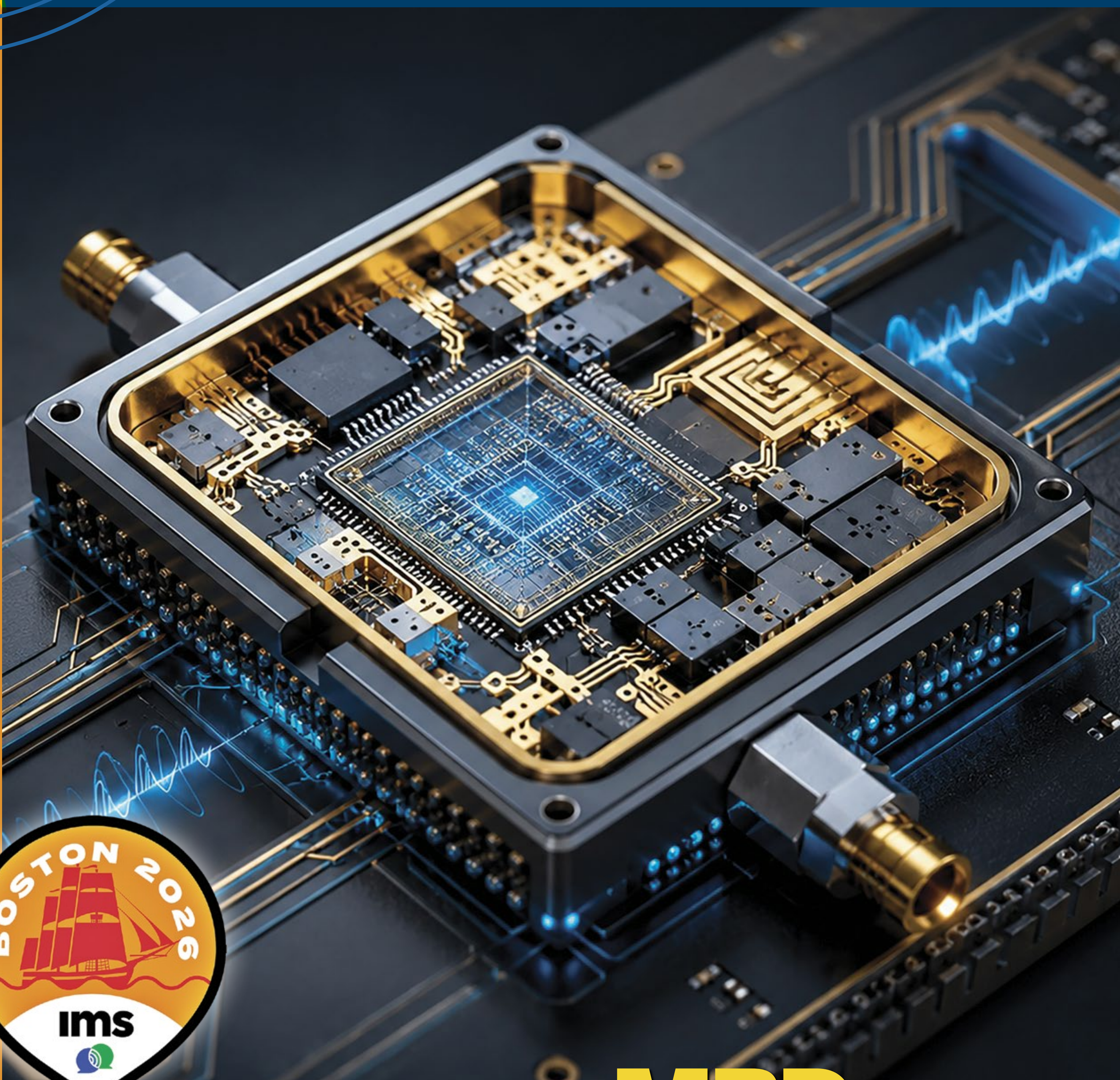
MAY 2026

MICROWAVE PRODUCT DIGEST
& TECHNOLOGIES



BOSTON 2026
IMS

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EDITOR'S CHOICE
Featured Products

Diplexer for Quantum Systems

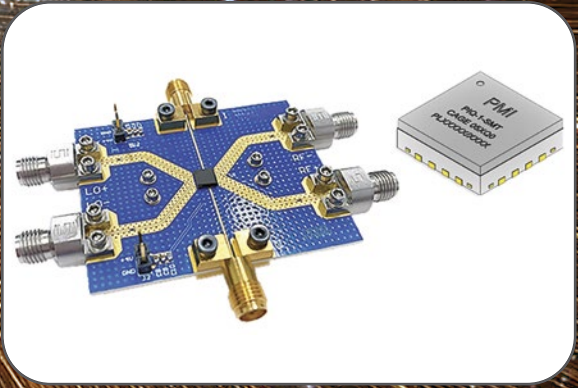
This terminated diplexer for quantum computing systems operating at mixing-chamber temperatures of 10 to 20 mK. It covers DC to 6000 MHz with low insertion loss and good return loss. Rather than reflecting out-of-band energy back toward the qubits, the internal diplexing routes it into a termination, which holds the stopband flat to within ±5 dB and limits the noise that can degrade qubit coherence. Custom designs are available from DC to 20 GHz.

NETWORKS INTERNATIONAL

IQ Vector Modulator

PMI's PIQ-1-SMT is an integrated broadband IQ vector modulator covering 0.1 to 20 GHz on its differential LO and RF ports, with single-ended I and Q baseband inputs from DC to 10 GHz. An on-chip quadrature generator gives multi-octave coverage without external hybrids. Typical performance includes 30 dB of sideband suppression, 0.5 dB of gain imbalance, and 1 deg. quadrature phase error, and -42 dBc carrier leakage. It operates from a single +4 VDC supply and is housed in a 4 by 4 mm QFN package.

PLANAR MONOLITHICS (PMI)



100-MHz OCXO

The REF100ECA-O is a compact 100 MHz oven-controlled crystal oscillator (OCXO) reference for laboratory test and field system use. Phase noise is -156 dBc/Hz at a 10 kHz offset, reaching a floor of -170 dBc/Hz at 1 MHz. It delivers a +7.5 dBm sine-wave output and maintains frequency stability of ±50 ppb from -40 °C to +85 °C. The device runs from a single wide-range supply of 7 to 18 VDC and comes in a rugged all-metal enclosure.

Z-COMMUNICATIONS

High-Power Solid-state Amplifiers

The BBA300-DE500 and BBA300-DE1000 solid-state broadband amplifiers are rated at 500 W and 1000 W, respectively. Both cover 1 to 6 GHz without band switching, eliminating the band changes that slow automated test sequences. The amplifiers target EMC work in automotive, aerospace, and defense, including vehicle component testing, full-vehicle testing, and high-intensity radiated field testing.

ROHDE & SCHWARZ

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EDITORIAL STATEMENT *of* PURPOSE

Microwave Product Digest serves RF and microwave design engineers, research and development engineers, applications engineers and engineering managers. These professionals, working in facilities that serve both the commercial and government markets, are involved with the design, development, application, and use of systems and subsystems, devices, and techniques involving frequencies from RF to light.

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FROM THE EDITOR


Barry Manz

The Speed You'll Never See

Every new generation of Wi-Fi arrives carrying higher data rates than the last. Wi-Fi 5 hit 1 Gb/s, Wi-Fi 6 pushed into the high single digits, and Wi-Fi 7 now advertises a peak near 46 Gb/s. That's more than an order of magnitude in a decade. But a data rate is only as useful as the devices that can act on it, and most of them never will. Few people replace their phones, laptops, and routers in step with each release of the standard, so the installed base trails the specification by years. Set that aside, and a more basic question remains, one the rising numbers rarely invite: how much throughput does anyone actually need?

Past roughly 10 Gb/s, the practical benefit of going faster begins to fade. It is hard to picture a home or office where many devices are contending for the air at once, where a user would notice the jump from 10 to 20 Gb/s. None of this makes the advances hollow, since each new version also brings real gains in efficiency, latency, and the handling of crowded environments. It is only that the headline figure, the one number every launch is built around, may be the part that matters least.

Start with that number. Reaching it requires 320-MHz channels, the highest modulation order, and sixteen spatial streams operating simultaneously. No client device implements sixteen streams. Phones implement two. Laptops implement two, occasionally three. The advertised rate describes a configuration that exists in no product a consumer can buy, decoded by a receiver that has never been built into anything you would carry. It is better understood as a theoretical upper bound than as a specification any user will meet.

The asymmetry is structural and worth stating in engineering terms. An access point can support eight or more antenna chains, mains power, and a thermal envelope that allows it to sustain the highest modulation continuously. A handset has two antennas if you are lucky, a battery to protect, and a front end built to a bill of materials. The advertised throughput scales linearly with spatial streams, so a two-stream client starts at one-eighth of the headline before any other impairment enters the picture. Everything after that only widens the gap.

Consider the modulation. Wi-Fi 7's signature feature is 4096-QAM, which packs 12 bits per symbol and delivers roughly 20% more throughput than 1024-QAM. However, 4096-QAM requires a signal-to-noise ratio of 42 dB, versus 31 dB for 1024-QAM in Wi-Fi 6 and 25 dB for 256-QAM in 802.11ac. That is not a marginal increase: Run the budget for a 160 MHz channel, with a thermal noise floor near -92 dBm, and a typical receiver noise

From the Editor, *continued on page 27*

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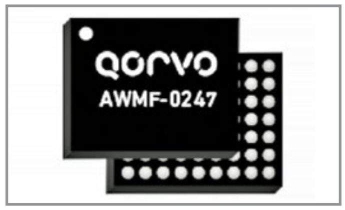


Beamformer IC

The Ku-band AWMF-0247 adds TDD half-duplex capability to the company's beamformer IC portfolio for LEO and NTN terminals, enabling transmit and receive in a single device. This allows flat panel satcom terminals to use a shared antenna aperture, reducing system size and component count. It has four elements covering the 13.75 to 14.5 GHz transmit band and 10.7 to 12.75 GHz receive band, as well as adjustable PA bias.

QORVO

EMF Emissions Tester

The SignalShark EMF is a portable system for monitoring electromagnetic field emissions. It performs frequency-selective EMF measurements from 9 kHz to 29.5 GHz using isotropic antennas to calculate total field strength. The SignalShark EMF is tailored for outdoor use in harsh environments and features easy setup, automatic measurements, and a 5G extrapolation tool for evaluating signal levels against public safety limits.

NARDA SAFETY TEST SOLUTIONS

3-way Power Divider

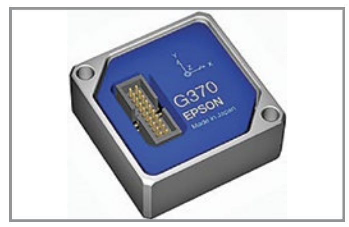
The 152-297-003 3-way power divider commercial distributed antenna systems, military antenna sharing, and test applications. It has a frequency range of DC to 4 GHz and is rated at 10-W average power. It has a maximum VSWR of 1.5:1, +/- 0.5 dB of insertion loss, and an operating temperature range of -0° C to +70° C. Other dividers in the family include 2, 3, 4, 5, 6, and 8-way configurations.

BROADWAVE TECHNOLOGIES

4x4 Butler Matrix

The KBM90240725 Butler matrix employs 90 deg. and 180-degree hybrid couplers. Frequency coverage is 2.4 to 7.25 GHz, and is well suited for beamforming, 5G NR, Wi-Fi 6, Wi-Fi 6E, MIMO links, and multi-path simulation and performance evaluation. It measures 4.75 in. x 3.46 in. x 1.11 in and has female SMA coaxial connectors.

KRYTAR



Internal Measurement Unit

The M-G370PDT IMU measures 24×24×10mm and weighs 10 g. It features gyroscopes with 0.8°/h bias instability and 0.03°/√h angular random walk, plus accelerometers with ±8G/±16G ranges. Power consumption is 16 mA at 3.3 VDC, and its output is via SPI/UART interfaces. The IMU is calibrated for -40° C to +85° C operation and is designed for satellite, UAV, and navigation applications..

EPSON

SSM and SMPN Cable Interfaces

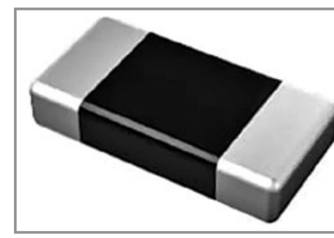
These 6-in. assemblies pair SMA and SMPM interfaces with 0.047 or 0.085 in. flexible cables for quantum computing, test and measurement, and defense systems. They maintain a maximum magnetic susceptibility of 10 with no field distortion. Supporting frequencies up to 40 GHz, these assemblies offer reliable signal integrity in environments where magnetic interference cannot be tolerated.

SAMPHENOL SV MICROWAVE

2.5 GHz Limiter

The LM-10M2D5G-100CW-1KWP-SFF RF limiter operates up to 2.5 GHz and can handle an input power up to 100 W CW and 1 kW peak (1% duty cycle, 1 µs maximum pulse width) and has an insertion loss of 0.5 dB and a recovery time of 2 µs. The package size is 1.8 in. x 0.6 in. x 0.4 in., and it uses female SMA connectors.

