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MICROWAVE PRODUCT DIGEST & TECHNOLOGIES



INNOVATIONS IN FILTER TECHNOLOGY

MPD

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EDITOR'S CHOICE

Featured Products

K-band Upconverter Mixer

The QPC4510 is a K-band image-reject upconverter mixer with an integrated x2 LO buffer amplifier and output variable-gain amplifier. It outputs an RF frequency from 17.7 to 26.5 GHz using IF inputs from DC to 4 GHz and a corresponding LO frequency. The QPC4510 provides 32 dBm of output at -10 dBm input power per tone and has a conversion gain of 13 dB. Optional nulling of the LO can improve LO Isolation by 30 dB.

QORVO



1-mm Connector

This 1-mm coaxial connector series complies with the IEEE Std 287 and supports frequencies up to 110 GHz. Featuring a compression-mount center contact, the connector accommodates a range of PC board thicknesses. They also have a threaded mount to reduce complexity and have a VSWR of 1.8:1 to 67 GHz and 1.9:1 from 67 to 110 GHz.

HIROSE ELECTRIC



Millimeter-wave Voltage-Variable Attenuator

The WR-8 VVA voltage-variable attenuator uses Faraday rotation technology and is optimized for systems operating from 90 to 140 GHz. It has less than 1 dB of insertion loss and is available in WR-6.5, WR-8, and WR-10 waveguide configurations. The attenuator can handle RF input power of 2.4 W, and each unit is characterized using a vector network analyzer, with data provided to the customer.

MICRO-HARMONICS



Coaxial Cavity Filter

The ZVBP-8100-S+ is a coaxial cavity filter that uses high-Q resonant structures to support narrowband applications. It is manufactured with a protective mechanical assembly that limits accidental detuning and reduces the need for field retuning or factory service. Typical insertion loss is 0.75 dB with return loss of 19 dB and rejection of 96 dB. Its stopband extends to 17 GHz, and the filter supports input power levels up to 5 W.

MINI-CIRCUITS



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

The Age of Connected EVERYTHING



Barry Manz

The Internet of Things spent its early years proving that devices could be connected to networks. That work is largely done. Today, the harder questions involve scale, reliability, and responsibility. IoT systems are no longer isolated experiments or pilot programs; they are embedded in facilities, vehicles, infrastructure, and industrial processes where failure carries operational and financial consequences.

What distinguishes the current phase of IoT is not the number of connected devices, but what we expect them to do: operate continuously, tolerate imperfect networks, receive updates without interruption, and remain secure over long service lives. They

must also integrate with existing operational technology, enterprise software, and regulatory frameworks, often under constraints that were not considered during early design phases.

As a result, IoT has shifted from connectivity to operations. The engineering effort now centers on managing fleets of heterogeneous devices, balancing local processing with cloud services, and maintaining trust across distributed systems that interact directly with the physical world. This evolution marks the point at which IoT stops being a novelty and begins behaving like infrastructure.

From the Editor, continued on page 18

In case you've been wondering about the future of MPD...

Microwave Product Digest has been in continuous publication for more than three decades, so longtime readers may have noticed we didn't send out any issues from January to March. That's because MPD is under new management, and we used the first quarter to put the operation on solid footing. Our editorial direction moving forward will be familiar, but we'll be covering more technical topics, providing insight from industry leaders, and digging deeper into the areas where the industry is moving fastest, from defense electronics and EW to the massive buildout of satellite constellations. If you're going to be in Boston for IMS 2026, please stop by Booth 17100 and we can tell you where we're taking MPD, and hear what you'd like to see covered.

IN THIS ISSUE

3 The Age of Connected
Everything
by Barry Manz

10

High-rel EMI Filters for
Military and Aerospace Systems
by Johanson Technology

6 Real-World Filters
vs. 6G Roadmaps
by Sam Benzacar

16

The Orbital Environment Is
Getting Crowded, and the
Math Is Getting Ugly
by Barry Manz

Components & Modules to 70 GHz

for mission-critical applications



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Thermal Power Sensor

The NRP150T thermal power sensor measures average power where signal modulation and waveform independence are required. It operates from 50 MHz to 6 GHz and supports average power measurements from 1 W to 150 W. The NRP150T can be used with compatible power meters or connected directly to a PC via USB.

