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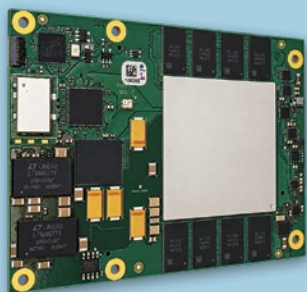
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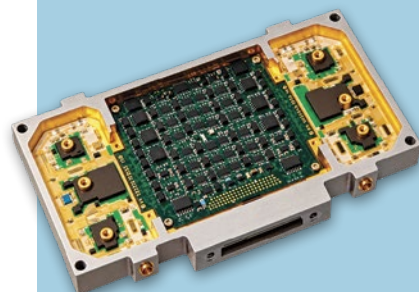


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EDITORIAL STATEMENT of PURPOSE

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

What ALPRs Reveal About Wireless Sensing

THE CONTROVERSY surrounding automated license-plate reader networks has focused almost entirely on privacy, data retention, and law-enforcement access. For RF engineers, however, there is another story to tell. An automated license-plate reader, or ALPR, is essentially a remote sensor with wireless backhaul, positioning, local processing and, in many installations, a tightly constrained energy budget. Viewed that way, it provides a useful example of how thoroughly wireless technology has changed the economics of distributed sensing.

Flock Safety has become the name most closely associated with the debate, and news accounts increasingly use “Flock camera” as shorthand for the entire category, which is not the case. Flock is one of several manufacturers (Table 1), while ALPR describes the technology. Unless a point concerns Flock Safety’s own products, claims, or policies, ALPR is the more accurate term.

This does not make the questions surrounding these networks any less important. Communities are still debating what ALPRs should record, how long the information should be retained, who should be permitted to search it and whether large collections of vehicle-location data require stronger legal safeguards. Those issues will be decided by policymakers, courts and the public. The engineering is relevant because it explains why systems of this scale have become so easy to deploy.

Flock describes its license-plate readers as solar-powered, LTE-connected and installable without trenching or a utility connection. Strip away the branding and the object is familiar: an untethered wireless sensor node that captures an event, processes information locally and sends selected data to a remote platform. The imaging

system attracts the attention, but the communications link is what turns an isolated roadside device into part of a searchable network.

The small solar panel and battery impose a significant energy budget as image capture, processing, storage, positioning, and communications all compete for the available power. An architecture designed around those limits would ordinarily avoid continuous transmission, capture images when needed, perform some processing at the edge, and then send a much smaller record upstream instead of streaming video. This means the cellular radio can remain inactive or operate in a low-power state whenever traffic and network conditions permit.

That description is an engineering inference, not a claim about the precise circuitry or operating sequence inside every Flock product or every competing ALPR. Public information does not provide a complete bill of materials, and different models or installations may use different radios and power-management schemes, as is the case with remote weather stations, pipeline monitors, agricultural sensors and industrial IoT equipment. What matters is not that any ALPR manufacturer invented the wireless sensor node; it’s that cellular coverage, compact electronics and lower-power processing have made it practical to deploy nodes by the thousands along ordinary roads.

When Backhaul Became a Service

A decade or two ago, connecting a large number of roadside sensors could become a massive infrastructure project. The operator might need leased lines, municipal fiber, private radio links, or a network of gateways.

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EDITOR'S CHOICE

Featured Products

1-kW RF Power Amplifier

The MAPC-P1060 is a 1 kW pulsed power amplifier pallet for X-band radar and high-power microwave systems. Built on GaN-on-SiC process technology, the pallet delivers 52 dB of gain at 30% efficiency. On-board power management ICs handle bias sequencing and temperature compensation across the amplifier's operating range, integrating drain and gate control at the pallet level. The design consolidates the RF and bias functions of a pulsed X-band stage into a single assembly.

MACOM



5 kW Pulsed SSPA

The AMP20203 is a solid-state high-power amplifier covering 150 to 400 MHz with 5 kW of pulsed output. The unit is a rack-mounted system with built-in control, monitoring, and protection circuitry, and it supports remote operation over Ethernet, USB, and serial interfaces, along with a local display. Like the rest of the Exodus VHF/UHF pulse line, it is offered as a turnkey chassis intended as a solid-state replacement for TWT amplifiers in EMI/RFI, radar, and communications test applications.

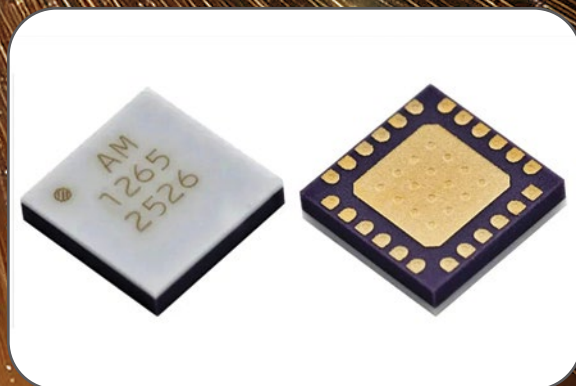
EXODUS ADVANCED COMMUNICATIONS



8 GHz Bypassable Amplifier

The AM1265 is a bypassable MMIC amplifier/attenuator operating from DC to 8 GHz. In amplifier mode, it provides broadband gain across the full band; a control line switches the device into a low-loss bypass or attenuation state without removing it from the signal path. The GaAs MMIC is DC-coupled with internal 50-ohm matching, packaged for a compact board footprint, and aimed at broadband receiver and signal-chain designs requiring switchable gain.

MERCURY SYSTEMS



8T8R SoC Transceiver

The Analog Devices ADRV9040 is an 8T8R RadioVerse system-on-chip with an integrated digital front end, supporting 400 MHz of instantaneous bandwidth. The device integrates digital predistortion, crest factor reduction, and carrier digital up- and down-conversion on-chip, folding signal-processing functions that previously sat on a separate FPGA into the transceiver. It anchors ADI's 8T8R 400 MHz radio-unit platform for O-RAN 7.2a deployments and is positioned as the lowest-power integrated transceiver in the ADRV904x family.

ANALOG DEVICES





2-way Power Dividers

The ULTRA+ family comprises seven matched-line directional divider 2-way power dividers spanning 500 MHz to 40 GHz. The patented MLDD topology delivers tight amplitude and phase tracking, low insertion loss, and high isolation in compact packages. Units ship with 3.5-mm or 2.4-mm coaxial female connectors.

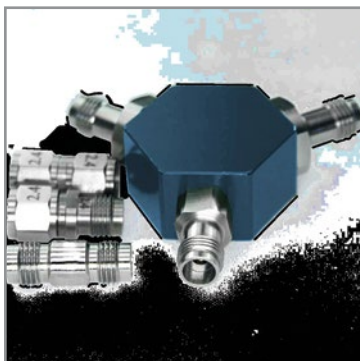
KRYTAR



2 kW SSPA

The Model 2180 is a 2 kW CW solid-state amplifier covering 1 to 2.5 GHz, built on GaN-on-SiC devices in an 8U air-cooled chassis with 64 dB gain. It supports CW, AM, FM, and pulse operation with blanking, plus AGC, ALC, and MGC modes. Electronic VSWR protection guards against adverse loads, and control is via a web browser, Ethernet, or RS-485. Unit has a front-panel touchscreen.

EMPOWER RF



Calibration Kit

The HAOSLT-24J-50G is a mechanical calibration kit for 2.4-mm female test ports operating to 50 GHz. It provides open, short, load, and through standards for one-port and two-port vector network analyzer calibration. The 2.4-mm interface supports broadband measurement across microwave and millimeter-wave frequencies.

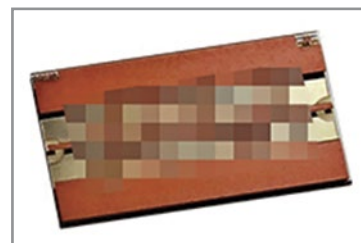
HASCO



BAW Bandpass Filter

The QPQ5230 is a bulk acoustic wave bandpass filter covering 2412 to 2472 MHz with 20 and 40 MHz bandwidth options and 0.8 dB insertion loss. Steep skirts provide high near-in rejection of adjacent LTE bands for Wi-Fi and LTE coexistence, with an extended upper corner accommodating Bluetooth. It occupies a 1.1 by 0.9 by 0.6 mm package.

QORVO



Bandpass Filter

The MFBP-00160GSM1 is a passive glass-substrate surface-mount bandpass filter. The glass process yields a smaller construction than circuit-board designs, with tight fabrication tolerances for low unit-to-unit variation and S2P data taken from measured production units. It targets small-form-factor, high-rejection filtering in RF and microwave signal chains.

MARKI MICROWAVE



8.4 GHz USB Attenuators

These USB-controlled programmable attenuators operate 400 to 8400 MHz in 2-, 4-, and 8-channel configurations, each channel independently controlled. Attenuation spans 0 to 95 dB in 1 dB steps with 50-ohm impedance, SMA female connectors, +24 dBm input rating, and 4 μ s switching. Windows test software is included with an optional Python library for scripted testing.

JFW INDUSTRIES



Signal/Waveform Generator

The 4088 Series combines an RF signal generator and an arbitrary waveform/function generator in a 2U chassis with simultaneous dual-channel output. The RF channel spans 50 MHz to 1.5 GHz with phase noise below -117 dBc/Hz at 1 GHz and supports AM/FM/PM and pulse modulation. The AWG channel provides 16-bit resolution, 250 MSa/s, and 4 Mpts memory to 80 MHz.

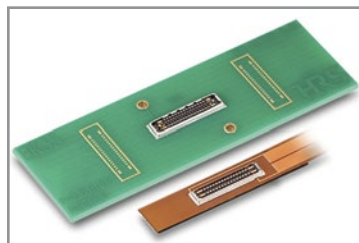
B&K PRECISION



Oscilloscopes in Chroma ATS 8000

Chroma's Power Conversion Device Automated Test System Model 8000 now supports Rohde & Schwarz MXO Series oscilloscopes. Built on the MXO-EP ASIC, the MXO captures up to 4.5 million acquisitions per second, resolves to 18 bits in HD mode, and reaches 0.5 mV/div sensitivity. ScopeSync links up to 24 channels across instruments for multi-rail power measurement.

ROHDE & SCHWARZ



Hybrid FPC-to-Board Connector

The BK35 Series is a fully shielded hybrid FPC-to-board connector on a 0.35 mm pitch, with 2.2 mm depth and 0.6 mm stacking height. It carries data to 40 Gbps and RF signals to 40 GHz alongside four 2.5 A power contacts, combining power and signal in a single connector. An armored structure protects the housing during mating and provides EMI shielding.

HIROSE ELECTRIC



Space-Grade ADC

The EV10AS940 is a 10-bit, 12.8 Gs/s, single-channel space-grade ADC with Ka-band input capability for satellite communications, synthetic aperture radar, and space electronic intelligence payloads. Single-event effects testing at RADEF and the Texas A&M Cyclotron showed no latch-up, and total ionizing dose characterization is complete. It supports frequency hopping and beamforming.

TELEDYNE E2V



Frequency Analyzers

The CNT-102B and CNT-104B are 2- and 4-channel frequency analyzers for automated test systems, controlled over LAN, WLAN, or GPIB. The display-free, rear-panel design fits up to 8 parallel counters in a 2U rack. Both provide simultaneous, gap-free frequency and time measurement, 14 ps resolution, and 1 million values/s to internal memory. The standard input reaches 400 MHz, with an optional input to 24 GHz.

PENDULUM INSTRUMENTS



Millimeter-Wave High Pass Filter

The HP-55G57G-185FF is a high-pass filter having a passband of 55 to 57 GHz. The cut-off frequency is 50 GHz, with a maximum passband insertion loss of 2 dB, and 50 dB of rejection from 34 to 45 GHz. The package size is 1.97 in. x 0.55 in. x 0.33 in., and it is equipped with 1.85 mm connectors.

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There were also issues with permits, power, coverage, and maintenance. Commercial LTE has changed that, and in many places the backhaul already exists, managed by the carrier and purchased as a service.

That may be the most important RF development behind large ALPR networks. The amount of data generated by a single license plate event is modest compared with continuous high-definition video, so the application does not require a particularly demanding link. Local processing can reduce the amount that must be transmitted, and wide cellular coverage removes the need to build a separate communications network for every jurisdiction. Instead of designing backhaul sites on a site-by-site basis, an operator can install a node, establish service, and use the existing carrier network.

The significance is not that these devices are likely to burden commercial spectrum. Compared with consumer video and other broadband traffic, their individual transmissions are modest. In short, cheap cellular connectivity has removed backhaul as a major barrier to persistent sensing, and a capability that once demanded dedicated communications infrastructure can now be offered through equipment, software and a recurring subscription.

This is also why the architecture extends well beyond ALPRs. Transportation departments, utilities, railroads, farms and industrial facilities all benefit from the same combination of remote sensing, edge processing and commercial wireless service. ALPR networks are a particularly visible example because their social consequences are being debated in public, but the underlying technology is part of a much broader change.