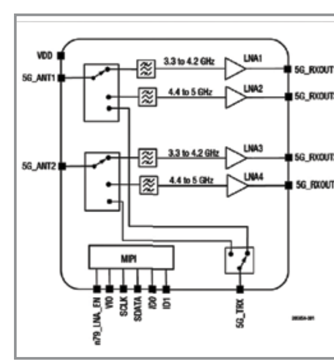
QUANTIC PMI



Ferrite Chip Beads

The CRFB Series ferrite chip beads provide EMI suppression with impedance values from 10 to 2000 ohms at 100 MHz and current ratings up to 10 A. Available in surface-mount packages with tin-lead over nickel terminations, they operate from -55° C to +130° C and withstand soldering temperatures up to 265°C for 10 s.

VANGUARD ELECTRONICS



LNA for 5G NR Bands

The SKY53754-11 LNA filter module supports 5G NR bands at 3.3 to 4.2 GHz and 4.4 to 5 GHz. Using advanced SOI process technology, it delivers low noise figure performance with integrated filtering to attenuate out-of-band blockers while maintaining low insertion loss. It is housed in a 2.8 × 2.6 × 0.7 mm, 21-lead SMT package and requires no external DC blocking capacitors.

SKYWORKS

Benchtop Attenuators

These benchtop programmable attenuator assemblies operate from 400 to 8400 MHz, including the wireless, ISM, and lower microwave bands. Both deliver 0 to 95 dB of attenuation in 1 dB steps and are rated for RF input power up to +24 dBm. Model 50BA-061-95 has two attenuators and shows the current settings on the front panel, where manual levers let the operator jog each one up or down by hand. Model 50PA-1322 is available with up to nine attenuators and adds a front-panel keypad and an Ethernet address on the display, so the assembly can be addressed and controlled over a network in an automated test setup. The two cover the common bracket of attenuator use, from manual bench work to programmatic control of multiple channels.

JFW INDUSTRIES

Dual-Band GNSS Positioning in a 20 mm Patch

The GVLB208 Series is a dual-band GNSS L1/L5 stacked patch antenna and the first in a new family of ultra-compact parts. In a 20 x 20 x 8 mm ceramic footprint, it delivers concurrent L1/L5 support and stable right-hand circular polarization for centimeter-level positioning usually associated with larger antennas. The single-feed stacked patch design reduces multipath interference, with peak gain up to 1.5 dBi, roughly 50% efficiency across both bands, and an axial ratio near 4 dB. It supports GPS, Galileo, GLONASS, and BeiDou. The passive GVLB208.A uses a pin mount optimized for a 70 x 70 mm ground plane, while the active AGVLB208.A adds electronics and filters with an I-PEX MHF I connector for delivery robots, UAVs, and asset tracking.

TAOGLAS

Hybrid Couplers Cover 10 to 40 GHz

The ULTRA+ 90-deg. hybrid couplers deliver 3 dB of coupling over 10 to 40 GHz in compact packages. The ULTRA3100400 and ULTRA3100400K both operate from 10 to 40 GHz with amplitude imbalance of ±0.8 dB, phase imbalance of ±18 deg., isolation greater than 14 dB, maximum VSWR of 1.6, and insertion loss under 1.5 dB. Both handle 20 W average and 3 kW peak and serve splitting and combining in amplifiers, switching circuits, and antenna beam-forming networks. The ULTRA3100400 uses 2.4 mm female connectors and the ULTRA3100400K uses 2.9 mm (K) female connectors. The package measures 1.10 by 0.86 by 0.50 inn. And has an operating temperature range of -54° C to 85° C.

KRYTAR

Switch Boxes for Test Integrators

Two new standardized switch boxes give test system integrators use configurations in place of custom builds. The RF2037 covers DC to 6 GHz with six electromechanical coaxial latching SPDT switches. The RF2038 extends to DC to 26.5 GHz and carries six switches in a mixed arrangement, four SP6T units and two terminated SPDT units, for denser routing at the higher frequency. Both target low insertion loss and high power handling, and both are controlled remotely over a web interface and an API. The two boxes suit production testing, MIMO systems, and automated test setups in telecom and mobile device manufacturing, where off-the-shelf switching shortens deployment time.

RANATEC

S-Parameters Without a Full VNA

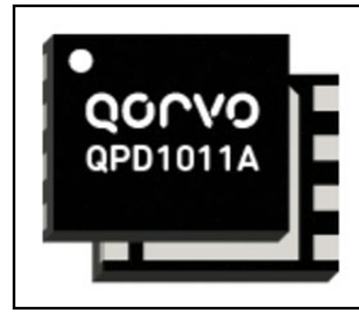
The BFx-02 Frequency Extension Base performs millimeter-wave S-parameter measurements without a full vector network analyzer in the extension path. It acts as a coherent RF and LO source paired with an IF processing engine, driving millimeter-wave frequency extenders and ratioing the test and reference IF they return to compute S-parameters. Because the extenders carry the reflectometer and conversion stages, the measurement front end moves out to the extender. The BFx-02 covers 4 to 20 GHz with RF output up to +20 dBm, holds level over long cable runs, and works with extenders from any vendor, giving production floors a lower-cost path to parallel test stations.

COPPER MOUNTAIN TECHNOLOGIES

High-Speed Acquisition Platform

The DAS1820 is a portable two-slot version of its DAS1800 high-speed data acquisition system, keeping the larger unit's architecture and analysis capabilities in a package that weighs about 5 kg with a battery and two modules. The slots take the same plug-and-play modules, swappable without factory recalibration, allowing up to eight isolated universal channels or 16 multiplexed channels. Sampling is 1 MSa/s at 16-bit resolution, and the high-voltage module is rated to ±1500 VDC. A 12-in, touchscreen, embedded scripting, and a power analysis module are included. The platform targets power, industrial, automotive, and aerospace sectors where several high-speed channels must be logged at once in the field.

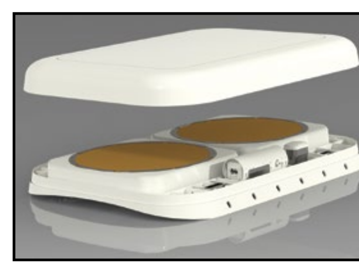
B&K PRECISION



GaN HEMT Covers HF Through L-Band

The QPD1011A 7 W (P3dB) GaN-on-SiC HEMT operates from 30 to 1200 MHz, covering HF through L-band in a single device. It is input-matched to 50 ohms through an integrated network for wideband gain and power across the full range, while the output is matched on the board so the designer can tune power and efficiency for the portion of the band in use. Typical gain is 20.8 dB. The device is housed in a a 6 x 5 mm leadless SMT package, and a Modelithics nonlinear model supports simulation. Applications include military and civilian radar, land mobile and military radio, test instrumentation, EW, and wideband or narrowband amplifiers.

QORVO



Multi-Orbit Aircraft Antenna

The ThinAir Nexus is a multi-orbit aircraft antenna that supports GEO, MEO, and LEO constellations from a single installation, fitting that capability into a package the size of the single-orbit ESAs. It is built on ThinKom's patented VICTS technology, a low-power mechanically-steered approach with 65 million hours of on-wing operation. The low power draw lets it run gate-to-gate in extreme climates without the thermal problems that can affect ESAs. The hardware already works with SES Open Orbits, Hughes JUPITER In-Flight, Telesat Lightspeed, and other sovereign networks, with new networks added through a modem swap.

THINKOMS

FR3: The Band Everyone Wants

by **Barry Manz,** ***Editor***

The 6G community has effectively settled the spectrum question, and the answer is the 7 to 24 GHz range (**Figure 1**). 3GPP calls it Frequency Range 3 (FR3), while marketing departments have taken to calling it the "golden" band, which says more about the marketing departments than about the spectrum. The band is the last large block of cellular-suitable spectrum that isn't already saturated by something else. The technical work is solvable. The coexistence work is harder.

Why this band and not another

Below 7 GHz, every desirable slice is allocated, refarmed, or aggregated. Above 24 GHz, the millimeter-wave deployment record from 5G has been chastening: high path loss, brutal building penetration, and a coverage economics problem that no amount of beamforming has solved cleanly. FR3 sits between these fail-

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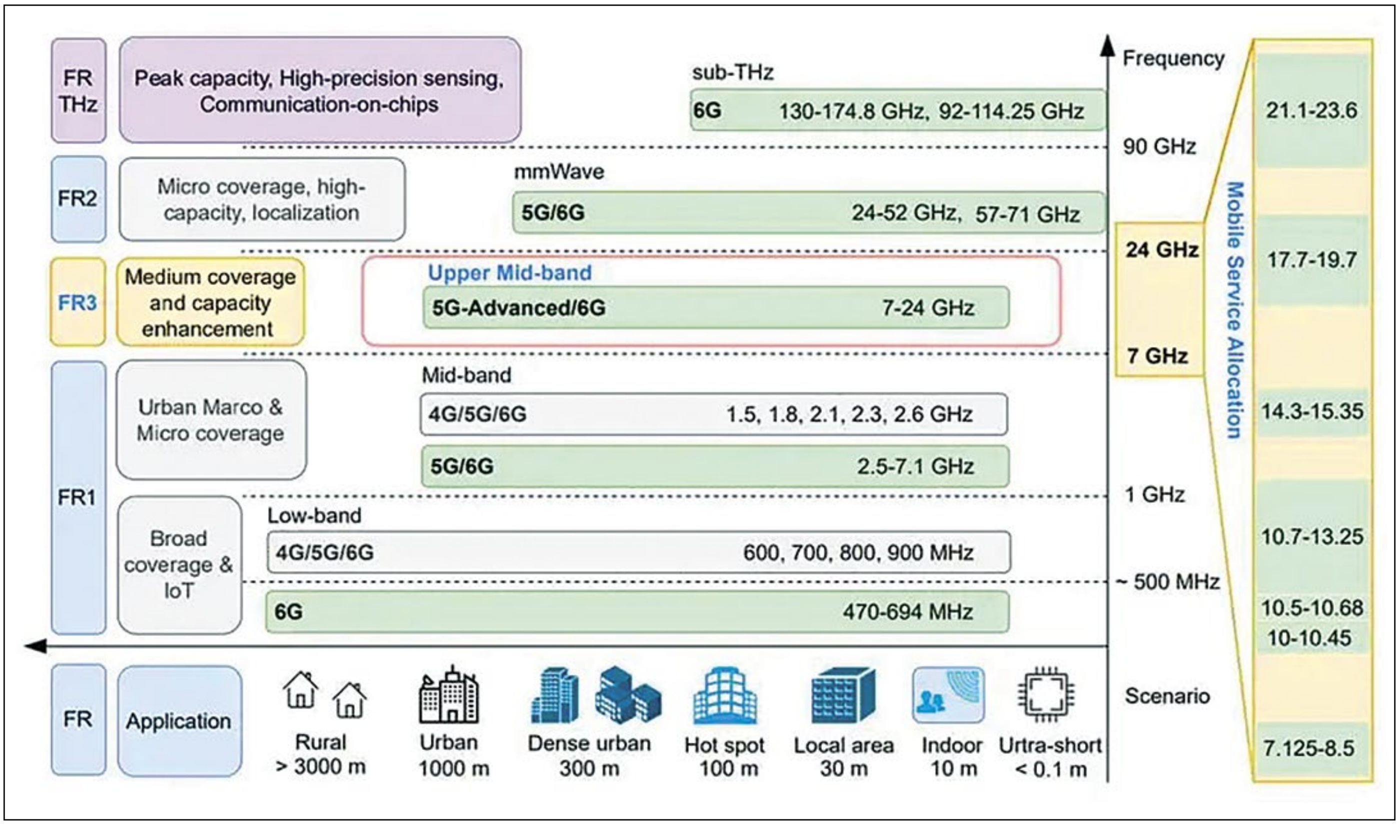

Figure 1—**FR3 occupies the 7 to 24 GHz upper mid-band, positioned between the sub-7 GHz FR1 range used through 5G and the FR2 millimeter-wave range above 24.25 GHz. The bands under study for IMT identification sit within this span rather than filling it continuously.** *Source: RFpage.com arxiv.org*

continued from page 7

ure modes. At the lower end near 7 GHz, propagation is close enough to traditional sub-6 GHz cellular that conventional macro deployments remain plausible. At the upper end near 15 to 24 GHz, bandwidth opens up considerably while path loss remains within range of dense urban small cells equipped with larger arrays.

Samsung's analysis frames FR3 as the band that can satisfy both capacity and coverage requirements, with EIRP for FR3 systems needing to be at least 6 dB higher than FR1 systems to match mid-band coverage. That number assumes the operator can use the band, which is where the difficulty starts.

The incumbents

The 7 to 24 GHz range is occupied by, among others, fixed satellite service downlinks and uplinks, Ku-band commercial satellite operations, government and military communications, fixed terrestrial microwave links, Earth exploration satellite service passive bands, radio astronomy bands, and radar systems including military X-band, weather radar, maritime navigation, and synthetic aperture radar.