ROHDE & SCHWARZ



RF Surge Protector

The MDGXZ+06NFN-A is a coaxial RF surge protector for systems with Type-N female-to-Type-N female interfaces. It passes DC up to 6 VDC and operates from 800 MHz to 2.5 GHz. The unit uses hybrid protection technology with a continuous power rating of 300 W and a surge current capacity of 20 kA. It meets IP67 ingress protection requirements and includes a hole-mount bracket for line-side installation in antenna and communication systems.

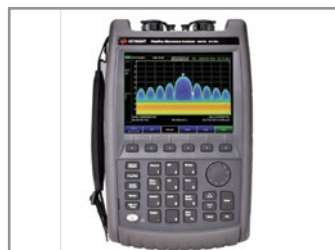
POLYPHASER



50 GHz Cable Assemblies

The PinPoint™ 50 GHz P1DB50-24M24M-36 36-in. cable assemblies offer high phase stability under flexure and temperature, low insertion loss, and low VSWR. They use armored low-loss coax with a 0.24-in. outer diameter, support more than 50,000 flex cycles, and operate up to 125° C without shrink-sleeve boots. Each assembly is terminated with stainless steel 2.4 mm male connectors.

P1DB



Portable Microwave Analyzer

The N9918B 26.5 GHz hand-held FieldFox microwave analyzer is an integrated RF and microwave test instrument for spectrum monitoring, signal analysis, interference location, and cable and antenna testing from 9 kHz to 26.5 GHz. It combines a spectrum analyzer, a cable and antenna tester, a pulse generator, power measurement, and optional vector network analysis functions.

KEYSIGHT TECHNOLOGIES



Quad Low-IF Receiver

The CMX992Q3 is an RF quadrature/low-IF receiver IC intended for use in analog and digital radio systems operating from 100 MHz to 1 GHz. It uses a supply voltage of 3 VDC to 3.6 VDC and is packaged in a surface-mount 48-VFQFN package. The device supports GMSK modulation at data rates up to 9.6 kb/s and operates over a temperature range from -40° C to +85° C.

CML MICROCIRCUITS



S-band Circulator

The C2AG23 S-band circulator operates from 2.7 GHz to 3.1 GHz with insertion loss of 0.2 dB, isolation of 20 dB, and a VSWR of 1.2:1. It routes energy between ports while directing reflected power to an adjacent port. It is rated for average forward power handling of 75 W and peak power handling near 750 W, with a drop-in configuration for integration into assemblies.

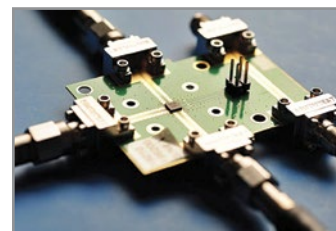
SONOMA SCIENTIFIC



Type-N Crimp Plug

The 0401-292-AJ is a Type-N male crimp plug intended for termination to LMR-240 coaxial cable and supports operation from DC to 6 GHz. It uses a crimp attachment that secures the connector to the cable braid and center conductor, and the interface mates with Type-N female connectors.

SAN-TRON



12 GHz SPDT Switch

The FW2002 SPDT switch operates from 30 MHz to 12 GHz and supports CW power handling of 15 W and pulsed power up to 30 W at 1 GHz. Its input third-order intercept point is 68 dBm, and insertion loss ranges from 0.4 dB at low frequencies to 1.9 dB at 12 GHz. The device uses differential control voltages with switching times of 150 to 250 ns and is packaged in a 3 mm x 3 mm QFN for board-level RF signal routing applications.

POLYFET RF DEVICES



1.85-mm Adapter

The PE91603 is a 1.85-mm male-to-1.85-mm female RF and microwave adapter that supports operation up to 65 GHz. It is used to connect compatible 1.85 mm interfaces while ensuring both signal continuity and mechanical alignment. This adapter is well-suited for test and measurement, laboratory, and system integration applications requiring consistent electrical performance across repeated connections in millimeter-wave environments.