GNSS and Resilience

A GNSS receiver can provide an installed unit with an accurate location and a common time reference, both of which are useful when records from geographically separated sensors must be organized and compared. The exact role of GNSS in an ALPR in a distributed sensor architecture raises familiar questions about interference, antenna placement, receiver sensitivity, and the integrity of position and time data.

Commercial cellular and GNSS services make an ALPR network practical, but they

also define part of its resilience. A remote node cannot upload data when adequate cellular coverage is unavailable, although local storage and subsequent transmission may mitigate the effect. A receiver that relies on GNSS also inherits the service's known susceptibility to blockage, interference, and spoofing unless the design includes suitable checks or alternative references. These are not weaknesses of an ALPR; they are ordinary engineering considerations for any unattended wireless sensor.

In one documented effort, researchers linked installed ALPRs to Wi-Fi signatures recorded in WiGLE, a public database compiled from crowdsourced wireless observations. Projects such as DeFlock have used publicly reported information to map reader locations. That does not necessarily reveal the contents of a communication or indicate a defect in a particular device. It demonstrates that the effects on the transmitter emitting a signal can be detected and located, even when the sensor itself is visually inconspicuous.

For engineers accustomed to radar warning receivers, spectrum monitoring or interference hunting, that observation is hardly surprising. For a public discussion centered almost exclusively on databases and access policies, it is an easily overlooked reminder that a wireless network has physical characteristics as well as software rules.

ALPR in the Future

Flock's product portfolio also shows where this category is heading. The company now offers more than fixed ALPRs, including video products, acoustic gunshot detection, and drone-based services. Each sensor has different bandwidth, latency, coverage, and reliability requirements, and bringing them together turns what began as a collection of ALPRs into a heterogeneous wireless sensing network.

The drone element is especially relevant. An airborne platform introduces command-and-control links, payload data transmission, changing propagation conditions, antenna constraints, and, depending on the mission, the challenge of maintaining connectivity beyond visual line of sight. Video has a very different traffic profile from an occasional license-plate

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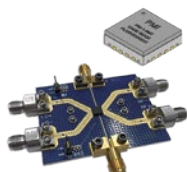
Attenuators: Digital & Voltage Variable, Fixed, Mechanical



Filters & Switched Filter Banks



Integrated Microwave Assemblies (IMAs)



IQ Vector Modulators



Limiters: High Power (100 W CW, 1 kW peak)



Log Amplifiers: DLVAs, ERDLVAs, & SDLVAs



Phase Shifters & Bi-Phase Modulators



Switches: Solid State (SPST to SP128T)



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record, while an acoustic sensor has its own timing and coverage requirements. Combining these endpoints places greater importance on network management, cybersecurity, and the ability to maintain service across multiple link types.

Flock has stated that facial recognition is not included in its products and is not planned. The engineering point does not depend on facial recognition or any other speculative feature. It is evident in the product category itself: once communications, processing, and storage share a common platform, additional sensor types can be incorporated without building an entirely new network for each one.

The components are familiar as well: cellular modems, GNSS receivers, antennas, filters, low-noise amplifiers, power-management devices, and the RF chains used by unmanned aircraft. None was developed specifically for automated license-plate reading. Their availability reflects decades of integration, falling component costs, improved energy efficiency, and the massive scale created by commercial wireless markets.

That progress has changed who can deploy distributed sensing and how quickly they can do so. The same general system pattern appears in industrial monitoring, intelligent transportation, public safety, security and environmental measurement: sensors collect information, local processors decide what is worth sending, a constrained wireless link moves it, and software combines records from many locations. ALPR deployments are noteworthy not because the block diagram is new, but because they show how far the cost and deployment barriers have fallen.

There is no need to assign collective responsibility to the RF and microwave industry for the ways every resulting system is used. A modem, filter, or GNSS front end does not determine the policy governing the data it carries. But engineers do have a useful perspective on what the technology makes possible, where its limitations lie, and which claims about coverage, resilience, or detectability deserve closer examination.

ALPR networks are interesting for reasons that extend beyond the argument over license-plate data, as they illustrate what happens when the technologies behind remote sensing—cellular connectivity, satellite positioning, low-power electronics, edge processing and inexpensive RF front ends become commodities. Equipment that once required dedicated

communications infrastructure can now be mounted on a pole, powered by a solar panel, and connected almost anywhere a suitable cellular signal is available. The rules governing how such networks should be used will be settled elsewhere. The technology that made them practical is very much the business of the RF and microwave community. 

Top Automated License Plate Reader (ALPR) Vendors

Market presence and footprints for dominant players in the ALPR ecosystem as of 2026.

Vendor / Camera Line	Primary Focus Market	Market Footprint & Share Metrics	Key Strengths
Flock Safety (Falcon Series)	Neighborhoods, HOAs, & Local Law Enforcement	~40% of all US law enforcement agencies use Flock. Over 120,000 active cameras deployed nationwide.	Subscriptions include hardware; unified nationwide 'National Lookup' network.
Motorola Solutions (Vigilant / Avigilon)	Enterprise Law Enforcement & Federal Agencies	Operates one of the largest commercial vehicle data networks (NVLS) with billions of historical plate reads.	Massive commercial database access; deep integration with police dispatch & cruiser systems.
Axon Enterprise (Axon Fleet / Fleet 3)	Citywide Police Deployments & In-Car Systems	Dominates the in-cruiser ALPR market. Fast-growing share in citywide fixed contracts (50+ camera deployments).	Seamless integration with Axon body cameras and Evidence.com digital ecosystems.
Rekor Systems (Rekor Scout / Edge)	Highway, State Transit, & Commercial Retail	Industry leader in high-speed stateway and highway monitoring.	Open-source foundation AI capable of reading plate data on standard IP security cameras.
Genetec (AutoVu)	Smart Cities, Tolls, & Enterprise Parking	A global leader in fixed, high-throughput traffic and parking management infrastructure.	Highly scalable backend software that bridges building security with municipal transit systems.

Market Insights & Nuances

Regional Discrepancies: While Flock Safety is highly visible in the United States, traditional international markets (Europe and Asia-Pacific) are largely led by hardware conglomerates like Hikvision, Axis Communications, and Jenoptik AG.

What Defense Primes Are Really Buying

by Rich Sorelle, *President and CEO, Spectrum Control*



I spent the first half of my career on the other side of this conversation. I started at Grumman working on Navy aircraft programs, including the F-14D, A-6F, and EA-6B Prowler. Then twenty years at ITT, later Exelis, most of it in electronic warfare. In those jobs, I was the customer. I wrote requirements. I sat in source selections. I decided which suppliers made the cut and which ones did not.

When I started out as an engineer and program manager, a system meant multiple boxes, each box with multiple boards, and multiple chips on every board. Today that same capability fits on a single chip. That is still really mind-boggling to me.

What has not changed is that somebody at a prime is deciding which supplier to trust. What has changed is what that decision turns on.

Here is something you learn after enough years in this business. Most standard products are standard because somebody designed them into a program once and they stuck. That makes a catalog a very good record of what the last generation of programs needed. It tells you very little about the next one, and the next one is what is being funded right now.

This is not a normal cycle

Defense investment is accelerating across the United States and Europe. At The Hague last year, NATO members committed to 5 percent of GDP by 2035, with 3.5 percent against core defense requirements, which is the part that buys hardware. Two things are happening at once, and they ask different things of a supplier. Existing inventories have to be replenished, and that is mostly a matter of rate and schedule relative to existing designs. At the same time, the next generation of platforms and the upgrades to current ones are being shaped by new threats and lessons from ongoing conflicts. On that side, requirements move while programs are already running, which means a supplier who can only quote a catalog part is going to lose.

At the platform level, customers want more sensing, more connectivity, more electronic protection, and faster decisions, in less volume, at lower weight and power, with higher reliability, and at a price that closes their business case. That is a tall order, and everyone in this industry knows it. For those of us down the supply chain, I think it requires us to reconsider what it means to be a good supplier.

Specifications are the price of admission

In RF and microwave, we love specifications, and we should. Frequency range, power, noise figure, linearity, insertion loss, size, weight. These determine whether a system works. There is no substitute for good engineering talent, and there never will be. But when I was on the prime side, the questions that actually decided an award came after the datasheet. Can you fit that performance into the space I have? Can you integrate more of the RF chain so I do not have to? Can you modify it to my electrical, mechanical and environmental requirements? And once we get the design right, can you build enough of them, on time, when I need them?

At Spectrum Control, we have organized ourselves around those questions. Internally, we talk about it as innovate, adapt, and deliver. Three words are easy to say. Doing all three at the same time is not. A supplier that can innovate but cannot adapt becomes a bottleneck. A supplier that can adapt but cannot deliver becomes a schedule risk. And a supplier that delivers yesterday's technology faster is not solving tomorrow's problem.

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We hear customers asking for more capability in less space. Adding another box is usually not an option. Neither is adding power, cooling, or weight.

Miniaturization matters, and it matters more every year. But the greater value is usually integration. Every function we integrate is one the customer does not have to design, qualify, and manage. That is engineering time they get back, which means cost they do not spend, which means a capability that reaches the field sooner.

We have put serious engineering effort into integrating RF and digital functionality, reducing SWaP-C, and moving from individual functions toward highly integrated assemblies and subsystems. None of that counts for much if it stays in the lab. We released six times as many new products in 2025 as in 2022, and that is the metric we watch, because a portfolio that is not turning over is a portfolio that is falling behind.

I said at the start that a catalog is a record of what the last generation of programs needed. Here is what that means in practice. Every program is trying to meet a mission-focused specification, and a catalog part was built for someone else's mission. Sometimes it had already been adapted once for a different mission before that. The further you get from the mission it was built for, the less well it fits.

So we built the company around that reality rather than around the catalog. We sell standard products and we always will. But derivative and custom work runs across the portfolio, including lines that look like pure catalog from the outside. Our design process assumes it. Our manufacturing process assumes it. That is a deliberate choice, and it is why a customer can bring us a requirement that does not exist yet and get an answer they can build a proposal around.

That takes more than engineering talent. It takes an organization that is comfortable listening, responding quickly, and making decisions close

to the customer. Delivering is what I would put first, and I think our industry has underinvested in it for a long time. For years, manufacturing capacity got treated as an operations problem, planning work that somebody handled as a second job on top of their real job. That is hard to do well, and I understand how it happened. But it cannot be that going forward.

Governments are sending clear demand signals. Primes are being asked to accelerate. But a prime can only ramp as fast as its supply chain allows, and that responsibility travels all the way down the chain to us.

When you think about what it takes to ramp up, most of it isn't glamorous.

Our customers need suppliers who understand the mission, the platform, and the program, including all its complex requirements.

It is people, equipment, and the information systems that tell you where you are spending, where you are not spending, and where you should be spending. On equipment, we have been investing across every plant we run. New equipment in Pennsylvania, Massachusetts, Michigan, Mexico, and across our operations in the UK.

The people side is the one I think our industry seriously underestimates. Consistent, dedicated employees create customer value. Manufacturing turnover runs 25 to 30 percent across our industry. Four years ago we were right there with everybody else, at about 30 percent.

Last quarter we were at 5 percent. You cannot properly service a customer or sustain a production ramp at 30 percent turnover. You cannot sustain qualification discipline, audit trails, or first-pass yields if the operator who knew how to run the process left in March. Workforce stability is really a capacity

investment, and it does not appear on anybody's datasheet or balance sheet.

It also means concentrating the manufacturing footprint where the real capability exists, because a footprint spread too thin is less efficient, which means it costs more and makes us less competitive going forward. And it means designing for manufacturability from day one, not discovering it in production or at rate. None of what we did to transform the company was painless, but it was necessary because waiting for the purchase order to arrive before thinking about capacity is waiting too long.

Some of the plants in this industry have been building the same kind of hardware since the Second World War. There are people on our floors today with forty years in, forty-one, forty-two. That legacy is worth something, but it does not entitle anybody to the next program. Our customers need suppliers who understand the mission, the platform, and the program, including all its complex requirements. They also need suppliers who understand the specifications.

At the end of the chain there is a warfighter who did not choose the specification, the schedule or the budget. Less than one percent of the American population wears a military uniform. That one percent is not only defending the homeland and the people in it. They are defending an economy. Sea lanes, shipping, chokepoints like the Strait of Hormuz. Most of us depend on all of it every day and never really think about any of it. They put it all on the line for our way of life, and they deserve the best technology we can design, build, and deliver, at a speed that matters. We owe it to them. That is the standard I think our industry should be working toward, and it is the standard we are working toward at Spectrum Control. 

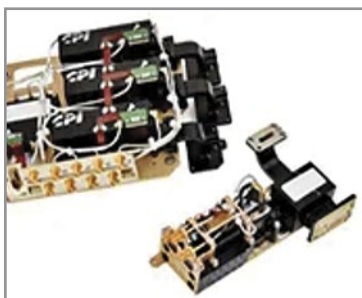
• Spectrum Control •



24.5-29 GHz GaN Power Amplifier

The TMC2111-D is a two-stage, single-ended GaN HEMT power amplifier MMIC covering 24.5 to 29 GHz and delivering 52 W of saturated output. The design is internally matched, eliminating the need for RF port matching, and is fabricated on a 4-mil SiC substrate biased at 28 VDC. Its layout is optimized to lower peak junction temperature for rugged operation. At 29 GHz on a 5G NR signal it has demonstrated 10 W linear output at 3.5% EVM with 30 dBc ACLR. Supplied as bare die, it targets solid-state power amplifiers, extended range fixed wireless access, SATCOM, and military radar and EW.