The Federal Aviation Administration operates microwave links in the 7.125 to 8.4 GHz band to connect air traffic control centers with remote aeronautical radionavigation radars. Defense satellite communications systems use geostationary satellites in this range, with 7.25 to 7.7 GHz allocated for downlink and 7.9 to 8.4 GHz for uplink. Non-federal uses include unlicensed ultra-wideband devices operating in the 7.75 to 8.75 GHz range, covering item tracking, wall-penetrating radars, automotive radars, and wearable technology. The upper portion intersects the satellite Ku-band at 12 to 18 GHz, where commercial satellite systems are the incumbents, including Starlink and every other GEO and NGSO commercial satellite operator currently in service.

None of these incumbents will be evicted. Defense satellite communications operate under treaty obligations and serve mission-critical functions that cannot be replicated on alternative bands. Earth exploration satellite service passive allocations are protected under ITU Radio Regulation 5.340 with all emissions prohibited. Radio astronomy carries similar protections. Fixed satellite service operators have billions of dollars of orbital assets that will not relocate to accommodate a terrestrial mobile system. The only path forward involves sharing.

WRC-27 and what's on the table

The 2027 World Radiocommunication Conference is scheduled for October 18 through November 12, 2027, in Shanghai, the first time the conference has been held in the Asia-Pacific region. Agenda Item 1.7 will consider IMT identification for three specific portions of the upper mid-band: 4.4 to 4.8 GHz in Regions 1 and 3, the 7.125 to 8.4 GHz range with regional variations, and 14.8 to 15.35 GHz globally.

The FCC's IWG-2 advisory group preparing the

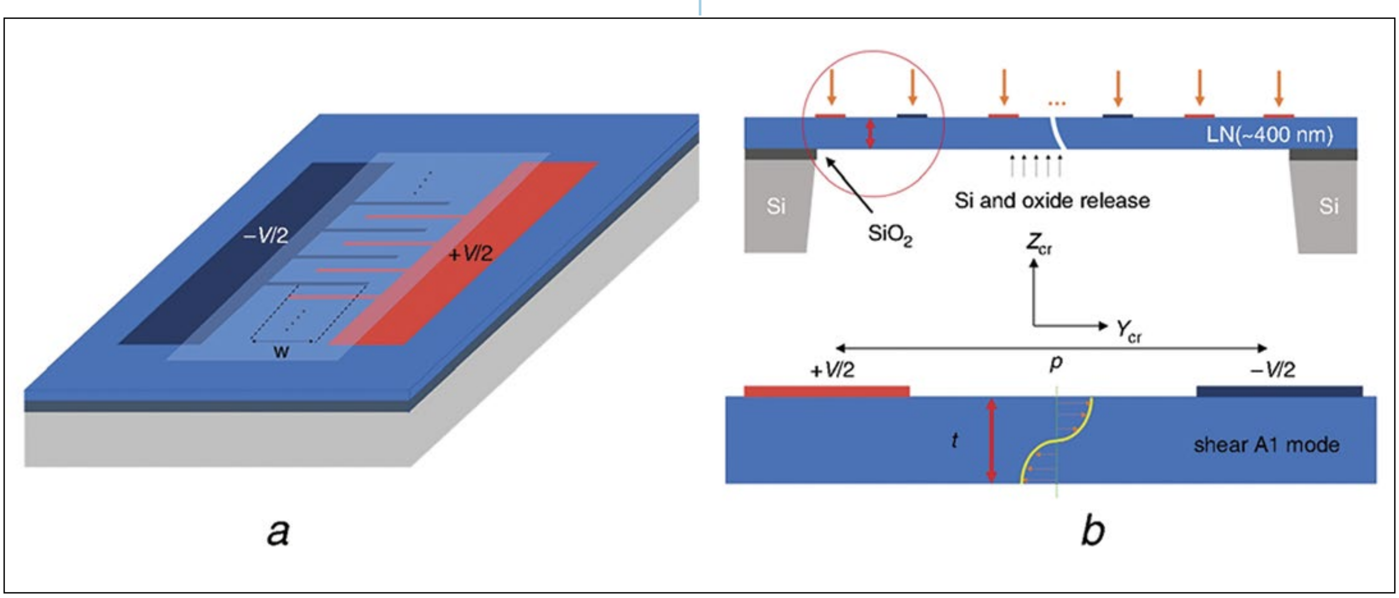

***Figure 2*—An XBAR excites a bulk acoustic wave through the thickness of a suspended lithium niobate membrane using interdigitated electrodes on a single surface. Because resonant frequency is set by membrane thickness and mode order rather than electrode pitch, the structure reaches FR3 frequencies that SAW and FBAR devices cannot.**

Source: 5 GHz laterally-excited bulk-wave resonators (XBARs) based on thin platelets of lithium niobate, V. Plessky, et al, Institution of Engineering and Technology.

U.S. position has been unable to reach consensus on Agenda Item 1.7. The pro-IMT view is supported by CTIA, AT&T, Ericsson, GSMA, Nokia, Qualcomm, T-Mobile, and Verizon. A more cautious view is supported by Apple, Boeing, Broadcom, Charter, Comcast, Lockheed Martin, Planet, and the Satellite Industry Association, among others. The European position has been similarly contentious.

The European Commission's Radio Spectrum Policy Group has noted that certain frequency bands being considered for IMT identification at WRC-27, including 4.4 to 4.8 GHz, 7.25 to 8.4 GHz, and 14.8 to 15.35 GHz, may jeopardize usages relevant to the Common Security and Defense Policy or to the EU's space policy. None of this is unusual for a WRC cycle but what is unusual is the scope of equity at stake and the inadequacy of traditional sharing solutions. The conventional approach of geographic exclusion zones around incumbent earth stations does not scale when the incumbent is a low-Earth-orbit constellation.

Where filters fall apart

Whatever WRC-27 produces, the result will not be a clean contiguous block. It will be a set of channelized allocations with hard adjacent-band rejection requirements driven by the need to protect specific incumbent services. That is a filter problem, and at FR3 frequencies it is a problem the existing component ecosystem is not ready for.

Acoustic filters have been the workhorses of mobile front ends below 6 GHz for decades. Surface acoustic wave filters dominate below roughly 3 GHz. Bulk acoustic wave filters, particularly film bulk acoustic resonators, extend the range upward but encounter problems above 10 GHz. Although FBARs are commercially successful, their ultrathin piezoelectric layers, heavy metallization loading, and intrinsic mechanical losses hinder scaling beyond 10 GHz.

An FBAR or film bulk acoustic resonator, is a piezoelectric device in which a thickness-mode bulk acoustic wave resonates within a thin film, typically aluminum nitride, sandwiched between top and bottom electrodes. The resonant frequency is set by the film thickness, so higher frequencies require thinner films. An acoustic mirror or an air cavity beneath the stack confines the energy and sustains a high quality factor, yielding low insertion loss and good power handling below roughly 6 GHz. Above about 10 GHz the film becomes impractically thin, and insertion loss, quality factor, and power handling degrade together.

In contrast, an XBAR (**Figure 2**), or laterally excited bulk acoustic resonator, is a piezoelectric resonator in which interdigitated electrodes patterned on a single surface of a suspended thin-film membrane apply a lateral electric field that excites a bulk acoustic mode propagating through the membrane thickness. The membrane is typically thin-film lithium niobate. The excited mode is the first-order antisymmetric (A1) Lamb mode.

The configuration decouples resonant frequency from electrode pitch. In a SAW resonator, frequency is governed by interdigital transducer pitch, which constrains operation above approximately 3 GHz. In an FBAR, frequency is set by film thickness. In an XBAR, resonant frequency is determined primarily by membrane thickness and mode order, permitting oper-

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ation from 10 to 25 GHz and, using higher-order antisymmetric modes, beyond 100 GHz, while retaining a membrane thickness compatible with available fabrication processes.

Lithium niobate provides high electromechanical coupling, yielding wide fractional bandwidth. The suspended membrane, released with free surfaces on both faces, confines acoustic energy and sustains high quality factor, holding insertion loss low. Periodically poled piezoelectric film, in which alternating poled layers are stacked, extends operation to higher frequencies and higher-order modes. Demonstrated tri-layer periodically poled lithium niobate filters have achieved 2.2 dB insertion loss, 8.5 percent fractional bandwidth, and 49 dB close-in rejection at 19.3 GHz.

DARPA's Compact Front-End Filters at the Element-Level program has funded substantial work on XBARs in suspended thin-film lithium niobate, which can scale beyond 10 GHz and even above 100 GHz while maintaining high electromechanical coupling and quality factor. Recent results from the University of Texas at Austin demonstrate a tri-layer periodically poled lithium niobate filter at 19.3 GHz with 2.2 dB of insertion loss, 8.5% fractional bandwidth, and 49 dB of close-in rejection. An earlier prototype achieved 1.79 dB of insertion loss at 20.5 GHz with out-of-band rejection greater than 14.9 dB across the FR3 band, in a footprint of 0.9 by 0.74 mm^2. These are laboratory results, not production parts, but they suggest that the underlying physics permits acoustic filtering through at least the lower half of FR3.

What is not yet clear is whether acoustic technology alone will be the predominant solution. Electromagnetic alternatives such as ceramic, cavity, and dielectric resonator filters work at these frequencies but bring size and integration penalties that mobile handsets will not tolerate. Tunable filters using BST, MEMS, or YIG technologies offer a partial answer for base stations but introduce their own loss, linearity, and reliability constraints. The likely outcome is a mix: integrated acoustic filters where possible, cavity or dielectric filters at base station level, and aggressive use of digital filtering to clean up what passes through.

The power amplifier question

Power amplifier efficiency degrades with frequency as parasitic capacitance, transit time, and losses in matching networks all scale unfavorably. At sub-6 GHz, gallium arsenide and laterally diffused MOS handle most of the cellular workload. Above 7 GHz, gallium nitride becomes hard to avoid for any application requiring meaningful output power. Power amplifiers have degraded power efficiency at these frequencies, which becomes a design constraint that the rest of the system has to accommodate.

This is pretty good news for the GaN supply chain as MACOM, Wolfspeed, Qorvo, and the smaller pure-play GaN houses have been positioning for this transition for several years. GaN-on-silicon for high-volume base station applications and GaN-on-SiC for higher-performance defense and infrastructure roles

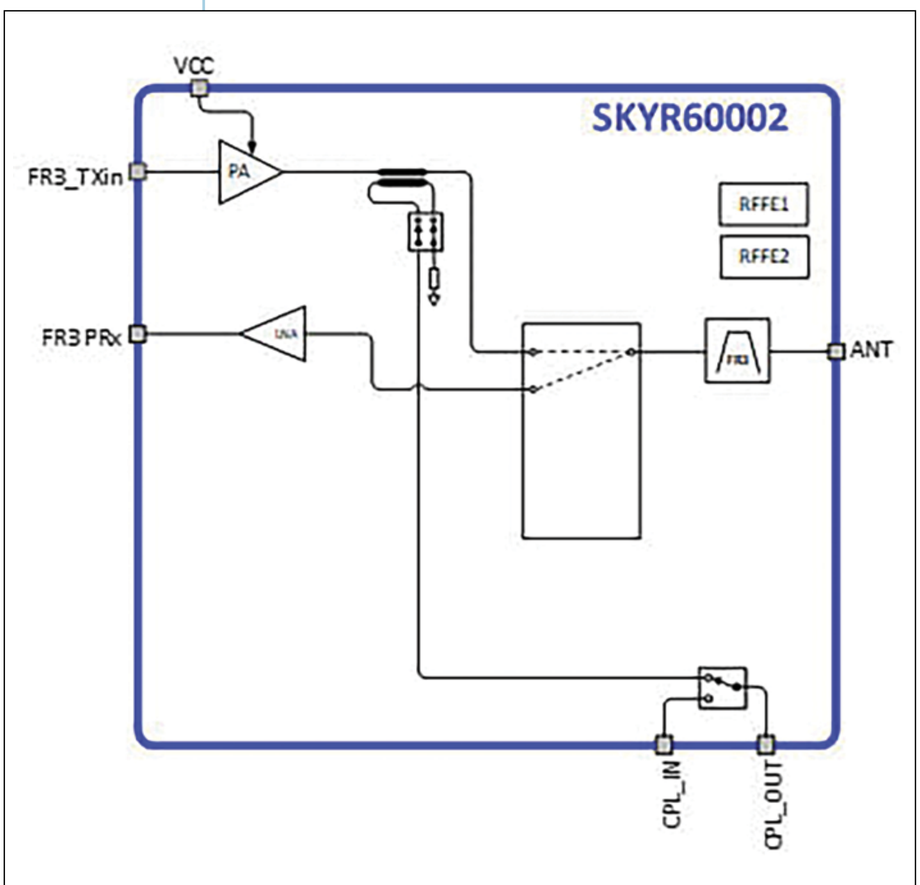


***Figure 3*—The Skyworks SKYR60002 integrates a low-noise amplifier, power amplifier, and filtering for the lower FR3 range from 6.425 GHz to above 7 GHz. MediaTek demonstrated it in a 6G reference design at MWC 2026.**

Source: Skyworks Solutions

cover most of the FR3 PA design space.