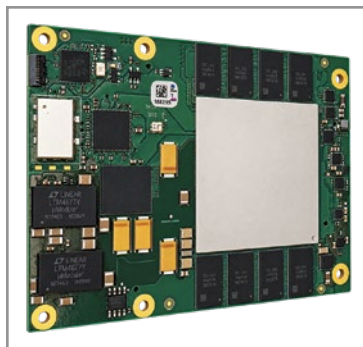
MMTRON



GaN Library v26.5.11

Version 26.5.11 is the latest release of the Modelithics Qorvo GaN Library, a collection of high-accuracy nonlinear simulation models for Qorvo GaN die and packaged transistor devices. The models run in the Keysight ADS and the Cadence AWR Design Environments and have features including variable bias, temperature scaling, self-heating, intrinsic I-V sensing, and bond wire on/off modes for die parts. Each model is measurement-validated against broadband S-parameters and load-pull data, with example projects and power amplifier reference designs that support first-pass GaN PA design.

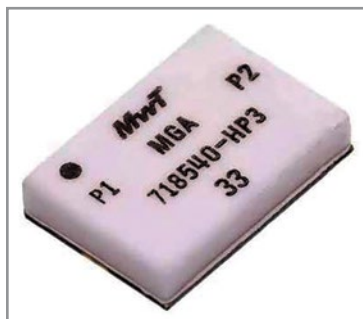
MODELITHICS



ASTRO RFSoc System-on-Module

ASTRO is a direct-RF system-on-module built on the AMD Zynq UltraScale+ RFSoc Gen 3, which combines RF data converters, FPGA fabric, and quad ARM processors on one device. The module integrates eight 5 GS/s 14-bit ADCs and eight 10 GS/s 14-bit DACs on compact 94 by 69 mm board. The module has reconfigurable onboard or external sample clocking and a multichannel, multimodule sync controller for coherent operation. Designed to drop onto custom carrier boards including ASTRO Nova and 3U VPX, it targets digital beamforming, radar, and multichannel software-defined radio in low-SWaP airborne, unmanned, and distributed sensing systems.

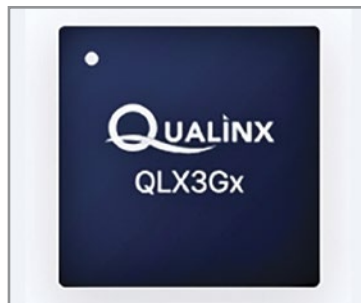
SLIPSTREAM DESIGN



10-W GaN Power Amplifier

The MGA-718540-HP3 is a 10 W GaN power amplifier operating from 7.1 to 8.5 GHz with 14 dB gain and 40% power-added efficiency. CW output is 10 W, OIP3 is 54 dBm (34 dBm per tone), and the RF input and output are matched to 50 ohms. The device is biased at 28 V and mounted on a solid copper base for thermal management, giving an overall thermal resistance of 3.3 C/W. It suits X-band radar, military communications, and other high-efficiency amplification requirements.

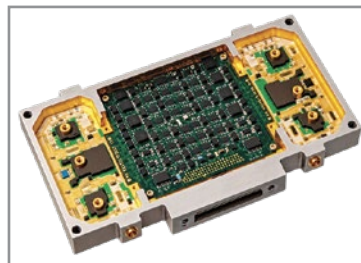
CML MICRO



Dual-Band GNSS SoC

The QLX3Gx is a low-power dual-band GNSS system-on-chip built on Qualinx's Dragonfly Digital RF architecture, which moves the traditionally analog receiver front end into the digital domain using high-speed ADCs and DSP. A single chip combines the digital RF front end with a multi-constellation GNSS baseband engine, keeping tracking and navigation on chip. It draws about 1 mW in low-duty-cycle GNSS mode, roughly 10 mW in continuous tracking, and under 10 uW in deep sleep. The software-reconfigurable design adds hardware-native Galileo OSNMA authentication for anti-spoofing in IoT, wearable, and asset-tracking devices.

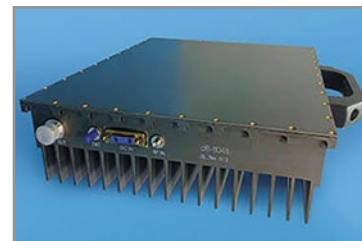
QUALINX



Integrated Microwave Assemblies

These nitrated microwave assemblies include beamformers, complex oscillator assemblies, frequency converter assemblies, and switch matrix systems for defense, satellite, and commercial systems. Its patented Multi-Mix multilayer laminate technology fuses circuits Teflon on Teflon into a uniform structure, placing features on inner layers to cut assembly size and weight and reaching up to 5X to 10X reduction over traditional converters. The SOSA-aligned mmW-IMA family includes 2 to 18 and 18 to 40 GHz converters and synthesizers in a 3U VPX form factor, with outputs from 500 MHz to 22 GHz and 29 to 43.56 GHz.

CRANE AEROSPACE & ELECTRONICS



GaN Pulsed Power Amplifier

The dB-8048 is a GaN-on-SiC solid-state power amplifier operating from 2.9 to 3.3 GHz and delivering 1.5 kW of peak output power in pulsed operation, with instantaneous pulse operation across the full band and a duty cycle up to 10%. Input and output impedance is 50 ohms. A modular, scalable architecture allows phase combining to reach 6 kW and 10 kW output. Small and lightweight with built-in fan cooling, it is designed for MIL-STD applications including radar, high-resolution SAR, and ground, naval, and airborne platforms where reliability and ruggedness are critical.

DB CONTROL



SATCOM/Radar Rotary Joints

These rotary joints pass RF signals across a rotational interface through waveguide or coaxial lines, and are available in single, dual, and multi-channel configurations for S, C, and X-band operation. Ancillary elements can be integrated to form a complete rotational subsystem: high-power waveguide and coaxial RF channels, slip rings or roll rings for power and data, azimuth positioning with encoder, resolver, or Inductosyn, and fiber-optic or fluid rotary joints. They are well suited for military-qualified ground, ship-board, and airborne SATCOM and radar systems.

DIAMOND ANTENNA

Taking 6G Waveform Generation Into Sub-Terahertz Bands

by Rohde & Schwarz

GENERATING and analyzing candidate 6G waveforms above 100 GHz places demands on both the signal itself and the test equipment used to create it. The attraction of the sub-THz spectrum is straightforward: frequencies between 100 and 300 GHz offer extremely wide bandwidths and, in principle, the capacity needed for very high data rates. The difficulty is that the RF hardware becomes less forgiving as frequency rises. Phase noise, linearity, and power-amplifier efficiency all become more significant constraints, meaning that the choice of waveform and the measurement architecture are closely linked.

A Rohde & Schwarz testbed developed for sub-THz 6G research illustrates one way to address those prob-

lems using commercially available instruments. The system generates and analyzes DFT-s-OFDM waveforms and extends the measurement path into the 70 to 170 GHz region using external frequency-conversion front ends. A custom graphical interface coordinates the instruments, waveform parameters, and measurement sequence.

Why DFT-s-OFDM Matters at Sub-THz Frequencies

The waveform used in the testbed is based on discrete Fourier transform spread OFDM (DFT-s-OFDM). It combines many of the useful properties of OFDM with a lower peak-to-average power ratio. That distinction becomes particularly important at sub-THz frequencies, where available RF output

power is limited and power-amplifier efficiency is a major concern. A waveform with a high PAPR forces an amplifier to operate with additional back-off to preserve linearity, reducing the usable transmitted power. Lowering PAPR therefore makes better use of the available RF hardware.

The proposed numerology is also substantially different from conventional 5G NR. The subcarrier spacing is 1.92 MHz, which is 128 times the 15 kHz reference spacing used in 5G NR. The larger spacing is intended to make the waveform more tolerant of the increased phase noise encountered at sub-THz frequencies while also allowing low-latency FFT processing. The cyclic prefix is approximately 79 ns, a value chosen to accommodate the short delay spreads expected in small-cell deployments.

The time-domain structure moves away from the traditional slot concept. Transmission can begin or end at nearly any DFT-s-OFDM symbol, producing a minimum latency of about 600 ns plus processing time. For control signaling and system information, the structure is organized around 1 ms subframes. Each subframe contains eight TDD periods, each with 208 symbols. A slightly extended cyclic prefix is inserted every 52nd symbol so that each 1 ms subframe contains

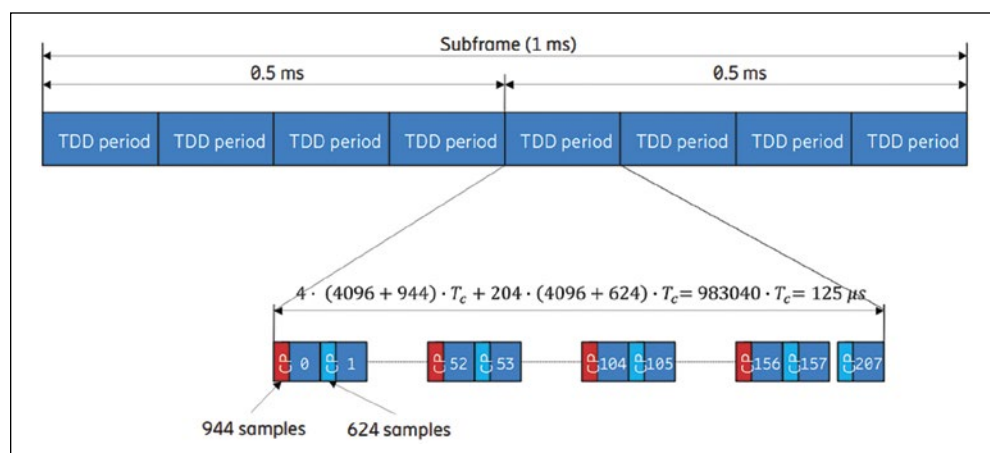


Figure 1—Time-domain structure for the proposed DFT-s-OFDM waveform, organized as eight TDD periods within a 1 ms subframe.

an integer number of DFT-s-OFDM symbols. This avoids the much longer cyclic-prefix interval that would result from directly scaling the 5G NR structure (Figure 1).

Dynamic TDD provides additional flexibility. Three predefined downlink-to-uplink ratios are supported: 3:1, 1:1, and 1:3. Each 208-symbol TDD period includes a 12-symbol guard interval, while the uplink allo-

Building the Signal Chain

The testbed separates the baseband/IF generation and analysis functions from the sub-THz frequency conversion. An R&S SFI100A vector signal generator produces the intermediate-frequency signal. That signal is applied to an external transmit frontend, either an FE110 or FE170, which translates it to the required RF frequency. The FE110 covers 70

second frontend downconverts the sub-THz signal to an IF that can be analyzed by an R&S FSW signal and spectrum analyzer (Figure 3).

Synchronization is critical in a measurement system spanning several instruments and frequency converters. The SFI100A supplies a 10 MHz reference for frequency alignment, a 1 GHz reference split between the transmit and receive frontends, and a trigger to synchronize the start of the FSW measurement. Keeping the generation, conversion, and analysis chain on common references reduces the number of independent frequency and timing errors that would otherwise complicate evaluation of the waveform itself.

The architecture also makes it possible to work at IF without a front end

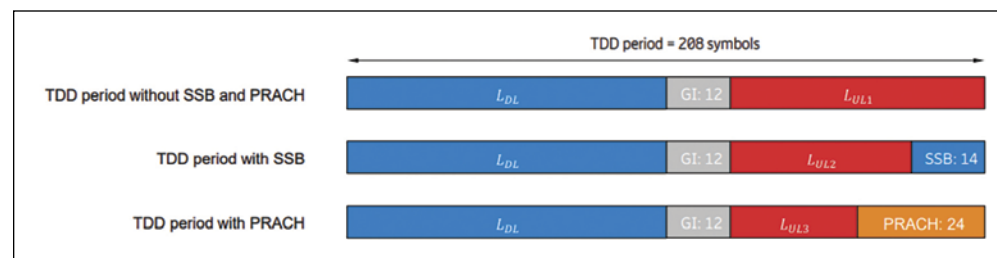


Figure 2—Supported 208-symbol TDD periods showing configurations without SSB/PRACH, with SSB, and with PRACH.

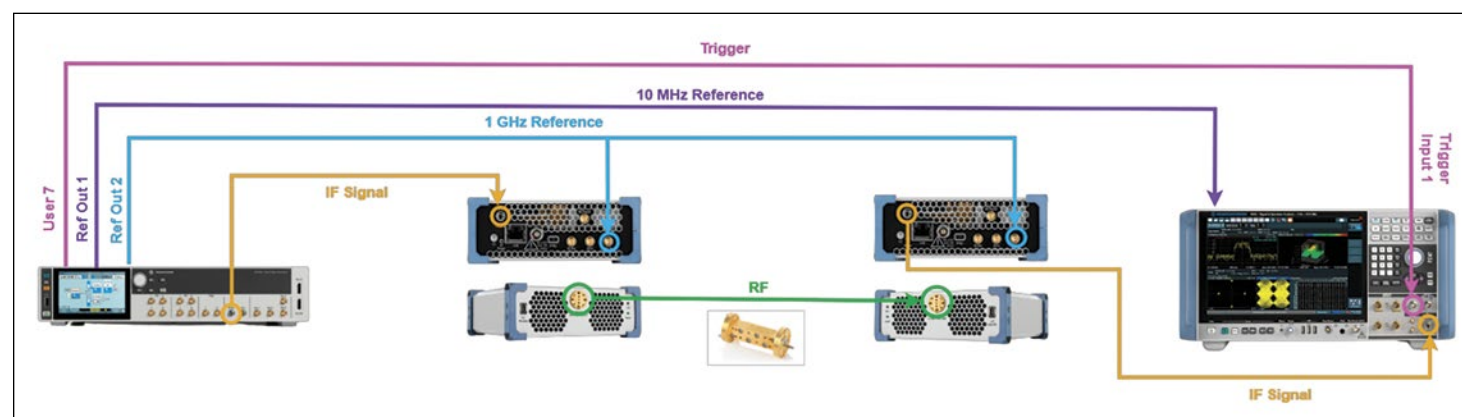


Figure 3—Sub-THz testbed connection diagram. The SFI100A generates the IF signal, external front ends perform up- and downconversion, and the FSW analyzes the resulting IF signal. Common 10 MHz and 1 GHz references, along with a trigger, synchronize the measurement chain.

Ratio	Downlink	Guard	Uplink		
	L_{DL}	L_{GI}	$L_{UL,1}$ (no PRACH, no SSB)	$L_{UL,1}$ (SSB)	$L_{UL,1}$ (PRACH)
3:1	140	12	56	42	32
1:1	90	12	106	92	82
1:3	48	12	148	134	124

Table 1—Supported downlink-to-uplink ratios and symbol allocations for TDD operation with and without SSB and PRACH.

cation changes depending on whether the synchronization signal blocks or the physical random-access channel are present. The arrangement allows the waveform to adapt to different traffic patterns while retaining the short symbol timing required for low-latency operation (Table 1 and Figure 2).

to 110 GHz, while the FE170 extends operation from 110 to 170 GHz.

After upconversion, the RF signal travels through a waveguide section. A power amplifier and bandpass filter can be inserted in that path when additional gain or signal conditioning is required. At the receive side, a

when appropriate. In that mode, the signal generator's frequency range used by the setup is 11 to 21 GHz. Adding the FE110 or FE170 moves the same basic measurement concept into the millimeter-wave and sub-THz bands without changing the overall workflow.

continued on page 16

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Controlling a Wideband 6G Experiment

A custom Python-based graphical interface was developed to manage the testbed. Rather than requiring the user to configure the signal generator, analyzer, front ends, and waveform software separately, the GUI provides a single control point for the entire chain. It handles instrument connections, waveform generation and loading, signal parameters, and measurement configuration (Figure 4).

The available controls illustrate the number of variables involved in a sub-THz waveform experiment. The user can select center frequency, output power, subcarrier spacing, uplink or downlink operation, TDD ratio, modulation, DMRS placement, FFT size,

occupied bandwidth, and the number of TDD periods. The FFT size is fixed at 4096 in this implementation. Subcarrier spacing can be selected from 30 kHz to 1.92 MHz, and the number of active subcarriers determines occupied bandwidth in combination with that spacing.

Reference-signal configuration is equally important. The system can generate waveforms with synchronization signal blocks with Physical Random Access Channel (PRACH) or without either structure, depending on the measurement objective. Demodulation reference signals can be placed every 16th or 32nd symbol. The implementation also allows different pilot/data arrangements, enabling the engineer to examine how the receiver behaves with specific time-frequency structures rather than

treating the signal as an undifferentiated block of occupied spectrum.

Once the parameters are entered, the software can generate a new waveform or load an existing waveform and its associated demodulation file. Applying the configuration sends the waveform and operating parameters to the signal generator and the demodulation information to the analyzer. For research work, this degree of automation is valuable because it makes repeated measurements with changed parameters more practical and reduces the chance that the generator and analyzer will be configured inconsistently.

Multi-Gigahertz Bandwidth in Practice

The example measurements in the

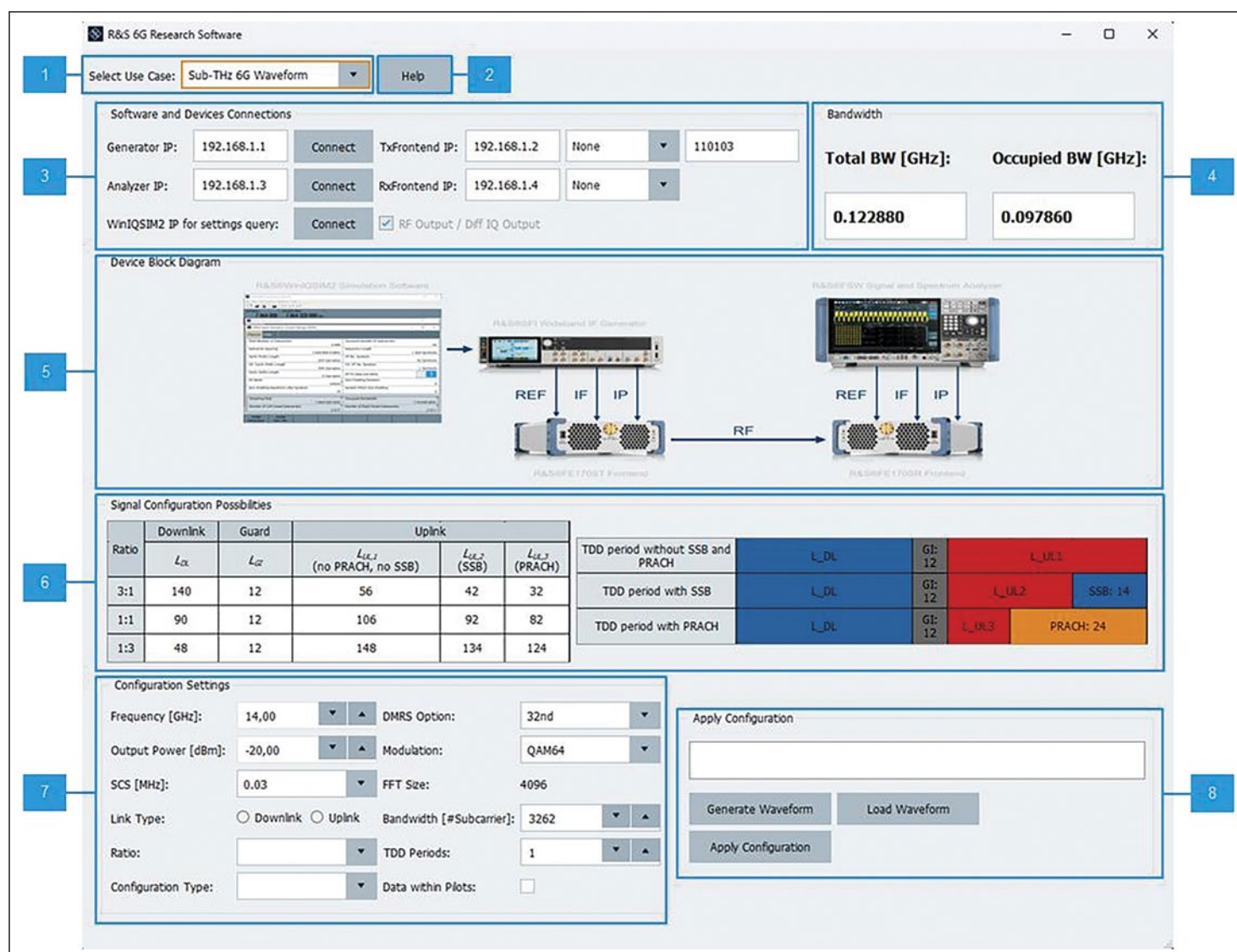


Figure 4—R&S 6G Research Software GUI for configuring the sub-terahertz testbed, waveform parameters, and instrument connections.

application note show both downlink and uplink configurations. In each case, the generated signal occupies 3.84 GHz within a total configured bandwidth of 7.86 GHz. The downlink example includes an SSB, while the uplink example includes PRACH. The analyzer displays the captured waveform, power spectrum, result summary, and modulation constellation, allowing the engineer to examine both spectral behavior and demodulation quality in a single measurement (Figure 5).

Those bandwidth figures help put the test problem into perspective (Figure 6). At sub-THz frequencies, the challenge is not simply reaching a high carrier frequency. The measurement system must generate, translate, transport, receive, and analyze signals spanning several gigahertz while maintaining adequate frequency coherence and modulation quality. Every part of the chain, from references and converters to waveguide components and analyzer bandwidth, contributes to the measurement uncertainty.

The testbed does not represent a finalized 6G air interface; the waveform concept is intended for research and evaluation. What it demonstrates is the instrumentation architecture required to investigate candidate signals in frequency ranges that conventional microwave test setups cannot reach directly. DFT-s-OFDM provides a waveform with characteristics suited to power-limited sub-THz hardware, while external converters allow familiar vector signal generation and analysis techniques to be extended well beyond 100 GHz.

As 6G research pushes toward wider channels and higher carrier frequen-

cies, the distinction between waveform design and RF test engineering will become increasingly difficult to separate. A promising modulation format still must survive real oscillators, amplifiers, converters, filters, and propagation paths. Sub-THz testbeds such as this one provide the bridge between a waveform that works in simulation and one

that can be generated, transmitted, and measured with actual hardware. 

Note: This article was adapted from Rohde & Schwarz Application Note 1SL417, "Sub-THz (6G) Communication Signal Generation and Analysis," by Damjan Perencevic and Meik Kottkamp, February 2026.

• Rohde & Schwarz •

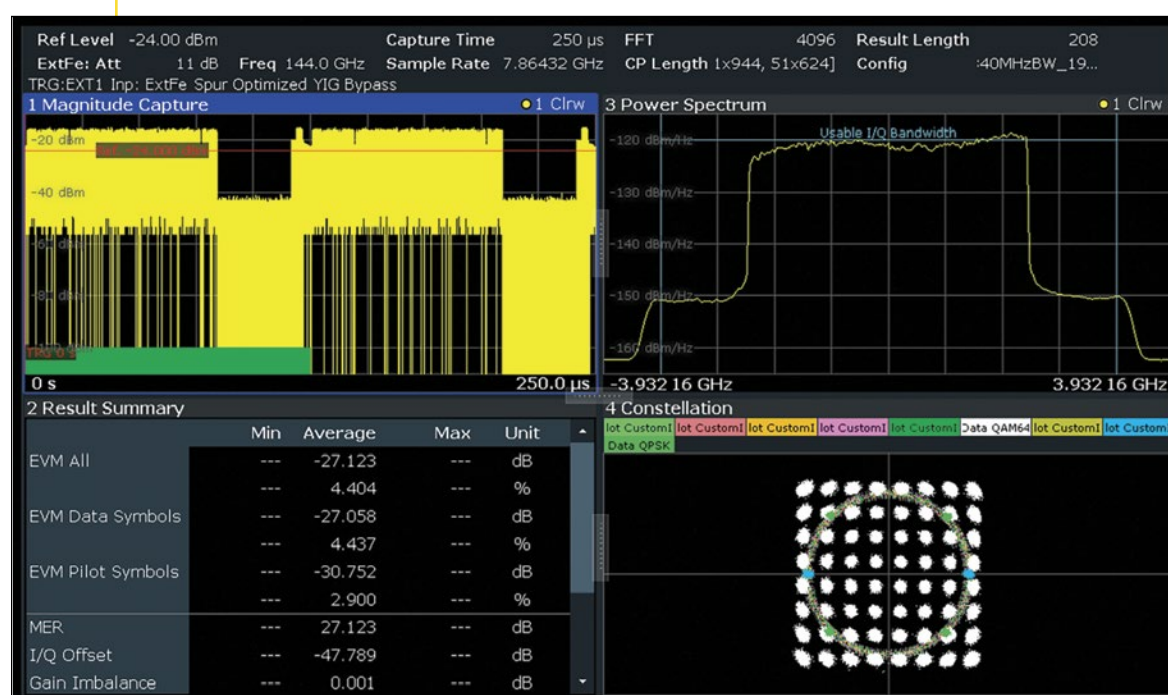


Figure 5—Example downlink configuration with SSB using 7.86 GHz total bandwidth and 3.84 GHz occupied bandwidth.