At MWC 2026, MediaTek demonstrated a reference design using the Skyworks SKYR60002 (**Figure 3**), a 6G FR3 LNA and power amplifier module with integrated filters designed to support the 6.425 GHz to greater than 7 GHz spectrum in the latest 3GPP standard. The module is specified for high linearity, wide bandwidth, and robust thermal performance.

Antennas and the array problem

Extracting useful capacity from FR3 will require large antenna arrays at both the base station and, increasingly, the user equipment. Samsung's coverage analysis assumes that X-MIMO with extremely large-scale massive MIMO (**Figure 4**) can offer more than twice the average user spectral efficiency of mid-band massive MIMO, but the additional path loss means EIRP at FR3 needs to be at least 6 dB higher than FR1 to match coverage. At 13 GHz, an antenna element is roughly 1.15 cm across, which makes 256-element and 512-element base station arrays practical.

The handset side is harder. A 6G handset using FR3 must accommodate multiple antenna elements at frequencies where the wavelength is comparable to the device thickness. Antenna-in-package solutions developed for 5G millimeter-wave frequencies provide a template, but lower frequency means larger elements, which means fewer elements can fit, which means less beamforming gain to compensate for path loss.

The path that ends in deployment

Assuming WRC-27 produces an IMT identification for at least some FR3 bands, the deployment path runs through dynamic spectrum sharing, large antenna arrays at base stations, spatial nulling toward incumbent satellite earth stations and overhead satellites, and front-end components that do not yet exist in production volume. Each is a serious engineering problem. The collective challenge is whether they can be solved on a schedule compatible with the IMT-2030 timeline, which anticipates initial 6G deployments around 2030.

The honest answer is that nobody knows. The filter work is moving fast but has not reached commercial maturity. The PA work is incremental from a well-understood baseline. The coexistence work is partly technical and partly political, and the political part is harder. WRC-27 will resolve some of the regulatory uncertainties. It will not resolve the question of whether terrestrial 6G can share Ku-band downlinks with LEO constellations without degrading either service to the point of uselessness, and that question may take another decade to settle. In the meantime, FR3 is the band the industry is committed to and the component ecosystem will have to catch up.

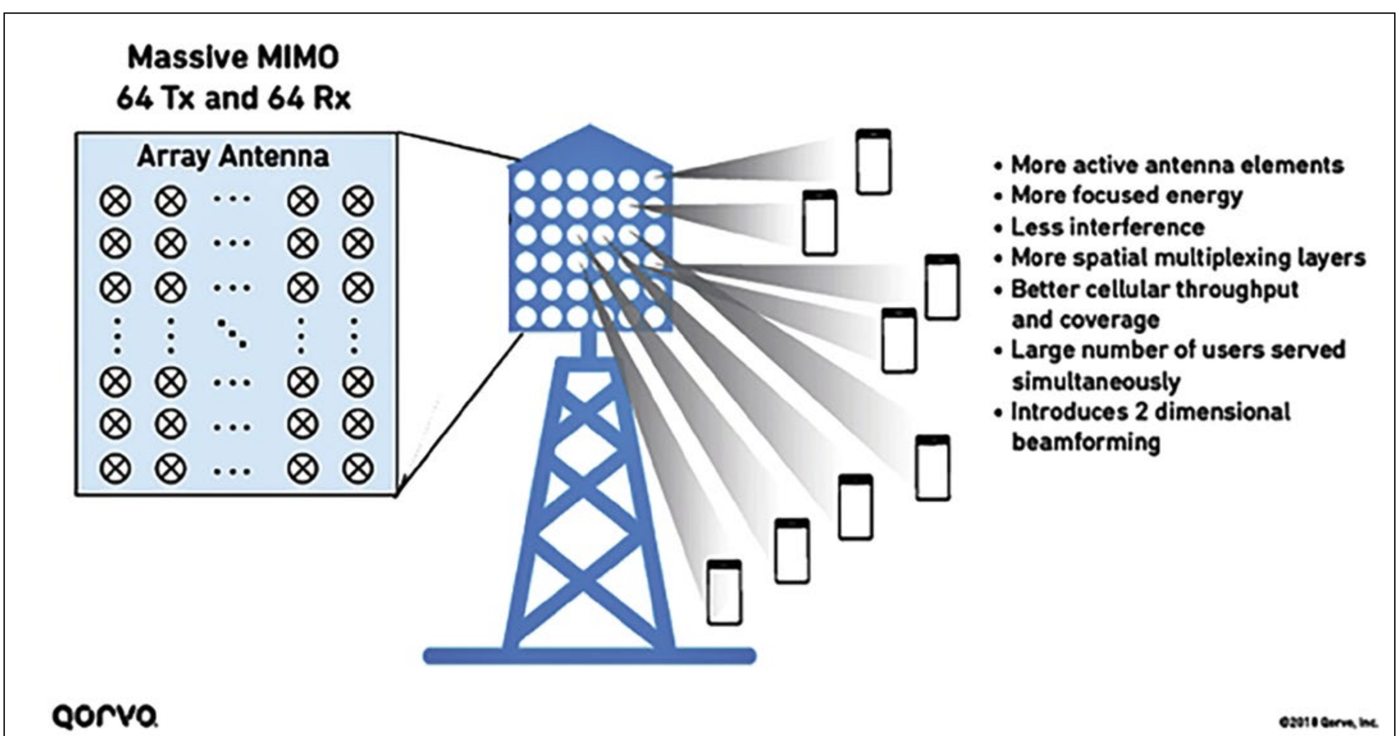


***Figure 4*—Recovering capacity from FR3 depends on large-scale massive MIMO arrays. At 13 GHz an antenna element measures roughly 1.15 cm, which keeps 256- and 512-element base station arrays within a practical aperture.**

Low-loss Flexible Cable

TFlex®-402 is a flexible microwave coaxial cable that offers low loss, strong EMI shielding, and low PIM. Featuring a silver-plated copper-clad steel core, low-density PTFE dielectric, and dual-braid shielding, it ensures reliable RF performance. The rugged FEP jacket suits it for aerospace, defense, and telecom applications in harsh environments.

TIMES MICROWAVE SYSTEMS

150 W Directional Coupler

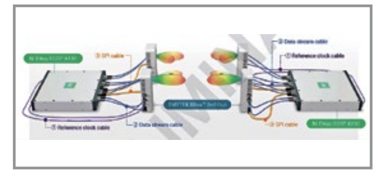
The IPP-8057 150 W directional coupler covers 500 to 2500 MHz, nominal coupling value of 33.0 dB, 20 dB of directivity, less than 0.25 dB of insertion loss, coupled flatness of +/-1 dB, and a VSWR less than 1.25:1. It is available as a dual-directional coupler, single-directional coupler or bidirectional coupler. It can be customized to add multiple forward and reverse power sample ports.

INNOVATIVE POWER PRODUCTS

PIN Diode Switch

The SW8A004 SP8T PIN diode switch operates from 100 MHz to 20GHz with low insertion loss, low VSWR, high isolation, and fast switching. Input ports terminate at 50 ohms in the off state, and features include TTL-compatible driver control and operation from +5 VDC with a negative supply of -12 VDC to -20 VDC. It includes field-replaceable female SMA connectors suitable for microstrip/stripline applications.

AMPLICAL



Phased Array Beamformer

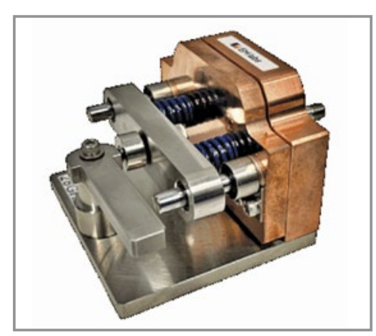
The BBox™ 8×8 Duo is a phased array beamformer that merges capabilities from the BBox One and UD Box series that integrate with existing testbeds. It features dual-polarized 8×8 arrays for FR2 MIMO testing with beam switching through GPIO control. It supports O-RAN-aligned experimentation and provides a scalable platform for massive MIMO, hybrid beamforming, and joint communications and sensing research in FR2 frequency bands.

TMY TECHNOLOGY

Tuner for On-wafer Measurements

The Delta series electro-mechanical tuners are designed for high-frequency on-wafer measurements. Its low profile allows it to be placed within the wafer perimeter with a direct connection between the probe and the tuner. It operates from 24 to 110 GHz with repeatability of 30 dB and weighs 5 lb..

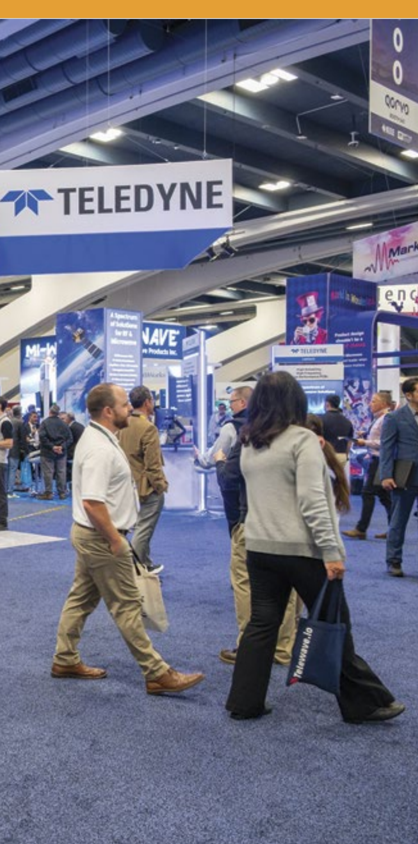
FOCUS MICROWAVES GROUP

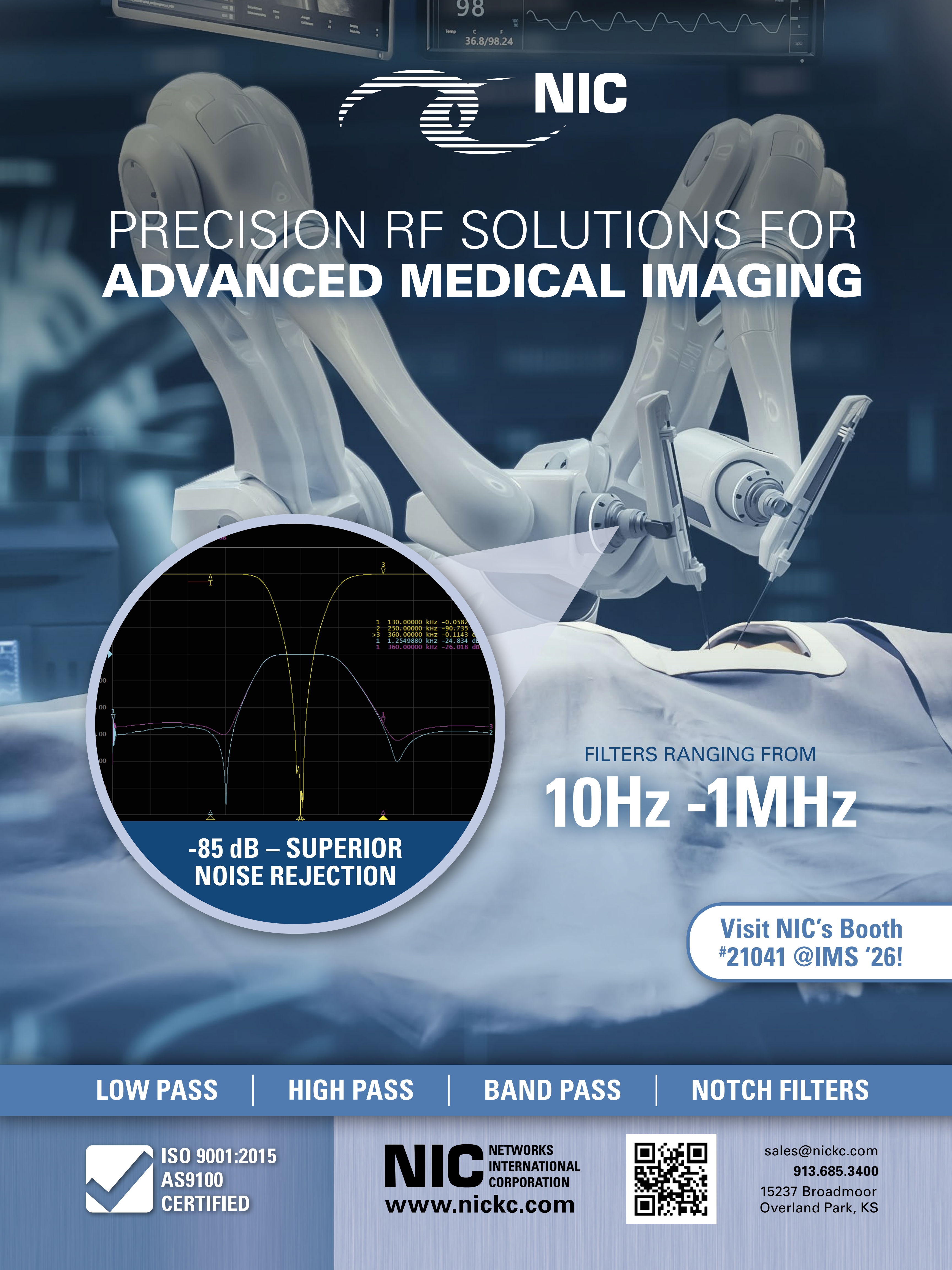


Resonator for Conductivity Testingr

The Split Cylinder Resonator enables accurate conductivity measurement from 10 to 40 GHz for copper foil evaluation in high-frequency circuit boards. It measures conductivity values > 0.8 with good reproducibility and features automatic measurement capabilities.

EM LABS

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A Million Satellites? *Good Luck With That*

by **Joel Levine**, *Co-founder and CEO, RFMW*

The numbers proposed for LEO satellite constellations are beginning to sound almost absurd. Active filings now point toward an orbital population approaching 1 million spacecraft, nearly 2 orders of magnitude above today's count, with the bulk of those proposals filed in the past 6 years. The RF and microwave consequences affect every part of every link, and the resulting interference, coordination, and hardware problems are severe.

Some historical perspective shows how rapidly the population in orbit has grown. In 2000, there were 700 satellites of all kinds in space. There are now more than 15,000, and by 2040, that figure is expected to reach approximately 560,000 based on planned launches and proposals.

SpaceX has already placed more than 10,000 Starlink satellites in orbit and is launching at an average rate of more than 11 per day. Amazon Leo, formerly Project Kuiper, has FCC authorization for 3,236 satellites. China's Guowang and Qianfan (Spacesail) constellations have publicly disclosed plans for approximately 13,000 and 14,000 satellites, respectively.

Even Rwanda, in coordination with E-Space, has filed for 330,320 satellites. Adding all current and proposed filings yields a grand total approaching 1 million satellites, all proposed within the past 6 years. Between 2021 and 2025, more LEO satellites have been launched than in the seventy years prior combined. The U.S. Department of Defense maintains its own LEO assets and is planning a substantial expansion through the Space Development Agency's Proliferated Warfighter Space Architecture, which envisions hundreds of additional spacecraft.

Why One Million Satellites Is a Real Possibility

These projections will almost certainly contract as costs, regulatory friction, and operational realities take effect. For example, the International Telecommunications Union (ITU) enforces strict deployment milestones to prevent spectrum warehousing, the practice of reserving radio frequencies or orbital slots without putting them into use. ITU rules require satellite operators to deploy 10% of their fleet within 2 years, 50% within 5 years, and 100% within 7 years. Operators that miss those targets lose the right to use the allocated spectrum.

Server Farms in Orbit, Because Why Not?

In addition to the constellations themselves, several operators are pursuing space-based data centers. SpaceX has sought regulatory approval for an orbital data-center system that could include large numbers of non-geostationary spacecraft, as has Blue Origin, with several other parties also active

Proponents argue that moving Big Data into orbit is environmentally desirable because it leverages the heat sink of the vacuum space and the high solar flux available in sun-synchronous orbits. By bypassing the land-use and water consumption required for terrestrial cooling, these facilities could enable high-edge computing to process satellite data in real time, eliminating latency and bandwidth bottlenecks associated with downlinking raw data. Whether this dream will eventually be realized at scale remains an open question. For a deeper look at how onboard processing and AI are reshap-

ing LEO architectures, see our previous article, *How AI Takes LEO Satellite Communication to the Edge.*

Conjunction Events and Collision Avoidance

Conjunction events, close approaches between orbiting objects, are now routine. Active satellites from major operators receive thousands of conjunction warnings per year, and SpaceX has reported that Starlink performs hundreds of avoidance maneuvers every six months. With the population growing roughly an order of magnitude over the next decade, the conjunction rate will rise dramatically.

Anti-Satellite Tests and the Growing Debris Problem

Orbital debris is a separate and worsening problem. The 2021 Russian direct-ascent anti-satellite test against Cosmos 1408 created more than 1,500 trackable fragments and many smaller pieces. China's 2007

This graphic illustrates the difference between intra-satellite link ISL communication, which maintains continuous links between adjacent satellites within the same cluster, and inter-satellite link (ISL) communication, which occurs less frequently between satellites in different clusters across orbital planes.
SOURCE: ResearchGate

Fengyun-1C ASAT test created fragments at a higher altitude, where atmospheric drag is negligible, and the debris will remain in orbit for centuries.

India's 2019 Mission Shakti test added more debris, although at a lower altitude where natural decay is faster. Each fragment poses a hazard to active spacecraft, and the cumulative density at popular altitudes raises the prospect of cascade events in which collisions generate fragments that in turn cause further collisions. Researchers refer to this as the Kessler syndrome, and although consensus on its imminence varies, the trend in the fragment population is unambiguous.

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End-of-life disposal practices are being tightened as the population grows. The FCC's 2022 ruling reducing the post-mission disposal window for U.S.-licensed LEO satellites from 25 years to 5 years is a significant change, but enforcement across foreign-licensed systems remains uneven.

Atmospheric Effects of Satellite Reentry

The reentry problem is increasingly tied to atmospheric chemistry. Routine deorbiting of LEO satellites at the end of life injects significant quantities of metallic compounds into the upper atmosphere. Aluminum oxide, lithium, copper, and other constituents are deposited in the stratosphere as the spacecraft ablates during reentry. NOAA and NASA researchers have recently quantified measurable concentrations of these compounds at stratospheric altitudes and are studying potential effects on stratospheric chemistry, including catalytic effects on ozone. The aluminum mass deposited annually by satellite reentry is now comparable to the natural meteoric aluminum flux and is projected to exceed it substantially as constellation populations grow.

Adjacent-Channel Interference and Receiver Desensitization

Interference in this environment can arise in several ways. Adjacent-channel emissions raise the noise floor for nearby users, and out-of-band emissions can leak into protected bands. Intermodulation products are generated when multiple signals pass through nonlinear devices. Strong signals can desensitize receivers even when those signals are outside the desired channel, and poor antenna sidelobe control can radiate energy where it is not intended. Inadequate isolation inside compact terminals can allow energy to leak into receive paths. As constellations grow, the number of cases in which all these problems matter grows with them.

Spectrum Congestion Across Ku-, Ka-, Q-, and V-Bands

LEO broadband systems operate across heavily used portions of the spectrum, including Ku-, Ka-, and increasingly higher-frequency bands for user links, feeder links, gateway connections, and inter-satellite connectivity. They must coexist with GEO satellite networks, terrestrial fixed service, 5G and future 6G infrastructure, radar systems, radio astronomy, military users, aviation and maritime services, and government networks.

Why RF Filters Matter More Than Ever

Filters have always been a major part of interference control strategies. A receiver exposed to strong nearby signals needs filtering that prevents unwanted energy from reaching the low-noise amplifier, mixer, or converter stages. At the same time, insertion loss ahead of the LNA directly degrades the noise figure, so filter design is a trade-off among rejection, loss, selectivity, group delay, power handling, temperature stability, and size.

The tradeoff becomes more severe as terminals become smaller and more integrated. User terminals for LEO broadband and direct-to-device services must operate in small form factors, often using phased arrays rather than mechanically steered antennas, which increases the number of RF channels and places LNAs, power amplifiers, phase shifters, switches, filters, bias networks, digital control, and thermal structures into dense assemblies. Crosstalk, leakage, mismatch, and thermal drift become system-level concerns.

Miniaturized Filters for Phased-Array Terminals

At higher frequencies, specifically Ku band and above, the operating wavelength puts strain on size due to the required spacing between antenna elements. Miniaturization of filters in the key Ku, Ka, Q, and V bands is critical for achieving high-performance arrays. Knowles has utilized high-dielectric-constant, temperature-stable, proprietary ceramics to create a portfolio of standard filters for this application, such as the B291MB0S in Ka band, which is just 4 mm wide. In addition, Nuvotronics uses additive manufacturing techniques to produce miniature interdigital filters at V and Q bands, such as the PSF39B04S downlink filter that measures only 6 mm x 3 mm x 0.1 mm.

LNA Performance Under High-Dynamic-Range Conditions

Low-noise amplifiers sit at the center of this problem because high sensitivity is valuable only if the amplifier also has the linearity and input power-handling to avoid compression from strong off-channel energy. In some cases, the most important LNA specification is not noise figure but its behavior under blocking, adjacent-channel, and high-dynamic-range conditions. A good example is the Marki Microwave ADM-10717PSM, which operates from 18 to 40 GHz, making it useful in broadband receiver front ends where a single LNA can cover multiple bands without the need for external components. It also draws only 6 mA from a 3 VDC supply, has 16.7 dB of small-signal gain, and a noise figure of 2.5 dB.

Power Amplifier Linearity and Spectral Regrowth

On the transmit side, power amplifiers face a different but equally substantial challenge. Satellite terminals must deliver sufficient effective isotropic radiated power (EIRP) while meeting spectral mask and adjacent-channel leakage requirements. Poor amplifier linearity creates spectral regrowth, intermodulation, and unwanted emissions that affect other users.

As the number of constellations increases, frequency reuse and beam density increase, making the performance of transmitter components critical. The CML Micro MMA-374030-M5 is a viable choice for these requirements because it combines 1W RF output power with 22 dB small-signal gain and high linearity and includes an integrated power detector. Its small 5 x 5 mm QFN surface-mount package and ability to operate up to 40 GHz make the designer's job much easier, simplifying assembly compared with chip-and-wire implementations that would require the use of bare die.

Phased Arrays at Constellation Scale

Phased arrays are central to the LEO architecture because moving spacecraft cannot rely on mechanically steered antennas to track ground users, and ground users in turn cannot rely on mechanical tracking of fast-moving satellites. Active electronically scanned arrays at the satellite and user terminal enable continuous tracking, beam hopping among users, and frequency reuse across spatially separated beams. Designing them for production at constellation scale is a different exercise from designing them for traditional military radar applications.

Modern LEO arrays often use a hybrid digital-analog beamforming architecture in which sub-arrays are formed in the analog domain by silicon beamformer ICs, with digital beamforming in the baseband combining or processing those sub-array outputs.

Beamformer IC Technologies and Tradeoffs

Beamformer IC processes include SiGe BiCMOS, RF-SOI, and bulk CMOS at lower frequencies, with each offering different tradeoffs in noise figure, linearity, integration, and cost. PAs at the array edge are typically GaN. LNAs are GaAs pHEMT or SiGe. A single user terminal may contain hundreds to a few thousand RF channels, while a satellite payload may contain tens of thousands.

Qorvo has addressed these challenges with its AWMF-0197, a K-band quad 4×2 receive beamformer IC designed for operation from 17.7 to 21.2 GHz. It supports four dual-polarization radiating elements with integrated beam steering, gain control, polarization flexibility, and receive-path control. It also offers 6-bit phase control and 5-bit gain control, allowing the array to shape and steer its receive pattern while compensating for element-to-element variation.

Optical Inter-Satellite Links and Space Networking

Inter-satellite links convert a constellation from a collection of bent-pipe relays into a routed network. Without ISLs, every connection must route through a ground gateway visible to both the source and destina-

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tion satellites, severely limiting coverage in oceanic and polar regions and increasing latency due to ground hops. With ISLs, traffic can be transmitted entirely in space, and gateway placement becomes an economic and regulatory choice rather than a physical necessity for connectivity.

Optical inter-satellite links operating at approximately 1550 nm have become the dominant technology for high-throughput crosslinks. Starlink has deployed laser ISLs across most of its current-generation systems and reports throughputs of 100 Gb/s or higher per link, while Amazon Leo plans optical crosslinks. Optical crosslinks deliver bandwidth that RF crosslinks cannot easily match and avoid spectrum coordination issues, but they impose stringent pointing, tracking, and acquisition requirements and add a payload subsystem that must be qualified, integrated, and tested (**Figure 1**).