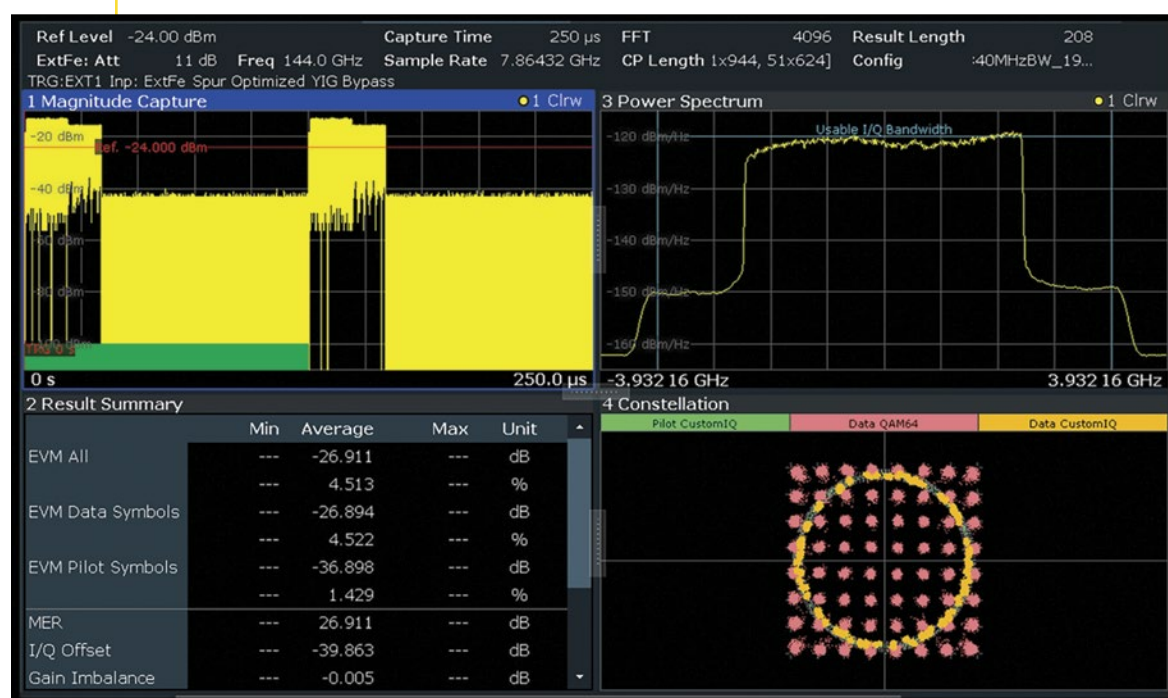


Figure 6—Example uplink configuration with PRACH, using a total bandwidth of 7.86 GHz and an occupied bandwidth of 3.84 GHz.

5G NR-NTN: Design and Test Challenges for Satellite-Connected IoT

by Raghul Premkumar, Business Development/Applications Engineer, Anritsu Company

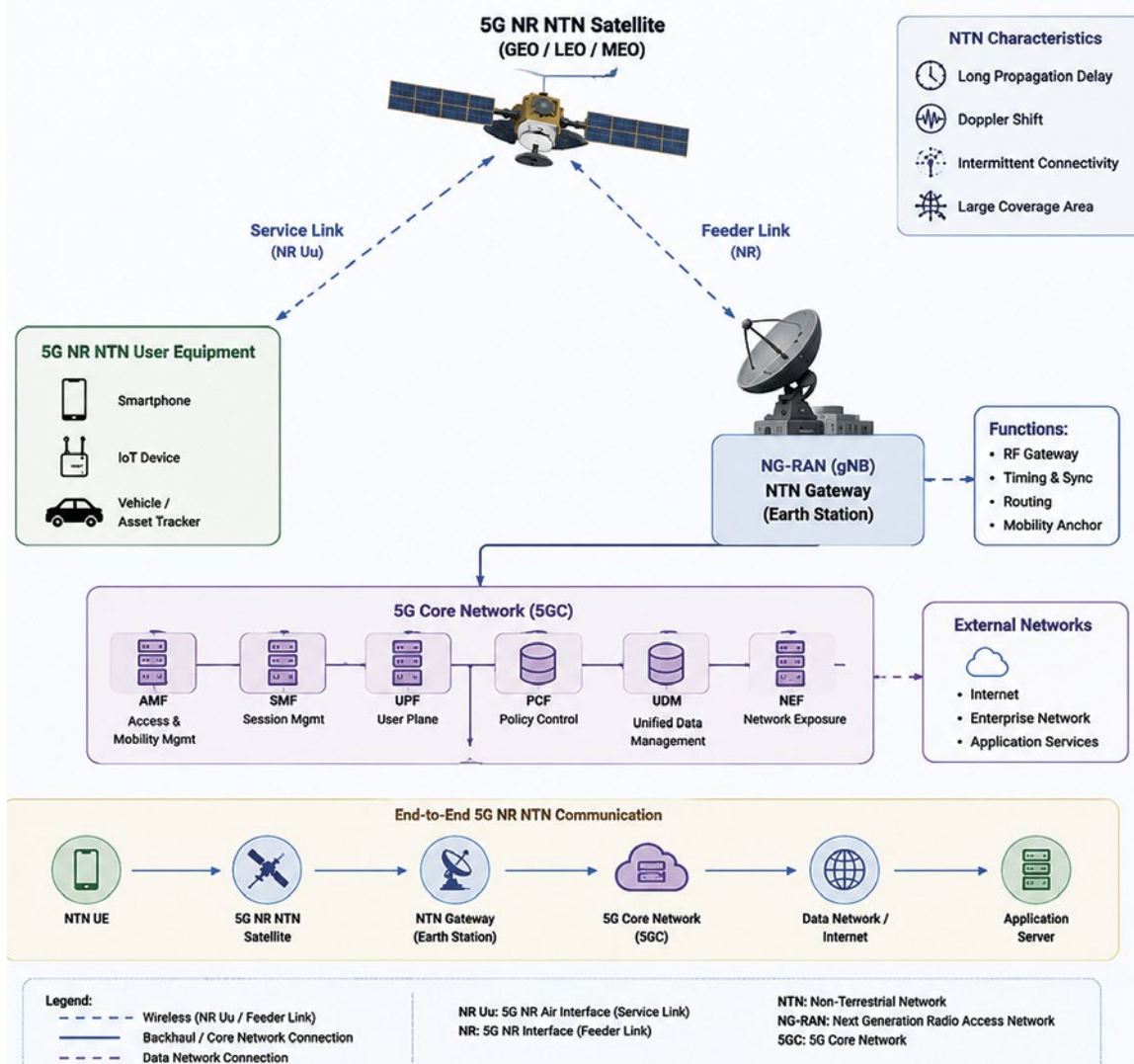
FOR THE PAST decade, cellular IoT has extended low-power connectivity to places where conventional network economics could not justify

the deployment of terrestrial infrastructure. Even so, roughly four-fifths of the earth's surface remains beyond the useful range of a base station, including

many locations where trackers, sensors, and monitors are expected to operate.

Until recently, reaching those areas required a separate proprietary satellite radio in addition to the cellular modem. Non-terrestrial networks (NTN) change that model by incorporating satellite access into the 5G standard, allowing the same modem to connect via satellite when no terrestrial cell is available. This application note examines what NR NTN requires of an IoT device and the components and test systems needed for verification, moving from the state of 3GPP standards and emerging use cases to the design challenges, test methods, and measurements that determine whether a device is ready for deployment.

5G NR NTN (Non-Terrestrial Network) Architecture



Evolution Toward 5G NR-NTN

3GPP's formal study of satellite integration with 5G began during Release 15, with study activities examining the use of NTN as part of the 5G system. One, in the radio group, examined how 5G NR could be adapted for NTNs and produced technical report TR 38.811. The other study was in

the services group and focused on the use of satellite access in 5G.

3GPP Release 16 continued to move momentum forward with a follow-up study. The IoT-specific branch took shape a bit later, when a study item on NB-IoT and eMTC support for NTN was approved at the TSG-RAN meeting – at which “NTN for IoT” became its own line of development rather than simply a subset of the NR effort.

The work advanced significantly with 3GPP Release 17, frozen in March 2022, which standardized NTN support for 5G NR (NR-NTN) and IoT technologies such as NB-IoT and eMTC (IoT-NTN). The central challenge Release 17 addressed was timing and synchronization. Because the satellite and the “base station” are in motion, an IoT device must maintain timing and a stable frequency relative to a constantly shifting reference.

The adopted solution uses the UE’s Global Navigation Satellite System (GNSS) position, together with satellite ephemeris data — which describes where a satellite is expected to be at

specific times — to pre-compensate for propagation delay and the Doppler effect before transmission. Because this kept changes to the air interface relatively modest, the existing NB-IoT and LTE-M ecosystem could be extended rather than replaced.

Why NTN for IoT?

IoT is particularly well suited to NTN because satellite links provide what many of these devices need without requiring the throughput or latency of a terrestrial base station. For example, a tracker typically sends small, infrequent, delay-tolerant messages, while the NB-IoT/Cat technologies it already uses are designed for low signal-to-noise ratios (SNR), extended coverage, and low power consumption. By standardizing satellite access within 3GPP, NTN draws on established cellular chipsets and module supply chains.

Use Cases Benefiting From NTN

Remote asset tracking and massive IoT are expected to generate much

of the traffic in the coming years. Shipping container and trailer tracking, fleet telematics, and heavy-equipment monitoring all involve routes that repeatedly move in and out of cellular coverage. A hybrid device can remain on the terrestrial network wherever service is available and fall back to satellite only when necessary, eliminating dead zones without requiring a second radio. Agriculture follows the same pattern, as soil and moisture sensors, weather stations, and livestock trackers often operate across such enormous amounts of land that no mobile operator can economically cover with towers.

Emergency and public-safety IoT applications also benefit from NTN because the incidents that create the greatest need for communications often occur where infrastructure is unavailable, damaged, or destroyed. Low-rate satellite messaging can provide a fallback path for alerts and telemetry when the ground network is down, while the same link can support command and control for unmanned aircraft oper-

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Use Cases Benefiting From NR NTN

1 Seamless Hybrid Connectivity (Terrestrial + Satellite)



A hybrid device can remain on the terrestrial network wherever service is available and fall back to satellite only when necessary, eliminating dead zones without requiring a second radio.

2 Emergency and Public-Safety IoT Applications



Reliable connectivity for mission-critical communications and IoT devices in remote or disaster areas where terrestrial networks are unavailable.

continued from page 17

ating beyond terrestrial coverage. In addition, offshore equipment and cargo spend much of their operating life outside the reach of terrestrial networks, making a standards-based 3GPP module more attractive than a proprietary terminal in cost and integration.

Challenges for Design Engineers

Engineers responsible for developing IoT devices have a multitude of challenges to overcome to ensure operation in these use cases. Three key factors are power efficiency, RF signal quality, and antennas.

Power Efficiency – The first design priority is efficient use of power because nearly every demand imposed by the link consumes energy. A tight link budget requires extensive repetition and low coding rates, which lengthens on-air time and increases the energy required per delivered bit well beyond the terrestrial case. GNSS acquisition adds a fixed cost to every transmission, and in a device that reports only a few times per day, a fix can dominate the daily energy budget. Sparse Low Earth Orbit (LEO) constellations and discontinuous coverage add another layer of complexity. Extended discontinuous reception (eDRX) and Power Saving Mode (PSM) are essential for achieving multi-year battery life, making the coordination of sleep schedules with satellite visibility a primary design consideration.

RF Signaling – The principal RF challenges are propagation delay, Doppler, and link budget. Satellites in geosynchronous orbit impose a round-trip delay of about 500 ms. LEO reduces that delay to tens of milliseconds but replaces it with rapidly changing Doppler and frequent handovers, which Geostationary Earth Orbit (GEO) satellites avoid because they hold a fixed position relative to the ground.

A LEO satellite moving about 7.5 km/s can produce Doppler shifts of tens of kilohertz at L- and S-band,

requiring Doppler pre-compensation based on satellite ephemeris and UE position information. The link budget remains tight in either orbit because satellites are constrained in power and bandwidth, slant-range path loss is high, and the device antenna is typically small and inefficient. As a result, UE design depends heavily on coverage-enhancement techniques and antenna efficiency to recover sufficient margin.

Antenna – Speaking of antennas, their design and form factor are major hurdles for engineers as they translate the link-budget problem into mechanical terms, since compact size and strong antenna performance tend to work against one another. NTN IoT operates in the mobile-satellite service spectrum, principally the L-band near 1.6 GHz and the S-band near 2 GHz, in bands n255 and n256. Because satellite links experience high free-space path loss and significant Doppler shift, antenna efficiency, frequency accuracy, and UE transmit performance become particularly important for maintaining reliable connectivity. Ku- and Ka-bands are generally reserved for VSAT terminals. At these margins, antenna efficiency and radiation pattern are extremely important. A tracker (or other IoT device) cannot assume a favorable orientation toward the satellite, and the combined behavior of the antenna, ground plane, and enclosure determines whether the device connects the link.

Test and Evaluation Solutions

Validating an NR NTN IoT device is difficult because the conditions that place it under the greatest stress are those the 3GPP standard was written to overcome. A static base-station emulator cannot be used to reproduce an accurate scenario because in the real world a satellite is moving, which creates long propagation delays, large and time-varying Doppler, and intermittent coverage. Consequently, a device can pass every static conformance test and

still fail when exposed to an actual satellite link.

For these reasons, a test environment dedicated to NTN must factor:

Satellite Links – The first requirement is a channel environment that faithfully reproduces the satellite link. That means applying controlled propagation delay, Doppler shift, and data rate based on a defined orbital pass, along with appropriate path loss and fading, and then confirming that the device's pre-compensation removes these effects. Verifying pre-compensation is equally important because an incorrect delay or frequency correction can place the transmission in the wrong time window or channel – an error that may remain invisible in a static test. For these reasons, a satellite channel emulator driven by an orbital profile is the recommended solution.

Signaling – The next challenge is signaling because a round trip of nearly 600 ms, once processing is included, disrupts procedures that terrestrial networks complete in milliseconds. Random access procedures must accommodate timing uncertainties and extended propagation delays far beyond terrestrial ranges and be exercised at those limits.

Hybrid Automatic Repeat Request (HARQ), an error-control method used in cellular networks, also requires waiting hundreds of milliseconds for feedback, which can stall the process. Consequently, NTN permits HARQ feedback to be disabled or to account for longer propagation delays and Radio Link Control (RLC) retransmission, defined as resending of missing or corrupted data in any cellular or IoT network.

Latency – Radio Resource Control (RRC) procedures that manage the control relationship between a device and the network, ephemeris-driven cell selection, and paging must also be tested under latency conditions. This requires a network emulator that can impose the delay and NTN-specific signaling conditions.

In LEO systems, the serving satellite's location may change every few minutes, requiring the device to go through mobility procedures as link quality changes throughout a pass. Feeder-link switching and transitions between terrestrial networks (TN) and non-terrestrial networks (NTN) introduce additional mobility events, each creating an opportunity for the device to drop a session or fail to reacquire the network. As a result, link adaptation must be verified across the full SNR range of a pass from low-elevation acquisition through peak visibility and back again.

Interoperability – Perhaps the least forgiving requirement is interoperability, because NTN isn't a single network. Services run across multiple constellations and operators, so a device that works perfectly on one network may not behave the same way on another.

Additionally, an operator can layer its own requirements on top of the 3GPP baseline, so the device must satisfy the targeted release and the operator's acceptance criteria. Hybrid operation — where a single-subscription device moves seamlessly between terrestrial cellular coverage and satellite coverage based on network availability using whichever is available — adds another challenge. Devices must be validated in both domains and throughout the handoff between them. This is why conformance testing alone won't suffice. Carrier acceptance and cross-network testing are essential.

Key Measurements to Verify Device Design

Four measurements – transmit power and modulation accuracy, spectral emissions, receiver sensitivity and throughput, and Block Error Rate (BLER) – determine whether a UE is fit for deployment. Each corresponds to a failure mode that NTN makes more likely. Throughput and link reliability must be measured at the low SNR that defines the NTN operating point, with an emphasis on BLER and sustained throughput under heavy repetition rather than peak data rate. Establishing that margin requires precise control of signal level, and the passive components in the test path can matter as much as the instruments themselves.

A brief description of each measurement and importance follows:

1. **Transmit Power & Modulation Accuracy:** Measures Error Vector Magnitude (EVM) and output power to ensure linear transmitter behavior under high-peak-to-average power ratio (PAPR) OFDM signals.
2. **Spectral Emissions:** Verifies Adjacent Channel Leakage Ratio (ACLR) and Spectrum Emission Mask (SEM) to prevent out-of-band interference.
3. **Receiver Sensitivity and Throughput:** Evaluates minimum input level performance and demodulation under low Signal-to-Interference-plus-Noise Ratio (SINR) conditions typical of space-to-ground links.

4. **BLER:** Characterizes link quality and data recovery under degraded channel environments.

Latency and timing performance combine fixed propagation delay with the accuracy of the device's timing advance and synchronization. Testing must determine whether pre-compensation places each transmission in the correct window and whether end-to-end latency remains within the application's limit after the entire path is considered. In addition, power consumption must be characterized across every operating state because battery life is determined by the interaction between them rather than by a single figure. Active transmit current under repetition, the energy required for GNSS acquisition, and sleep current in eDRX and PSM all contribute to the total. A credible estimate requires measurement of the actual duty cycle imposed by the satellite-visibility schedule.

End-to-end validation confirms the behavior of the complete chain, from the device through the satellite, gateway, and core network to the application server. Emulation provides controlled access to the RF and protocol layers, while live over-the-air (OTA) testing verifies operation against an actual constellation. Ultimately, message-delivery reliability across the entire path and over an extended period is the measurement most likely to predict field performance.

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1205POC/1210POC Series Power over Coax Injection Chokes

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- Small sizes to reduce board area of overall system solutions
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Testing Solutions for NRNTN

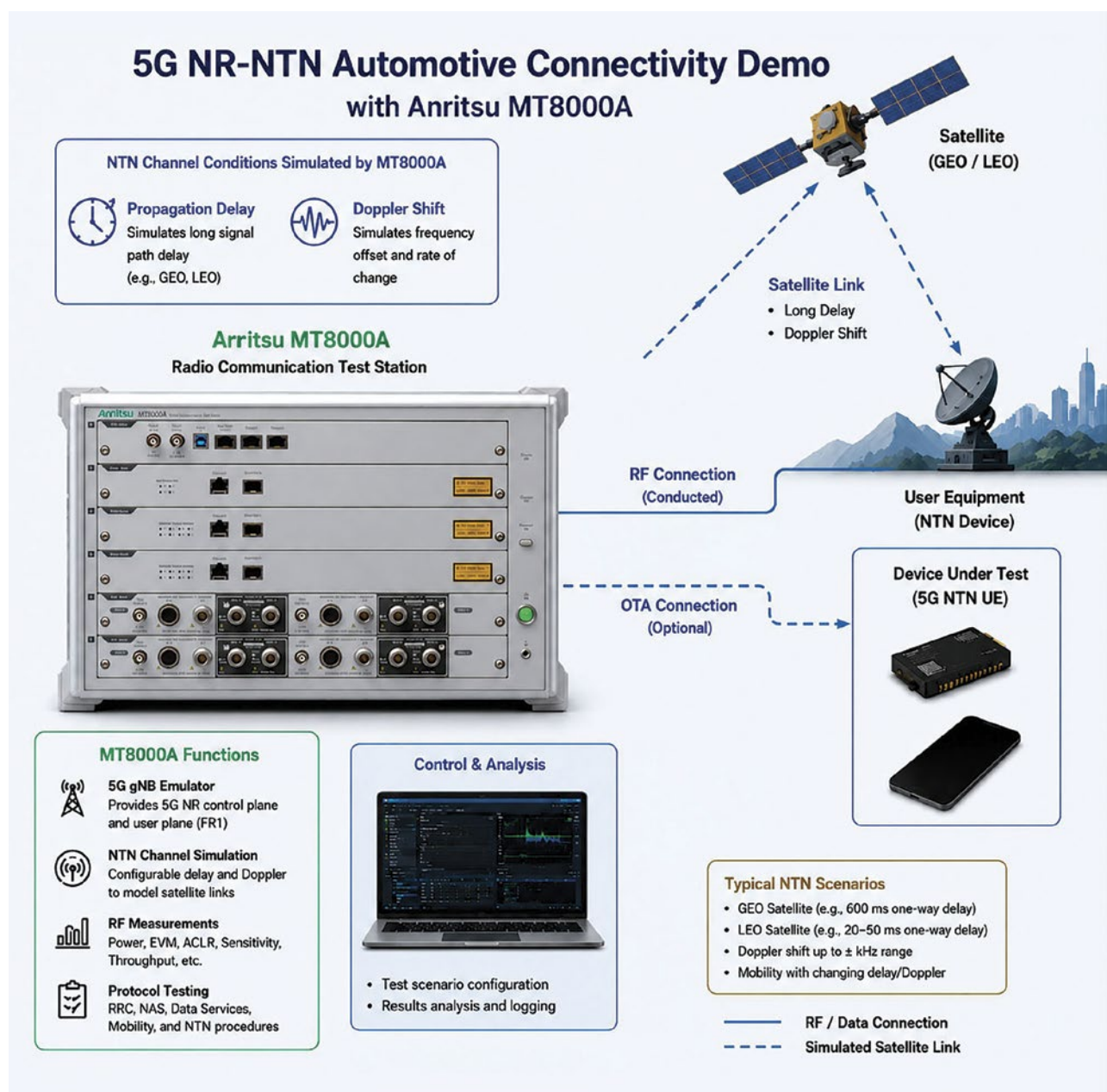
Given the dynamics associated with NR NTN, test solutions must have specific measurement capability. The Radio Communication Test Station MT8000A supports test conditions that comply with 3GPP Release 17 and simulates propagation delay and Doppler shift in 5G NR NTN environments. The tester introduces controlled propagation delay conditions so engineers can verify that a 5G NR NTN device maintains synchronization and protocol performance under satellite-like conditions. Doppler frequency offset, Doppler rate of change, and frequency tracking behavior can be simulated, so engineers can verify that the device can acquire the NTN signal, maintain a 5G NR connection, and correct frequency errors over time.

The Signalling Tester Base Station Simulator MD8430A is for data session testing. It supports Layer 1, Layer 2, and Layer 3 protocol verification. For NB-IoT devices, where multi-year battery life is an important design consideration, the MD8430A can be used to verify power-saving features, such as PSM and eDRX. The MD8430A also supports baseband fading to emulate different radio propagation conditions by applying 3GPP-defined channel models, enabling device performance to be evaluated under controlled multipath and fading environments. NB-IoT NTN GEO testing is supported to measure propagation delay and satellite link behavior.

NB-IoT uses techniques, such as repetition and narrowband operation, to extend coverage. The MD8430A can test device behavior under challenging channel conditions to verify

a specific network under conditions that arise only when the satellite is moving and the round trip is long.

Reproducing those conditions requires NTN-capable test platforms,



that a module maintains communication at weak signal levels.

Conclusion

NR NTN brings satellite access into the same standards framework, silicon ecosystem, and increasingly the same subscription model as terrestrial cellular networks. The remaining constraint on adoption is no longer whether the technology can work, but whether UE will operate reliably on

including Anritsu's MT8000A for NR device RF and protocol testing and MD8430A for NB-IoT signaling and terrestrial-to-satellite roaming. These solutions distinguish UE that passes conformance from devices that will perform reliably in the field — and that is where the engineering effort must be concentrated. Learn more by visiting www.Anritsu.com.

• Anritsu Company •

Quantum Gravimeter Navigates Vessel Without GPS

Q-CTRL has reported what it describes as the first fully GNSS-independent maritime navigation demonstration to use a quantum gravimeter. The company says it corrected inertial navigation over an 83-km area in the Coral Sea off the east coast of Australia.

The trials were run aboard the research vessel MV Miss Rankin during a week-long campaign north of Cairns. Using its Ironstone Opal platform, Q-CTRL performed autonomous gravity mapping and gravimetric navigation with no satellite input in the measurement chain, with about 1 nm of positioning accuracy. The company reports that figure as more than ten times better than the navigation-grade inertial backup used as a comparison.

The technique, which Q-CTRL calls GravNav, measures the small spatial variations in Earth's gravity field and matches them against a satellite-derived gravity anomaly map to bound the drift that accumulates in any inertial navigation system. It extends the company's earlier MagNav work, which uses magnetic-field signatures for the same map-matching approach. Q-CTRL posi-

tions gravimetric navigation as better suited to the ocean because gravity maps at sea are more widely available than comparable magnetic survey data. And as the sensor doesn't transmit or receive radio signals, it cannot be jammed or spoofed and can function day or night in any visibility.

Gravity-aided navigation has been around for decades, but Q-CTRL's approach needs no GPS signal, no periodic recalibration, and no special infrastructure. The company attributes this to what it terms software-ruggedized quantum sensing, as the instrument

pairs an atomic gravimeter with a classical accelerometer for bias stabilization, and AI-based control software holds the sensor stable under open-ocean motion.

Conventional cold-atom gravimeters typically require active temperature control, gyroscopic motion stabilization, and frequent manual recalibration. Q-CTRL installed the unit in an unconditioned passenger cabin and ran it autonomously, with the company reporting comparable performance between gimballed and rigid strapdown mounting. The authors identify reducing the sensor's size, weight, and power below the range of high-performing classical maritime systems as the next step toward wider unmanned deployment.

The demonstration lands amid rising interference with satellite navigation. Citing figures from maritime intelligence firm Windward, Q-CTRL says 978,000 GPS jamming events were logged worldwide in the first quarter of 2026, with 98% of them in the Middle East and affecting more than 1,100 vessels. Deliberate jamming and spoofing around the Strait of Hormuz have disrupted shipping across the region, and tankers have run aground after undetected spoofing.

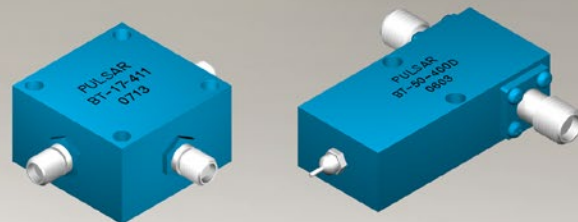
Q-CTRL's navigation work has drawn interests from the defense community including contracts and engagements with DARPA, the U.S. Defense Innovation Unit, the Australian Department of Defense, the UK Royal Navy, and other AUKUS partners. Its April 2025 MagNav trials on ground and airborne platforms were among Time magazine's Best Inventions of 2025. 