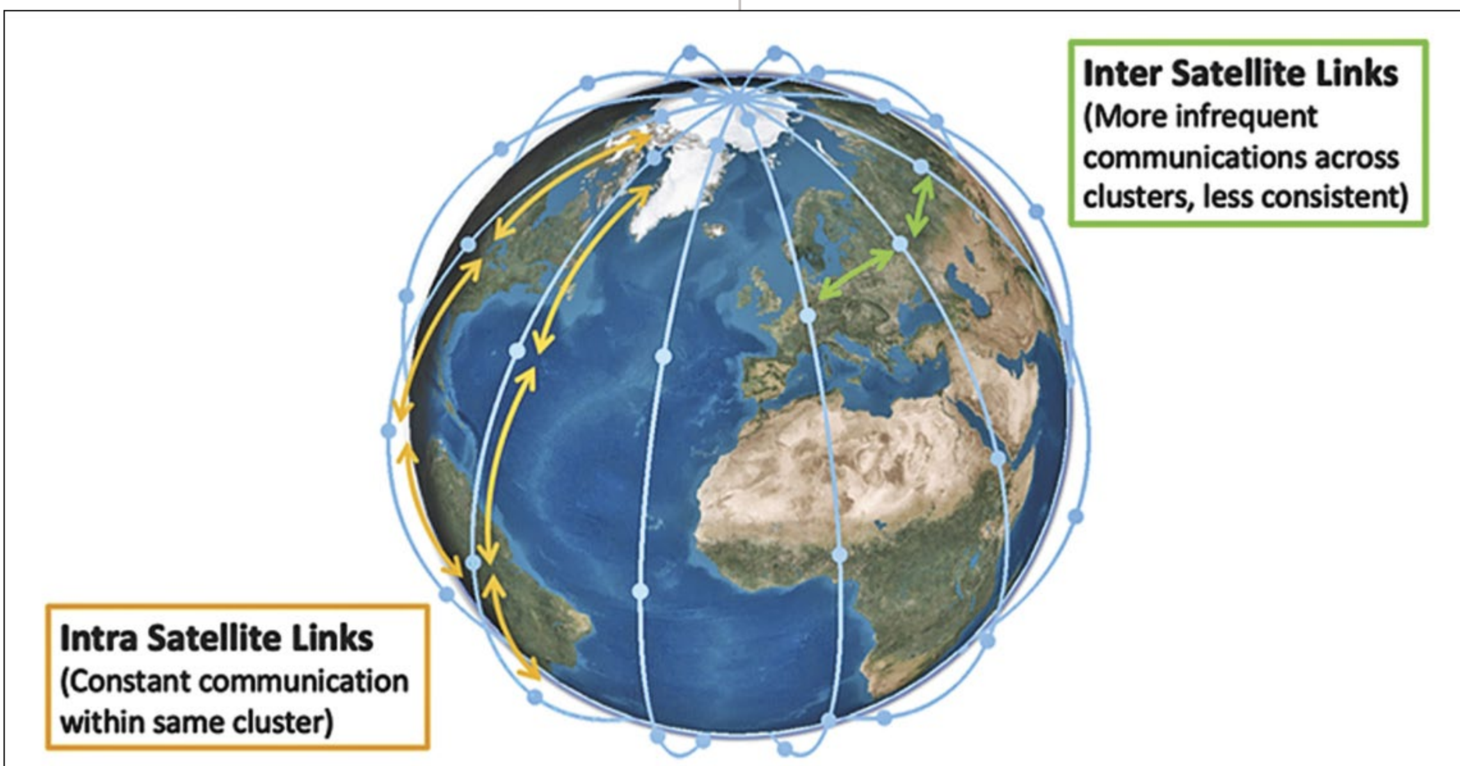

Figure 1**—A SpaceX Falcon 9 launch from Cape Canaveral delivers 29 Starlink satellites to low-Earth orbit, underscoring the rapid growth of satellite constellations and increasing orbital density.**
SOURCE: SpaceX

The RF Challenge of Connecting Directly to Smartphones

Rather than serving a managed terminal with a directional antenna, a D2D system serves an unmodified handset with an omnidirectional antenna, modest transmit power, and battery-driven RF behavior. The link budget must close end-to-end with these constraints, which forces the satellite-side antenna to be enormous. AST SpaceMobile's BlueBird satellites carry phased-array antennas with an aperture approaching 64 square meters, and follow-on designs are still larger. Lynk Global, Iridium, Globalstar, and Starlink's D2D payloads each take different approaches to the same fundamental problem of closing a link to a handset from LEO.

Spectrum Sharing Between Satellites and Cellular Networks

Spectrum for D2D operates in cellular bands. Starlink's arrangement with T-Mobile uses PCS spectrum near 1.9 GHz. AST SpaceMobile's partnerships use AWS and other cellular bands in cooperation with terrestrial mobile network operators. The coexistence problem arises between satellite downlinks and terrestrial base-station receivers operating in the same band.

3GPP Release 17 and Non-Terrestrial Networks

Out-of-band rejection, sidelobe control, and beam steering accuracy all bear on whether terrestrial networks experience desensitization. The 3GPP non-terrestrial network specifications in Release 17 introduced satellite operation as a standardized capability, with Releases 18 and 19 extending capabilities for handheld terminals and IoT devices and improving Doppler and timing handling. The standards work has accelerated the move from proprietary D2D protocols to integration with mainstream cellular, and the resulting RF performance requirements on the satellite payload are correspondingly stringent.

Phase Noise and Beamforming Coherence

Phase noise, spurs, frequency accuracy, and short-term stability affect modulation quality, demodulation margin, beamforming coherence, and adjacent-channel performance. In electronically steered arrays, the local oscillators driving thousands of channels must maintain phase coherence to within a small fraction of a wavelength to preserve beam shape. Distributed reference architectures with low-jitter clock distribution and careful attention to LO leakage and pulling are now standard practice in array payloads.

Chip-Scale Atomic Clocks and Precision Timing

Onboard frequency standards range from temperature-compensated and oven-controlled crystal oscillators in less demanding applications to ultra-stable oscillators and chip-scale atomic clocks where required. Some defense LEO programs are evaluating CSACs for applications that require holdover beyond what crystal-based references can provide. Phase noise budgets in V- and E-band terminals are tighter than in lower-frequency systems because phase noise multiplies with frequency in the upconverter chain.

Millimeter-Wave Losses and Transition Effects

At microwave and millimeter-wave frequencies, every transition has RF consequences. Board launches, coaxial connectors, cable assemblies, waveguide interfaces, flex circuits, package transitions, and shielding structures affect loss, VSWR, isolation, leakage, and repeatability. These effects become more difficult to control as terminals move toward thinner profiles, wider bandwidths, and higher channel counts. The packaging approach, whether organic substrate, low-temperature co-fired ceramic, or wafer-level integration, increasingly determines whether a phased array meets its intended performance at production volume.

The Future of RF Engineering in Low Earth Orbit

Whether projected satellite populations reach the numbers in the filings, the trajectory is a straight line upward. The LEO environment will become increasingly crowded over the next decade, and RF and microwave engineering challenges will compound. Filter selectivity, amplifier linearity, phase noise budgets, beam discipline, and test methodology that were adequate in a less crowded environment will not be adequate in the future. The components, subsystems, and test systems that succeed will be those designed with the assumption that the spectrum and the orbit are shared resources operating closer to their physical limits than at any time in the history of satellite communications.

• RFMW •

Washington Puts Quantum on the Fab Floor

by **Barry Manz,** ***Editor***

The U.S. government has decided that quantum computing is no longer a research line item. The Commerce Department said it would take equity stakes in nine quantum-computing companies tied to roughly $2 billion in funding, a move it framed as building a domestic quantum supply chain and countering China in advanced computing. The money is tied to CHIPS Act grants, and Commerce Secretary Howard Lutnick pitched it as spurring "a new era of American innovation."

The dollar figures are the headline, but for the RF and microwave industry, the destination of the money is the story, because the machines this funding is meant to manufacture are, beneath the quantum mystique, some of the most demanding microwave systems ever built.

Two fabs, not nine grants

The largest share goes to IBM, and it is not a simple transfer. IBM is launching a company called Anderon in New Albany, NY, billed as America's first dedicated quantum chip manufacturing facility, contributing $1 billion in capital, intellectual property, assets, and workforce, and attracting additional investors as the company scales. The government's stake in Anderon was not disclosed.

GlobalFoundries takes the next-largest piece, $375

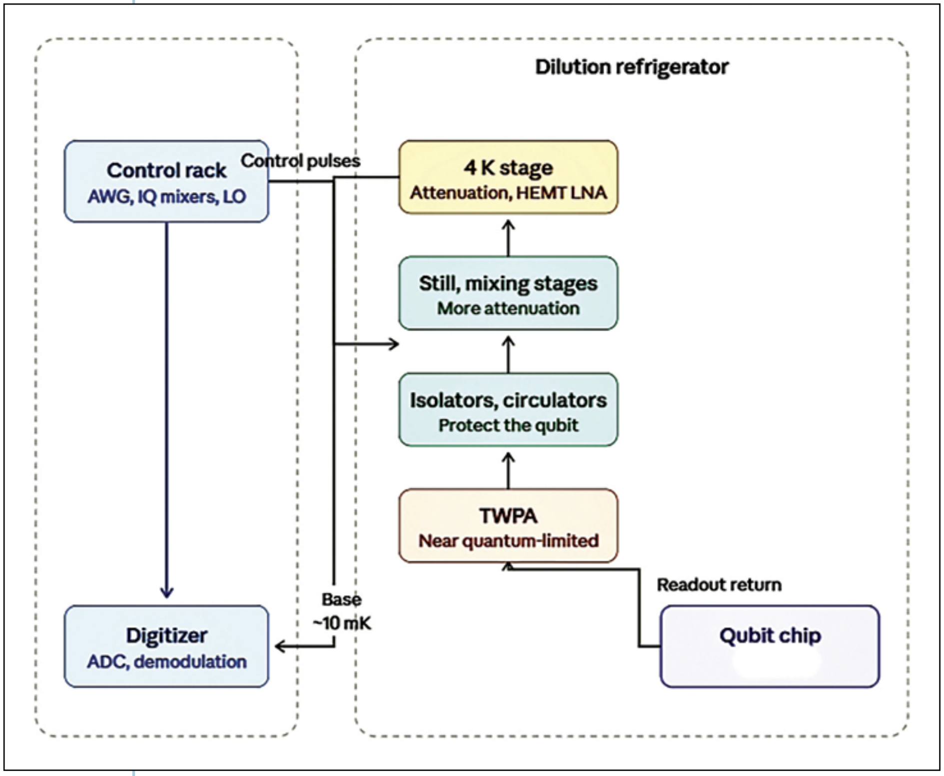

***Figure 1*—Seven of the nine recipients have disclosed or reported figures. Quantinium's award was reported, not disclosed. Totals approximate the roughly $2 billion package.**

million to build a domestic factory capable of producing components for several different types of quantum machines, through a new business it has launched called Quantum Technology Solutions, with the government taking an equity stake of about 1%.

Strip away the politics, and what remains are two new manufacturing operations aimed specifically at quantum hardware, one from a systems company that has run its own quantum program for years, the other from a contract chipmaker that knows how to scale a process. The smaller awards round out the field across competing approaches. D-Wave, Rigetti, and Infleqtion each receive about $100 million, and Diraq receives up to $38 million to address key technical hurdles. Those five, plus IBM and GlobalFoundries account for seven of the nine; the remaining names were not all disclosed, though Quantinuum was reported as a likely recipient in the $100 million tier.

Quantum As Microwave Instrument

Building a factory for quantum hardware is not the same problem as building one for logic or memory, and the reason will be familiar to anyone who designs microwave subsystems for a living. A superconducting quantum processor is only the cold endpoint of a large and intricate microwave instrument. The qubits themselves resonate in the neighborhood of 4 to 8 GHz, and every operation performed on them is a precisely shaped microwave pulse. Single-qubit gates are vector-modulated bursts a few tens of nanoseconds long, with amplitude, phase, and frequency controlled tightly enough to hold gate fidelities above 99.9%.

Generating them means a room-temperature rack of arbitrary waveform generators, IQ mixers, local oscillators, and vector signal sources, one chain per qubit, with the phase noise and spurious performance of every component folding directly into error rates.

The signal path from that rack to the chip is where engineering turns punishing. Each control line runs down through a dilution refrigerator across several temperature stages, and at each stage it must be attenuated, typically 20 dB at the 4 K plate and more below, to strip the room-temperature thermal photons that would otherwise wash out a qubit sitting near 10 millikelvin.

That demands cryogenic attenuators with stable, well-characterized performance at temperatures for which their datasheets were never written. Readout runs the other direction and is no easier. The dispersive signal coming off a resonator is a handful of microwave photons, so it has to pass through ferrite isolators and circulators that protect the qubit from amplifier back-action, then into a near-quantum-limited traveling-wave parametric amplifier, then a HEMT low-noise amplifier at 4 K, before it is warm and strong enough to digitize. Holding the whole chain phase-coherent across that thermal gradient is the actual problem.

Then there is the wiring. Every qubit needs control and readout lines, and the count climbs with the machine. Today's processors already thread hundreds of semi-rigid and superconducting NbTi coax lines through the cryostat, and the path to thousands or

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millions of qubits does not survive a linear scaling of that approach. The field is pushing toward frequency-division-multiplexed readout, cryogenic microwave switching, and integrated control electronics, which have moved closer to the chip precisely because the interconnect, not the qubit, is becoming the bottleneck.

A fab dedicated to quantum chips solves one layer of the problem, the device itself, while implicitly committing the country to scaling everything wrapped around it: the cryogenic attenuators and amplifiers, the ferrite components, the high-density microwave interconnect, the filters, and the room-temperature signal generation. That supporting hardware is specialized, low-volume, and today sourced from a thin bench of suppliers. For the RF and microwave industry, that is the more durable signal in Thursday's announcement than any single grant.

The model and the argument

The financing approach is itself a departure. The deals convert traditional grants into ownership positions, mirroring the Intel stake the administration took last year. The reaction split along familiar lines. Supporters call it strategic capitalism, arguing that taxpayer-backed high-risk technology should capture the upside if the bets pay off. Critics see government equity in private firms as a distortion that blurs the line between regulator and shareholder. The market voted with enthusiasm: IBM rose more than 7%, and GlobalFoundries, Rigetti, D-Wave, and Infleqtion climbed between 10% and 20% on the news.

The strategic rationale is straightforward. Quantum computing sits on the short list of technologies where a clear lead carries national-security weight, from cryptography to materials and sensing, and the administration is treating domestic fabrication capacity as too important to leave to private timelines. The CHIPS Act lineage makes the intent plain: this is semiconductor industrial policy extended to the next contested process technology.

The open question

What the government has bought is a diversified position across the field rather than a wager on a winner. Spreading capital over superconducting, trapped-ion, annealing, and neutral-atom approaches hedges against backing the wrong architecture, which is prudent given that no one yet knows which will scale to fault tolerance first. It is worth noting that the microwave dependency does not disappear if superconducting qubits lose the race.

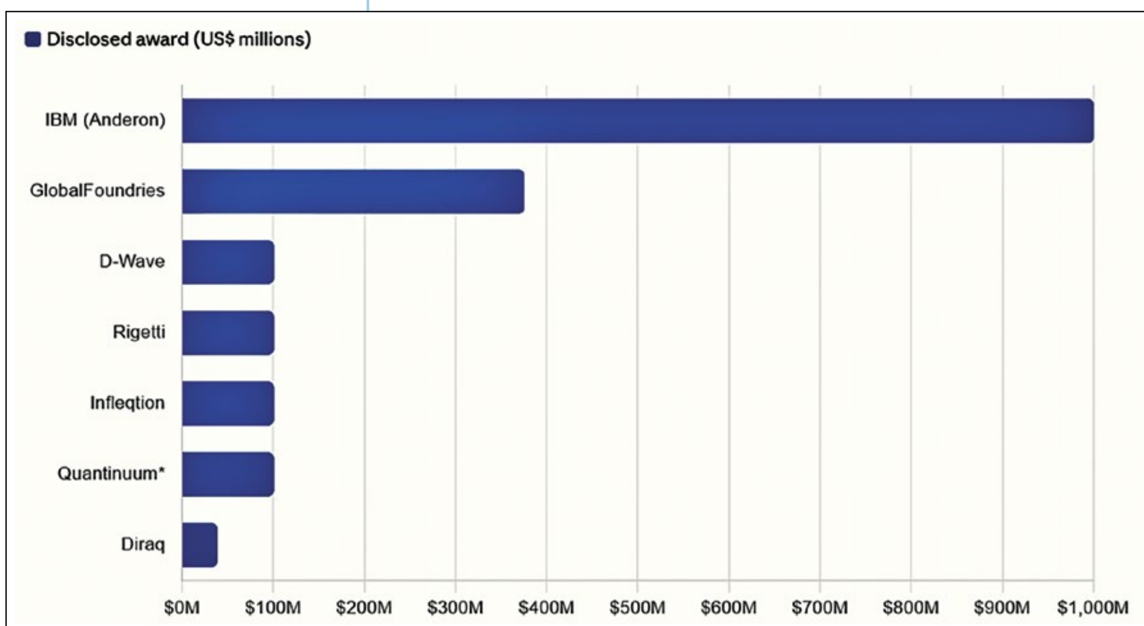


***Figure 2*—The various stages (outside room temperature)) and inside the quantum system (at cryogenic temperatures).**

Trapped-ion and neutral-atom machines trade some of the microwave control burden for laser systems, but they still ride on RF trap drives and low-noise microwave chains, so a domestic quantum buildout is a microwave-component buildout under any of the architectures on the table. Whether the policy reads as sensible diversification or as the government running ahead of the science will not be clear for years. What is clear now is that quantum has crossed from the lab into industrial policy, and the microwave hardware that powers these machines has just secured a federal sponsor.

Microwave Design Is Still Waiting for Its Chiplet Standard

The semiconductor industry is moving steadily toward chiplet-based design, and UCIe has become one of the most important pieces of that transition. Its purpose is to create a common die-to-die interconnect so chiplets from different vendors can communicate inside the same package. In the digital world, this is a major step toward disaggregated design. A processor, accelerator, memory controller, I/O block, or specialized logic die can be integrated into a package without every interface being a proprietary one-off. The microwave industry has no real equivalent.

That does not mean the microwave world lacks standards. It has many of them, covering coaxial connectors, waveguide interfaces, test methods, S-parameters, reliability screening, package outlines, environmental qualification, and modular defense architectures such as OpenVPX, VITA 67, and SOSA. These are important, and often essential, but they do not do for RF and microwave design what UCIe is intended to do for digital chiplets. They do not provide a broadly accepted, vendor-neutral way to combine microwave die, MMICs, filters, switches, mixers, amplifiers, limiters, beamformers, converters, and control circuitry inside a package with predictable interoperability.

For microwave designers, that absence is becoming a larger problem because integration is no longer optional. Radar, electronic warfare, satellite communications, phased arrays, test systems, and high-capacity wireless links all require wider bandwidths, higher frequencies, more channels, lower noise, greater linearity, better thermal performance, and smaller size. Meeting those requirements often means combining multiple semiconductor and packaging technologies in the same module.

A front end may need GaN for power amplification, GaAs or SiGe for low-noise or switching functions, CMOS for control and calibration, thin-film filters, high-resistivity silicon or glass interposers, and advanced thermal materials. On paper, this looks like an ideal environment for chiplets. In practice, it is much harder because RF and microwave interfaces are not simple data pipes.

In a digital system, the objective is usually to move bits across a defined electrical interface while maintaining timing, signal integrity, and acceptable error rates. That is difficult, but it can be standardized because the receiving circuit generally interprets logic levels or encoded data. In a microwave system, the signal itself is the thing being preserved. Its amplitude, phase, noise, impedance environment, harmonic content, group delay, linearity, and isolation all matter. The interconnect is not just a connection. It is part of the circuit.

That makes the package a design variable rather than a neutral container. A transition from one die to another can introduce mismatch, loss, parasitic inductance, parasitic capacitance, coupling, resonances, or mode conversion. At lower microwave frequencies these effects can often be managed, but as systems move into millimeter-wave and sub-terahertz territory, small physical dimensions become electrically significant. A bond wire, bump, via, cavity, lid, ground transition, or package seam can affect the RF behavior of the assembly. Two die that appear compatible on a block diagram may behave differently when placed in a real package.

This is one of the biggest differences between microwave integration and digital chiplet integration. A digital chiplet interface can hide a great deal of device-level variation behind protocol layers, equalization, and error correction. Microwave functions have much less abstraction. The designer must know where the RF reference plane is, how the die was characterized, what impedance it expects, how the ground return behaves, how much isolation is required, and how the package will affect gain, noise figure, output power, stability, and distortion.

The lack of a UCIe-like standard also increases engineering cost and schedule risk. Every multi-die microwave module becomes a custom electromagnetic, thermal, mechanical, and manufacturing exercise. Designers must model transitions, simulate coupling, characterize substrates, manage heat flow, and verify performance through multiple build-and-test cycles. However, a device from one supplier cannot simply be swapped with a similar device from another supplier without reconsidering matching networks, control lines, biasing, thermal interfaces, or calibration routines.

This is especially problematic in defense systems, where modularity and upgradeability are now major acquisition goals. SOSA and related open architectures help at the board and system level, but the RF payloads often remain highly customized. A program may use open standards for the chassis, backplane, Ethernet fabric, timing, and control interfaces, yet still rely on a proprietary microwave front end or converter module. The architecture may be open around the RF hardware while the most difficult RF content remains closed, specialized, and vendor-specific.

The industry is moving toward greater integration, but mostly through proprietary or semi-custom approaches. Advanced packaging, heterogeneous integration, glass substrates, silicon interposers, fan-out processes, embedded passives, and antenna-in-package techniques are all being applied to RF and millimeter-wave systems. These technologies can produce impressive results, particularly in phased-array and high-volume communications applications. But they do not yet amount to an open microwave chiplet ecosystem.

For microwave designers, the absence of such a standard means integration remains both powerful and painful. They can build compact, high-performance modules by combining the best available technologies, but each design still demands deep RF, packaging, thermal, and manufacturing expertise. The work cannot yet be reduced to connecting standardized microwave chiplets on a common substrate.

That is why the microwave industry's missing UCIe equivalent matters. It limits reuse, slows development, complicates second sourcing, and keeps high-performance RF integration in the realm of specialized engineering. Digital systems are beginning to standardize the way chiplets talk to each other. Microwave systems still have to negotiate with physics one transition, one package, and one reference plane at a time.

The Laser Comms Buildout Gathers Pace

For decades, satellites transmitted their data over radio. That is changing, and the list of companies positioning themselves to supply the shift now reads like a roster of the aerospace and photonics industries.

One recent market study puts the global free-space optical communications market at $362.50 million in 2025, rising to more than $1.3 billion by 2034. A separate projection from Novaspace values the optical satcom opportunity at $12.9 billion over 2026 to 2035.

The obvious appeal is bandwidth because optical links deliver data rates up to 100 times faster than RF-based solutions, and that makes it very appealing for Earth observation, broadband constellations, and intelligence collection that generate enormous amounts of data, which must be transferred as quickly as possible.

Not surprisingly, perhaps, the military is a major proponent. The U.S. Space Development Agency is building the Proliferated Warfighter Space Architecture, a layered network in which each satellite carries at least two optical terminals to communicate with other satellites, aircraft, ships, and ground stations. The agency mandates a common interoperability standard so terminals from different vendors can link in orbit. Baseline link speed is 2.5 Gb/s, though vendors say newer terminals reach up to 100 Gb/s.

Germany's Tesat-Spacecom reports having executed over 51,000 optical intersatellite links and has expanded into the U.S. to pursue government and commercial work. Mynaric, also German with U.S. operations, began volume production of its CONDOR Mk3 terminal in early April after resolving earlier supply-chain and production-scaling issues. CACI International, which entered the space through its acquisition of SA Photonics, was the first SDA-compliant terminal to establish a consistent link with the reference modem during interoperability testing of its CrossBeam product. Skyloom, Space Micro, and Ireland's Mbryonics round out the contenders.

Government research funding continues to seed the field. DARPA's Space-BACN program, aimed at low-cost, standardized terminals, is being transferred from DARPA to the Defense Innovation Unit, with optical payloads from Mbryonics and Mynaric scheduled for performance verification tests this summer.

Commercial constellation operators are also on board. MDA Space selected Tesat to supply terminals for Telesat's Lightspeed constellation, and Kepler Communications chose Tesat optical inter-satellite links for the first tranche of its next-generation ÆTHER satellites. SpaceX already runs optical links between Starlink spacecraft, validating the architecture at scale.

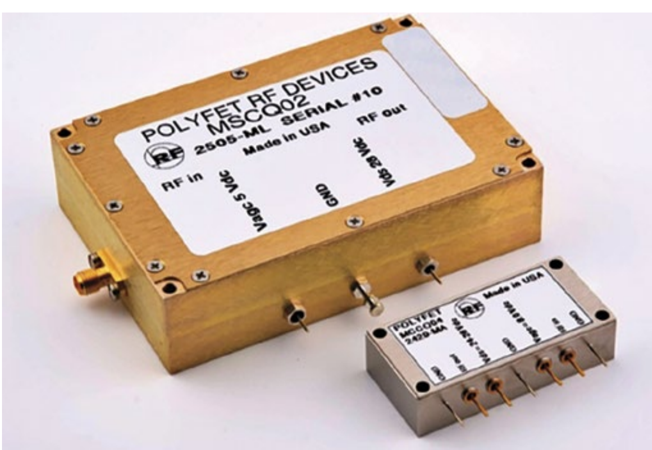
Europe is moving on a parallel track, with particular attention to the ground segment. In February, Hellas Sat, France's CNES, Thales Alenia Space, and Safran signed an agreement to develop an optical communications system for the future Hellas Sat 5 satellite, along with an associated optical ground station to be deployed in Cyprus. The partners frame the effort partly as insurance for critical networks, noting that terrestrial and subsea fiber links are increasingly subject to sabotage. The push extends to smaller players and to the ground stations themselves. Lithuania's Astrolight has commissioned the Holomondas Optical Ground Station in northern Greece, built through the ESA-backed PeakSat project led by the Aristotle University of Thessaloniki, to pull data from satellites over infrared laser links. Astrolight's ATLAS-1 terminal flies on the PeakSat and ERMIS-3 CubeSats launched in March under ESA's Greek IOD/IOV program, and the ground station uses an 808-nm beacon and an optical C-band receiver rated at 2.5 Gb/s.

The reason all of this is happening now is a convergence of pressures rather than a single breakthrough. The radio spectrum is crowded and contested. Data volumes are climbing. And for defense and dual-use operators, the physics of a tightly focused infrared beam offers something radio cannot match: a link that is far harder to intercept or jam. As constellations adopt optical mesh networks in orbit, a matching expansion of ground infrastructure must follow, and the firms that can deliver qualified terminals, optical amplifiers, tracking subsystems, and ground stations at production volume are the ones securing the contracts.