The Q-CTRL Ironstone Opal quantum navigation system. Source: Q-CTRL

Bias Tees

Up to 85 GHz



Freq. Range	Isolation (dB) min.	Insertion Loss (dB) max.	Current (mA) max.	VSWR max.	Model Number
50-800 MHz	25	0.6	6000	1.20:1	BT-10-E
10-1000 MHz	25	0.5	1000	1.20:1	BT-20
800-1000 MHz	30	0.5	5000	1.50:1	BT-21
1700-2000 MHz	30	0.5	5000	1.50:1	BT-22
500-2500 MHz	25	1.0	200	1.20:1	BT-02
10-3000 MHz	25	1.8	3000	1.50:1	BT-06-411
500-3000 MHz	25	1.0	500	1.20:1	BT-05
500-3000 MHz	30	1.8	2000	1.50:1	BT-23
10-4200 MHz	25	1.2	200	1.20:1	BT-03
1000-5000 MHz	35	1.0	1000	1.50:1	BT-04
100-6000 MHz	30	1.5	500	1.50:1	BT-07
0.5-10 GHz	30	1.0	200	1.50:1	BT-26
100 KHz - 12.4 GHz	40	1.5	700	1.60:1	BT-52-400D
100 KHz - 18.0 GHz	40	2.0	700	1.60:1	BT-53-400D
0.3-18.0 GHz	25	1.5	500	1.60:1	BT-29
30 KHz - 27.0 GHz	40	2.2	500	1.80:1	BT-51
30 KHz - 40.0 GHz	40	3.0	500	1.80:1	BT-50
30 KHz - 70.0 GHz	30	3.5	500	2.00:1	BT-54-401
30 KHz - 85.0 GHz	30	4.0	500	2.00:1	BT-55-401

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hanced and latch-up immune, it delivers 0.16 dB insertion loss and 64 dB isolation at 85 MHz, second and third harmonics of -121 and -140 dBc at 17 MHz, and high surge protection for cable modems, gateways, and set-top boxes.

PSEMI



Mechanical Switch Assemblies

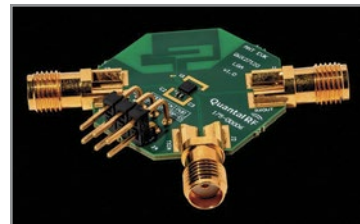
The RCMX Series mechanical switch

assemblies pair latching electro-mechanical SPDT through SP8T switches operating DC to 67 GHz with high isolation and low insertion loss. Each switch is absorptive with a break-before-make action and a typical 2-million-cycle life. RF connectors sit on the front of a compact benchtop housing, with USB or Ethernet control, a Windows GUI, and a Windows and Linux API.

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The QWX27104 is a DPD-efficient linear front-end module for Wi-Fi 7 and Wi-Fi 8 applications, integrat-



ing the power amplifier, LNA, switch, and coupler on a single die built on GlobalFoundries 8SW RF-SOI. The linear CMOS RF-SOI architecture holds EVM within 0.5 dB across channels at 160 MHz, yielding up to 3 dB more mask-compliant output power with a lighter DPD load and real-time self-optimization.

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GUERRILLA RF



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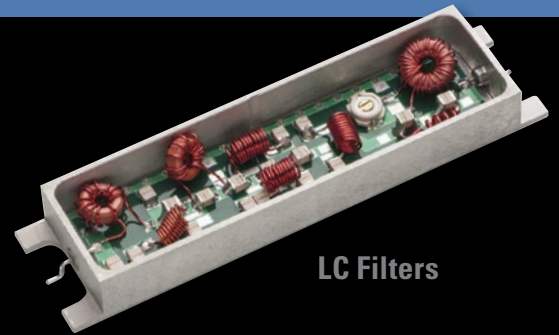
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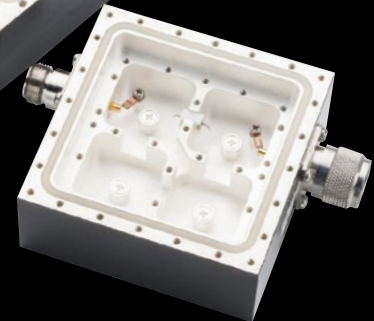
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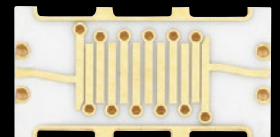
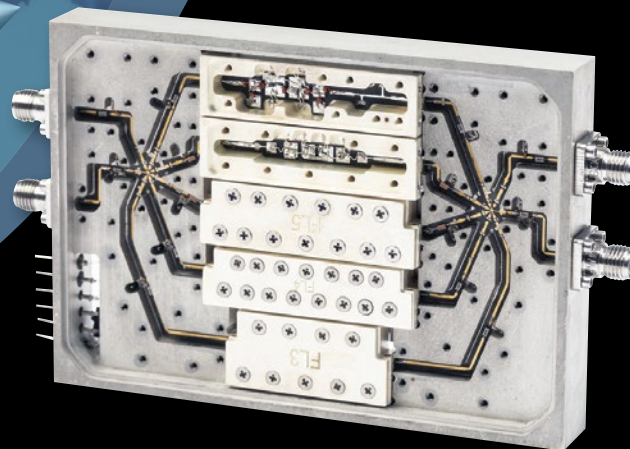
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How RF Filters Protect Military Systems

By **ANATECH ELECTRONICS**

Military radios, radar, electronic warfare receivers, and satellite links all have to do the same basic thing: extract useful information from an electromagnetic environment that may be crowded, noisy, or deliberately hostile. RF and microwave filters are a critical part of that process. They determine which signals reach sensitive receiver stages, help keep transmitter energy where it belongs, and limit the interference one system can create for another.

Defense hardware may operate across the frequency range from low-frequency bands to the millimeter-wave region. It must also work through shock, vibration, wide temperature swings, and, in some cases, radiation and vacuum. That makes filter design as much a mechanical and environmental problem as an electrical one. A device that meets its response on the bench but drifts with temperature, fails under high RF power, or cannot survive the platform environment has little value in the field.

At its simplest, a filter defines what portion of the spectrum is allowed to pass. A bandpass filter passes a selected band and rejects frequencies above and below it. Low-pass and high-pass filters reject energy on one side of a cutoff frequency, while band-reject or notch filters suppress a narrower region of unwanted energy. Defense systems often use several of these functions in the same RF chain: a preselector ahead of a receiver, harmonic filtering

after a transmitter, and one or more notches to suppress known interferers.

The specification is more involved than center frequency and bandwidth. Insertion loss determines how much wanted signal is sacrificed in the passband. Rejection quantifies how strongly unwanted energy is attenuated, and skirt selectivity describes how quickly the response transitions from the passband to the stopband. Return



Figure 1 — A U.S. Marine Corps operator using an AN/PRC-117 multiband manpack radio during Exercise Steel Knight. Source: U.S. Marine Corps, public domain

loss indicates how well the filter is impedance matched, while group-delay variation and phase response become important when the waveform itself has to be preserved. Power handling, temperature stability, and resonator Q can be just as important as the frequency response.

The physical implementation depends heavily on frequency, bandwidth, size, and power. Lumped-element filters can be very compact at lower microwave frequencies, while ceramic, coaxial, cavity, and waveguide structures are used when higher Q, lower loss, greater power handling, or higher operating frequencies are required. Surface-acoustic-wave and bulk-acoustic-wave technologies offer very small size in appropriate frequency ranges, although they are not suited to every high-power military application. At X-band and above, waveguide remains attractive where low loss and high power handling outweigh size and weight penalties.

Maintaining Clear Communications

Tactical radios rarely operate in isolation. Multiple emitters may share the same vehicle, command post, aircraft, or geographic area, often on closely spaced channels. A strong nearby transmission can desensitize a receiver long before the desired signal becomes unusable on its own.

Filtering provides the selectivity needed to separate those signals. Adjacent-channel rejection keeps strong energy outside the assigned channel from overwhelming a weaker wanted signal, while transmitter-side filtering suppresses harmonics and other unwanted spectral content before it reaches the antenna. In compact multi-radio installations, these functions can be the difference between radios merely working individually and working together (**Figure 1**).

Co-site operation is especially difficult because the interfering transmitter may be only a few feet from the victim receiver and may share the same platform power and antenna environment. A front-end preselector can reduce the amount of unwanted RF presented to the low-noise amplifier and mixer, improving the receiver's ability to operate in the presence of high-level off-channel signals. Diplexers and duplexers may also be used to route different bands, or transmit and receive paths, through a common antenna while maintaining the required isolation.

Frequency-agile and software-defined radios complicate the problem. A very wide RF front end gives the radio flexibility, but it also admits more unwanted energy. One common answer is a switched filter bank: the radio selects the appropriate filter as it changes bands. Tunable filters can reduce the number of fixed sections, but they must maintain low loss, adequate rejection, and repeatable tuning across temperature and over the life of the equipment.

Enhancing Target Detection in Radar Systems

Radar presents a different set of tradeoffs. The receiver must preserve very weak echoes while rejecting out-of-band energy and interference. Low insertion loss matters because signal power lost ahead of sensitive receiver stages directly reduces the margin available for detection.

At the same time, the filter must provide sufficient rejection to prevent unwanted energy from consuming the receiver's dynamic range or driving front-end components into compression.

On the transmit side, pulsed radar places additional demands on power handling and transient response. High peak power can create large electric fields and localized heating inside resonators, connectors, and coupling structures. The filter has to tolerate those stresses without arcing, detuning, or suffering permanent damage. Average power still matters because dissipated RF energy becomes heat that must be removed from the package.

The shape of the filter response also affects the radar waveform. Excessive group-delay variation across the occupied bandwidth can distort short pulses or wideband modulated signals, which in turn can degrade range resolution or complicate pulse compression. A design with excellent stopband rejection is therefore not automatically the best choice if it achieves that rejection at the expense of unacceptable passband loss or delay variation.

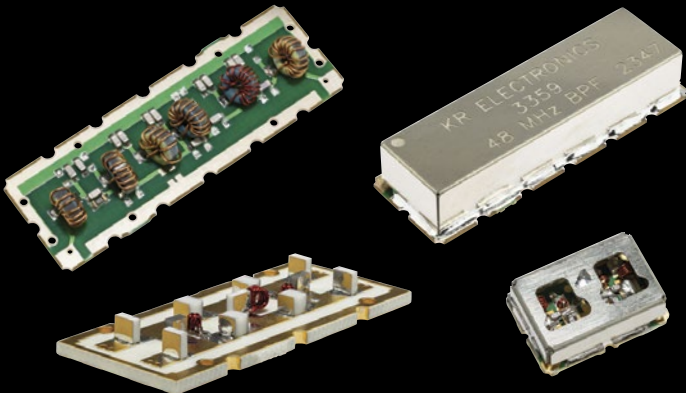
AESA (Active Electronically Scanned Array) radars add a packaging problem to the electrical one (**see Figure 2**). Their dense arrays of transmit/receive modules leave little room for bulky RF hardware. Depending on the architecture, filtering may be distributed among individual channels, subarrays, or common front-end sections. In each case, the available volume is limited, and parasitics from packaging, interconnects, and transitions are accounted for in the filter design. The result is a constant tradeoff among selectivity, loss, power

continued on page 26

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Operating on the Electronic Battlefield

Electronic warfare raises the stakes because the interference may be intentional. In a receiver-protection or preselection chain, filters attenuate high-level unwanted signals before they reach sensitive circuitry. The challenge is the enormous difference in signal levels: a jammer may be many orders of magnitude stronger than the signal the receiver is trying to detect.

That makes front-end linearity and filtering closely related. Even when an unwanted signal is outside the band of interest, it can drive an amplifier or mixer into compression or generate intermodulation products that fall inside the desired band. Once those products are created, later digital processing cannot simply remove the damage. The best place to reject the offending signal is therefore often as early in the RF chain as practical.

A fixed filter cannot solve every jamming problem, particularly when the jammer occupies the same band as the desired signal. Still, switched preselector banks, tunable bandpass filters, and narrow notches can reduce exposure to known or rapidly changing threats. The key is to obtain useful rejection without closing off so much spectrum that the receiver loses the wide instantaneous bandwidth needed for search, intercept, or situational awareness.

Intelligence-gathering receivers face a related problem. They may need to observe very broad spans of spectrum and then isolate individual emitters for characterization. Selectivity alone is not enough; the filter must preserve the amplitude, phase, and modulation characteristics required for analysis. In SIGINT and ELINT systems, the filter architecture therefore becomes part of the compromise between instantaneous bandwidth, sensitivity, dynamic range, and probability of intercept.

Space and Satellite Communications

For military satellite systems, electrical performance is only part of the requirement. Filters may be exposed to ionizing radiation, repeated temperature cycling, and vacuum, with no possibility of repair once the payload is in orbit. Reliability, size, and weight are therefore tightly coupled to RF performance.