Polyfet's RF Power Portfolio Spans VDMOS, LDMOS, and GaN

Polyfet RF Devices designs and manufactures RF power transistors and power amplifier modules for commercial, industrial, and defense systems. Its catalog spans three semiconductor technologies: VDMOS, LDMOS, and GaN. Across the portfolio, devices reach frequencies up to 3 GHz, output power up to 2 kW, and operate at voltages up to 50 VDC.

The three technologies occupy different parts of the design space. VDMOS remains a practical choice at HF through VHF, where its ruggedness and linearity suit broadcast, industrial heating, and lower-frequency communications. LDMOS offers high gain and efficiency from VHF through the lower microwave range and is widely used in communications infrastructure and broadband amplifiers. GaN extends usable power density and frequency further, supporting higher-voltage operation and the wide bandwidths increasingly required in radar and electronic warfare. Offering all three lets Polyfet match the device to the band and power level required by the designer and the application.



Within the module range, the MCCQ04 and MSCQ02 are internally matched RF power amplifier modules built around LDMOS transistors. Internal matching places the input and output matching networks inside the package, so the module presents a defined impedance to the system and reduces the external tuning a designer would otherwise have to develop. Operated at 28 VDC, the two modules form a cascaded chain that delivers 175 W of saturated output power (Psat) across the 30 to 512 MHz band with 47 dB of gain. That span covers the VHF and UHF range used in tactical and broadband communications, while the gain figure reflects the two stages working in sequence, the first providing drive for the second.

The MCCQ04 contains Polyfet's LP801 and LQ801 transistors, while the MSCQ02 contains the LR2401. Pairing them in a chain allows a low-level input signal to reach the full 175 W output without additional external gain stages, simplifying the surrounding circuit and shortening development time.

A broadband amplifier that provides useful gain and power from 30 to 512 MHz suits applications that must operate across multiple bands without retuning, including software-defined radios, EW, and general-purpose test equipment. By supplying the matching and the cascaded gain as an integrated module rather than a set of discrete transistors, Polyfet shifts part of the amplifier design effort from the customer to the device, an advantage where schedule or board area is constrained. For designers already working with the company's discrete VDMOS, LDMOS, and GaN transistors, the modules extend the same device base to a higher level of integration.

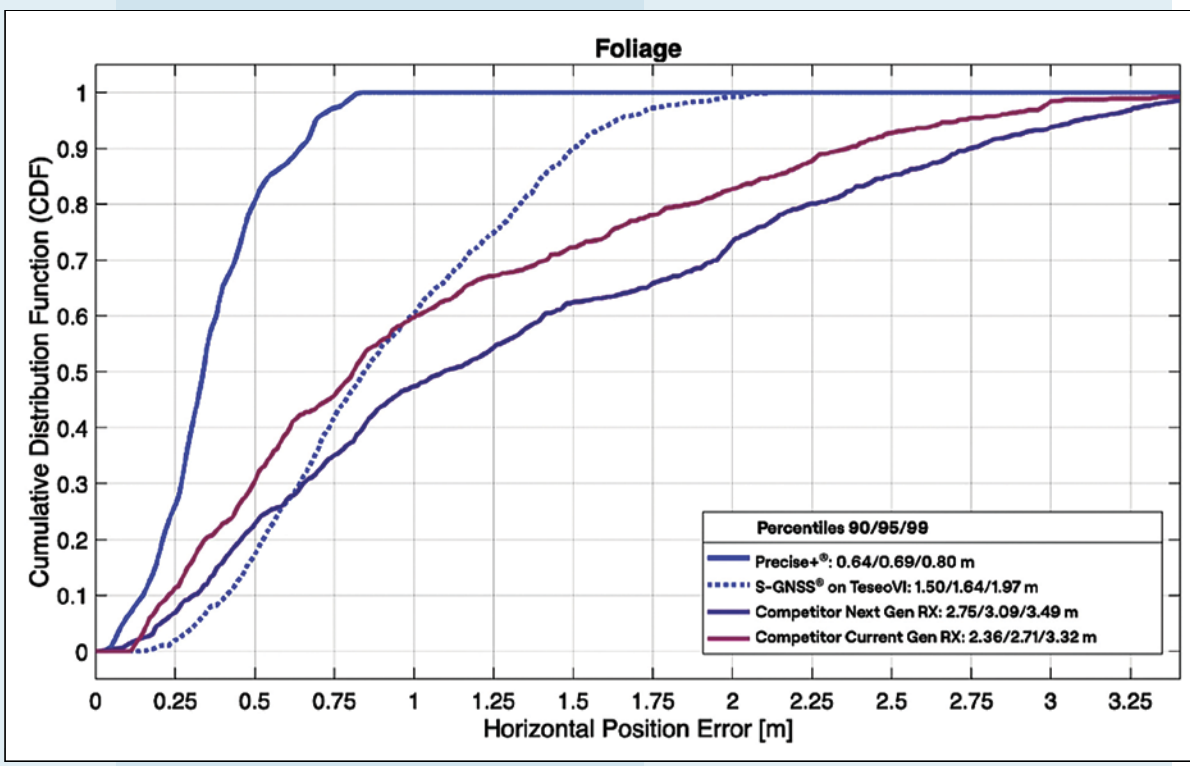
FocalPoint Delivers Precision GNSS Coverage

Focal Point Positioning has introduced Precise+, software that aims to keep high-precision GNSS signals together where they normally come apart. The Cambridge, UK company unveiled the technology at the European Navigation Conference 2026 in Vienna, where principal engineer Javier Garcia presented the supporting work in a technical poster.

Precise+ extends the company's patented Supercorrelation platform into the carrier phase domain.

Supercorrelation, a chipset-level software upgrade that has been the basis of FocalPoint's product line since the company was founded in 2015, performs long coherent integration to boost line-of-sight signals while rejecting reflected and non-line-of-sight energy. It has previously been licensed for integration with u-blox platforms and deployed as S-GNSS Auto on STMicroelectronics Teseo devices. Precise+ applies the same signal-processing approach to the measurement that high-precision systems actually depend on.

Centimeter-level positioning relies on continuous carrier-phase tracking. Interrupt that tracking and the receiver suffers a cycle slip, forcing the system to reinitialize. The interruptions are not rare events. They happen routinely in dense cities, under tree canopy, and anywhere multipath dominates. Real-Time Kinematic and Precise Point Positioning both deliver their advertised accuracy in open sky and degrade sharply once buildings, foliage, or reflections enter the picture. In ADAS, automated driving, and robotics, that degradation is the gap between demonstration and deployment.



Precise+ targets cycle slip at its source rather than papering over its consequences downstream. By stabilizing how carrier phase signals are tracked and interpreted in the presence of multipath and interference, it keeps RTK and PPP working through conditions that would otherwise force a reset.

FocalPoint tested its software-defined receiver at Thetford Forest, a reference site for evaluating GNSS performance under dense foliage. Precise+ held positioning error below 80 cm across 99% of measurements on the route. State-of-the-art receivers running on the same route, in the same conditions, produced errors exceeding 3 m (see figure).

The Precise+ figures are receiver-level performance with no inertial sensors, no dead reckoning, and no sensor fusion. It is a like-for-like measurement against competing GNSS solutions, which means whatever an integrator layers on top, whether that is sensor fusion, RTK, or PPP corrections, builds on a better starting point rather than compensating for a worse one.

"RTK and PPP deliver centimeter accuracy in open sky but degrade sharply where signals are disrupted by tree cover, buildings, or multipath," said Scott Pomerantz, CEO of Focal Point Positioning. He framed the limitation as a coverage problem: high-precision GNSS today operates on a narrow slice of the road network rather than the roads people actually drive on. Expanding that operating domain, in the company's framing, lets carmakers turn on autonomy and ADAS features across real conditions, and lets the corrections infrastructure they have already paid for return value outside open sky.

The company is positioning Precise+ for automotive use, including ADAS, automated driving, and V2X, and notes it applies to any system that needs sustained high-precision GNSS where the sky is not clear. FocalPoint says it is working with chipset manufacturers to bring the technology to market.

continued from page 3

figure of 6 dB lifts the effective floor to about -86 dBm. To achieve a 38 dB SNR for 4096-QAM, the signal at the receiver must be roughly -48 dBm, with modest transmit power and antenna gain. That corresponds to a separation of about 1.5 m between client and access point. The top modulation order is a feature you can use while holding the phone against the router.

Walk into the next room, and the rate adaptation algorithm has already stepped you down the MCS table toward a figure well below the one shown in giant letters on the box it came in. Apple's recent iPhones limit Wi-Fi 7 modulation to MCS 11 and do not implement 4096-QAM indices at all. One of the most widely sold premium handsets on the market omits the headline feature of the standard it supports because the silicon, power budget, and antenna just don't justify it. A modulation order reachable only at arm's length from the access point means little in a device meant to be carried, and the handset design reflects that, even if the specification sheet still leads with the larger number.

Now let's take a look at the spectrum. The 320 MHz channels that the peak rate assumes exist only in the 6 GHz band, and that band's availability and power rules vary by region, with much of the world having opened less of it than the U.S. With indoor and standard power operation governed by different limits and, in the standard-power case, by automated frequency coordination to protect incumbents. A wide channel also collects more noise, since doubling the bandwidth raises the integrated noise floor by 3 dB. That means the channel width that inflates the peak rate also raises the SNR bar the client must clear to use it. The two headline ingredients, the widest channel and the densest modulation, work against each other in any environment that is not a shielded room.

Even in ideal (i.e., never experienced) conditions, the air interface has not been the bottleneck for several generations. A client capable of delivering 2 Gb/s over the air is still bound by a 300 Mb/s access plan, congested backhaul, and a server on the far end that was never going to feed it that fast. For most of the real traffic, the Wi-Fi link had headroom to spare since Wi-Fi 5. Doubling a ceiling nobody touches produces a better spec sheet and an identical experience.

So why does every generation lead with a bigger number? Because the number is legible. Peak throughput fits on a box, sorts cleanly in a comparison table, and lets a buyer believe the more expensive router is the faster one. The genuinely valuable work, the scheduling and coordination that determine whether a video call survives a crowded conference room, does not reduce to a single digit. Latency, jitter, and determinism are what users actually feel, and none of them headline a press release. The industry has spent two decades leading with the metric that may matter least to the people buying it.

What makes this worth saying now is that the standards body has finally said it, too. Wi-Fi 8, the IEEE 802.11n amendment, declines to raise the peak rate. It supports the same 320 MHz channels, 4096-QAM, eight spatial streams, and peak PHY rate as Wi-Fi 7. For the first time, a new generation keeps the headline figure flat while putting its engineering elsewhere. The stated goals are at least 25 percent higher throughput in challenging signal conditions, a 25 percent reduction in 95th-percentile latency, and 25 percent fewer dropped packets when a device roams between access points, all under a banner the committee named Ultra High Reliability. The draft reached version 1.0 in 2025, with publication targeted for March 2028.

The mechanisms tell you where the real problems were hiding. Wi-Fi 8 introduces coordinated spatial reuse and coordinated beamforming so neighboring access points cooperate rather than interfere, dynamic sub-channel operation to use fragments of spectrum that would otherwise sit idle, and enhanced modulation and coding schemes aimed at the low end of the SNR range rather than the top. The most telling addition is at the physical layer.

Distributed resource units spread a transmission's tones across a wider slice of bandwidth to raise the per-tone transmit power, and enhanced long-range frames use power-boosted preambles and frequency-domain duplication to extend uplink coverage. That feature exists because the client is power-limited and constrained by spectral-density rules, so the only way to improve its uplink is to use the spectrum mask more effectively rather than demanding a higher modulation it can never achieve. This is the opposite of the peak-rate philosophy. It is engineering for the device that actually exists.

Read the scope document, and the subtext is unmistakable. The committee responsible for the headline figure has concluded that it is no longer a source of meaningful gains. The remaining problems are reliability problems. The edge user with a weak signal, the warehouse with 200 contending clients, and the factory floor that needs a packet to arrive on time rather than quickly. None of these is solved by another doubling of a rate the client cannot reach. They are solved by coordinating access points, by extending uplink range within a power budget, by making the worst case less bad rather than the best case more theoretical.

There is a lesson here for anyone specifying a network, and it runs counter to the buying process. The right question was never how many gigabits the radio claims. It was how the link behaves under ordinary conditions, which is to say, most of the time. A system that delivers 200 reliable Mb/s to every device in a full room is worth more than one that promises 2 Gb/s to a single device a meter from the antenna, and the gap between those two systems is exactly the gap the peak rate conceals.

Wi-Fi 8 will ship with a smaller headline figure than its predecessor, but a more useful set of improvements. The open question is how to communicate that. A reliability gain shows up mainly by its absence, in the call that did not drop and the file that transferred without a stall. The engineers writing the standard have already made their choice about what matters. The rest of the industry now has to find a way to convey a benefit that resists being reduced to a single number.

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