Satellite payloads also tend to place a premium on low insertion loss because every fraction of a decibel affects the link budget. High-Q cavity and waveguide filters (**Figure 3**) are commonly attractive where their size can be accommodated. In multicarrier, high-power payloads, passive intermodulation can become another concern: imperfect joints, surfaces, or materials can generate unwanted



Figure 2 — An avionics specialist discusses an AESA radar installed in an F-16.

Source: U.S. Air National Guard, public domain

mixing products even though the filter itself contains no active devices. Mechanical design and manufacturing quality are therefore part of the RF specification.

Ground terminals face the opposite end of the link. They may need to recover a very weak satellite signal while rejecting much stronger nearby terrestrial interference. That puts a premium on low loss, a stable frequency response, and adequate front-end rejection. As military and commercial systems occupy increasingly adjacent spectrum, the transition bands available to the filter may become narrower, forcing

greater selectivity from the same or smaller package.

Key Design Challenges

Size and weight. Aircraft, vehicles, UAVs, and man-portable equipment have little room for excess hardware. The filter must deliver the required response in the smallest practical package without sacrificing robustness. Miniaturization usually carries a cost: smaller resonators can increase loss, reduce power handling, or make the response more sensitive to manufacturing tolerances.

Temperature stability. A passband that moves as the platform heats or cools can be as damaging as excessive insertion loss. Resonator dimensions and dielectric properties change with temperature, so materials and mechanical construction must be selected to hold the frequency response across the specified range. In tightly specified filters, temperature compensation may be required to keep the passband where the system expects it.

Power handling. Radar transmitters and other high-power RF systems can place substantial thermal and electrical stress on a filter. Geometry, conductor finish, dielectric materials, connector transitions, and thermal paths all influence the maximum usable power. A design that withstands high peak power may still fail to meet its average-power requirement if it cannot remove heat efficiently.

Selectivity versus loss. Sharper skirts and greater rejection generally require more resonators or stronger coupling constraints, which can increase insertion loss, size, and sensitivity to tolerances. The system designer therefore has to specify the actual rejection required rather than simply asking for the steepest possible response.

Signal fidelity. Wideband radar, communications, and EW waveforms can be sensitive to amplitude ripple, phase non-linearity, and group-delay variation across the passband. Those parameters may receive less attention than insertion loss and rejection, but they can determine whether a high-data-rate waveform or short radar pulse remains usable after passing through the filter.

Future Trends and Evolving Requirements

Defense radio architectures are becoming more software-defined, but that does not eliminate the analog filtering problem. A radio that can change bands or waveforms in software still needs an RF front end that can reject signals outside the channel or operating band before they

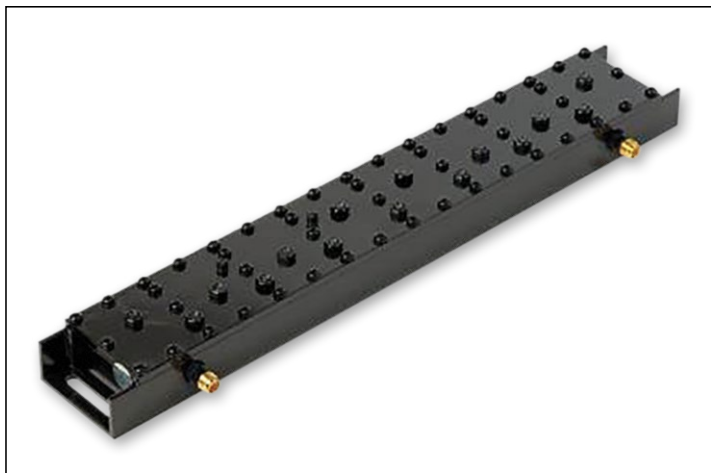


Figure 3 — Anatech Electronics' AE10000WB11552 waveguide bandpass filter is centered at 10 GHz with a 9875 to 10125 MHz passband, 0.5 dB maximum insertion loss, and at least 50 dB rejection outside the passband at the specified offsets.

consume dynamic range. Digital filtering is extremely powerful once the signal has been converted, but it cannot restore headroom that was already lost due to an overloaded analog front end.

That is why tunable and reconfigurable filtering continues to attract attention. Switched filter banks provide a proven approach, while electronically tunable resonators can offer finer control with fewer discrete sections. The engineering challenge is to achieve that flexibility without introducing excessive loss, distortion, tuning error, or control complexity. In many military systems, the most practical answer will remain a hybrid architecture that combines fixed high-performance filters with selectable or tunable sections.

Integration is moving in the same direction. As RF functions are packed more tightly and semiconductor-based implementations expand, filter designs must increasingly co-exist with amplifiers, converters, and processors within very small footprints. At millimeter-wave frequencies, even package transitions and short interconnects become electrically significant, so the boundary between the filter and the rest of the RF assembly becomes less distinct. Technologies such as planar resonators, integrated passive structures, and substrate-integrated waveguides can reduce size, while conventional cavity and waveguide approaches remain useful where loss and power handling dominate the requirement.

Conclusion

Filters seldom attract the attention given to radars, radios, or EW processors, but they determine how much of the electromagnetic environment the rest of the system has to

deal with. In communications, they make co-site operation practical; in radar, they preserve weak echoes without distorting the waveform; in EW, they protect sensitive receiver stages and help manage enormous signal-level differences; and in satellite links, they must deliver the same performance under severe environmental constraints.

The design problem is rarely a matter of maximizing one specification. Low insertion loss, steep rejection, small size, wide bandwidth, high power handling, stable delay, and temperature immunity all compete with one another. The useful filter is the one that balances those requirements for the specific platform and threat environment. As defense systems move toward smaller packages, reconfigurable architectures, wider instantaneous bandwidths, and higher frequencies, that balance will become more demanding rather than less. The component may be passive, but its effect on system performance is anything but. ■

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Software-Defined Radio Product Survey

SOFTWARE-DEFINED RADIO HAS BEEN AROUND

long enough that the term itself no longer sounds particularly revolutionary. What has changed dramatically is what sits behind it. Improvements in RF data converters, FPGAs, RFSocS, and high-speed digital interfaces have steadily pushed the boundary between the analog and digital portions of the radio toward the antenna, reducing the amount of hardware required to perform functions that once demanded multiple conversion stages.

The traditional SDR architecture remains widely used and for good reason. An RF front end selects and conditions the desired portion of spectrum, mixers translate it to a lower frequency, and ADCs and DACs provide the bridge to an FPGA, DSP, or general-purpose processor. Integrated RF transceivers have condensed much of that chain into a single IC, and devices such as Lime Microsystems' LMS7002M and many products from Analog Devices have enabled complete radios to shrink to module and even M. 2 card dimensions. But that is no longer the only way to build an SDR.

Converter sample rates have increased to the point where direct-RF sampling can eliminate one or more analog frequency-conversion stages. Analog Devices' AD9084, for example, combines four 20-GSPS, 12-bit ADCs with four 28-GSPS, 16-bit DACs and provides usable analog bandwidth to 18 GHz. Texas Instruments' AFE8108 integrates eight 6-GSPS receive ADCs and eight 12-GSPS transmit DACs, with RF coverage from 100 MHz to 7.4 GHz and a signal bandwidth of up to 2.4 GHz when operated as a 2T2R device.

The FPGA has been moving in the same direction. AMD's third-generation Zynq UltraScale+ RFSoc combines RF ADCs and DACs, programmable logic, and Arm processing in one device. The ZU47DR provides eight 14-bit ADCs operating at up to 5 GSPS and eight 14-bit DACs at up to 9.85 GSPS, with RF input frequencies up to 6 GHz. More recently, devices such as the Altera Agilex 9 Direct RF-Series have pushed integrated converter rates to 64 GSPS. The AGRW027 incorporates eight 10-bit ADCs and eight 10-bit DACs, each capable of 64-GSPS operation.

This level of integration is now appearing in deployable COTS hardware rather than simply evaluation plat-

forms. Mercury Systems and Annapolis Micro Systems both offer 3U VPX products based on the Agilex 9 Direct RF architecture, while Abaco Systems packages AMD RFSoc technology in a SOSA-aligned VPX card. Epiq Solutions offers SDR hardware ranging from very small, embedded modules to multichannel VPX products, and Ettus Research has extended its USRP family to 20 GHz with the X420, which provides 1 GHz of instantaneous bandwidth per channel.

The effect is especially significant in EW, SIGINT, radar, and spectrum-monitoring applications. Wider instantaneous bandwidth enables simultaneous observation of more spectrum, while multiple phase-coherent channels support direction-finding, beamforming, and phased-array systems. Moving more of the signal chain into programmable devices also enables changes to channelization, filtering, modulation, demodulation, and other functions without redesigning the RF hardware.

There are limits to how far the concept can be taken. Direct-RF does not eliminate the analog front end. Filters, amplifiers, protection devices, switches, and, often, frequency conversion are still needed, depending on operating frequency, dynamic-range requirements, and the signal environment. Sampling rate should also not be confused with instantaneous bandwidth: a converter operating at tens of gigasamples per second does not automatically provide an SDR with an equivalent usable RF bandwidth.

What has changed is the number of architectural choices available to the designer. At one end are compact integrated RF transceivers optimized for relatively modest bandwidths and low SWaP. At the other are direct-sampling devices capable of digitizing enormous portions of microwave spectrum, backed by FPGAs powerful enough to process the resulting data streams in real time. Between them are RFSocS, embedded SDR modules, networked instruments and rugged VPX cards.

The products in the following survey reflect that range. They are not intended to be direct substitutes for one another. Rather, they show how broadly the definition of software-defined radio has expanded and how rapidly the analog-to-digital boundary continues to move toward the antenna. ■

Software-Defined Radio Product Survey

Representative current products spanning direct-RF devices, RFSocS, modules, VPX cards and complete SDR platforms

Manufacturer	Product	Type	RF Range / BW	Channels	BW / Sample Rate	Resolution*	Form Factor	Web
ANALOG DEVICES	AD9084 Apollo MxFE	Direct-RF front end	to 18 GHz	4 Rx / 4 Tx	10-GHz IBW (2T2R); ADC 20 GSPS; DAC 28 GSPS	12 / 16 bit	24 × 26-mm BGA	analog.com
TEXAS INSTRUMENTS	AFE8108	RF-sampling transceiver	100 MHz–7.4 GHz	8 Rx / 8 Tx	800 MHz (8T8R); 1.6 GHz (4T4R); 2.4 GHz (2T2R); ADC 6 GSPS; DAC 12 GSPS	—	17 × 17-mm FCBGA	ti.com
AMD	ZU47DR	RFSoc	RF input to 6 GHz	8 ADC / 8 DAC	ADC 5 GSPS; DAC 9.85 GSPS	14 / 14 bit	RFSoc IC	amd.com
LIME MICROSYSTEM	LimeSDR XTRX	SDR module	30 MHz–3.8 GHz	2 Rx / 2 Tx	120-MHz BW; 120 MSPS SISO / 90 MSPS MIMO	12 bit	Mini PCIe	limemicro.com
ETTUS RESEARCH/ NI	USRP X420	Networked SDR	10 MHz–20 GHz	2 Rx / 2 Tx	1-GHz IBW/ch.; IQ rates to 1.25 GS/s	12 / 14 bit	Networked SDR	ettus.com
EPIQ SOLUTIONS	Sidekiq VPX400	SDR transceiver card	to 6 GHz	4 Rx / 4 Tx	up to 450-MHz IBW/ch.	16 / 14 bit	3U VPX, SOSA-aligned	epiqsolutions.com
PER VICES	Cyan	Wideband SDR subsystem	near DC–18 GHz	up to 16 Rx/Tx	1 GHz/ch.; optional 3 GHz/ch.	16 bit; 12 bit (3-GHz option)	19-in., 3U	pervices.com
MERCURY SYSTEMS (PENTEK)	DRF5270	Direct-RF FPGA card	Direct RF	8 ADC / 8 DAC	64-GSPS ADC/DAC	10 / 10 bit	3U OpenVPX, SOSA-aligned	www.mrcy.com
ANNAPOLIS MICRO SYSTEMS	WILDSTAR 3AE1	Direct-RF FPGA processor	32-GHz ADC input BW	8 ADC / 8 DAC	64-GSPS ADC/DAC	10 / 10 bit	3U OpenVPX, SOSA-aligned	annapmicro.com
ABACO SYSTEMS	VP431	RFSoc processing card	Direct RF	8 analog in / 8 analog out	ADC 5 GSPS; DAC 10 GSPS	14 bit	3U VPX, SOSA-aligned	abaco.com
SUNDANCE DSP	PCIe104-RFSOC	Embedded RFSoc board	Direct RF	up to 8 ADC / 8 DAC	ADC 4.096 GSPS; DAC 6.554 GSPS	12 / 14 bit	PCIe/104	sundancedsp.com

* Where two converter resolutions are shown, ADC resolution is listed first and DAC resolution second. Specifications are based on manufacturer-published information available in September 2026; maximum bandwidth, channel count and sample rate may depend on configuration.

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