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Solid State Switches



Detectors



Mixers & Active Mixers



Gain & Loss Equalizers



Integrated Microwave Assemblies (IMAs)



Isolators & Circulators



Monopulse Comparators



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Receiver Front Ends & Transceivers



Switch Filter Banks



Switch Matrices



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Real-World Filters vs. 6G Roadmaps



by Sam Benzacar, *President, Anatech Electronics*

I've designed RF and microwave filters for more than 35 years, and I have watched the industry repeatedly underestimate the need for filters. Looking at the current 6G roadmaps, I see this pattern repeating. But this time, these challenges will make every wireless standard before them seem relatively simple in comparison.

When we designed filters for early cellular systems at 800 and 90 MHz, we achieved insertion losses of 3 or 4 dB, and cavity filters provided more than adequate rejection. Today, 5G requires insertion losses of less than 2 dB and rejection of more than 40 dB. But the 6G standards propose that operation will enter the upper reaches of the millimeter-wave region and beyond.

Conductor losses scale with the square root of frequency. A filter topology that delivers 1 dB insertion loss at 30 GHz might exhibit 3 dB loss at 100 GHz using the same materials. At these frequencies, surface roughness—which is negligible at microwave frequencies—becomes a dominant loss mechanism because the skin depth approaches the size of the copper grain boundaries.

We also face a geometric conflict. I have designed cavity filters with unloaded Q-factors above 10,000, but they are physically large. Those dimensions do not fit in smartphones or millimeter-wave base station arrays, where element spacing is strictly limited by wavelength. We also cannot rely on bulk acoustic wave (BAW) and surface acoustic wave (SAW) filters, which revolutionized handsets. Their operating frequencies are limited to around 15 GHz due to material constraints in aluminum nitride and lithium niobate.

The industry has proposed alternatives like substrate-integrated waveguides (SIW), silicon micromachined cavities, and metamaterials. SIW filters typically achieve Q-factors of 200 to 500 at millimeter-wave frequencies, resulting in insertion losses that break link budgets. Micromachined air cavities struggle with manufacturing yield. Dielectric resonators offer high Q-factors but suffer from batch-to-batch variation. As for metamaterials, I have seen very few implementations that achieve compact size and adequate Q-factors simultaneously.

Integration presents another hurdle. Co-packaging filters with amplifiers requires isolation above 50

dB and careful management of parasitics. I have debugged enough modules to know that wire-bond inductance and solder-bump capacitance will shift filter responses. A filter showing 1.5 dB insertion loss on a test fixture often degrades to 2.2 dB after packaging. Electromagnetic simulation helps, but it does not capture every variable. Physical prototyping is still essential, and that takes time.

From a filter design standpoint, fundamental design theory does not disappear at these frequencies because coupled-resonator synthesis and network realizations still describe the desired transfer function. The issue is that what engineers mean by “standard topologies”, such as lumped element, microstrip, stripline, hairpins, interdigital structures, run into a steep wall set by loss, parasitics, and manufacturing tolerance.


For example, at 300 GHz the free-space wavelength is about 1 mm, so feature sizes and coupling gaps become so small that ordinary fabrication variation becomes extraordinarily challenging and package/transition discontinuities stop being “parasitic” and start behaving like unintended resonators.

In addition, conductor loss and surface roughness become dominant because the skin depth is minimal at these frequencies, so the effective RF resistance is driven by metallization quality and roughness statistics. This means that unloaded Q is reduced for many planar structures, forcing a more aggressive trade-off between selectivity and insertion loss.


So are the filter topologies we’ve been using still viable at these high frequencies? The answer is that RF and microwave structures tend to look less like standard filters and more like precision electromagnetic structures, such as micromachined waveguide resonators, and tightly controlled integrated-waveguide concepts. Consequently, filtering often becomes more dependent on packaging, transitions, and beamforming. System partitioning is adjusted so that the hardware is not asked to deliver “brick-wall” selectivity at sub-THz frequencies, as designers are accustomed to at microwave and millimeter-wave frequencies.

This brings me to my main concern: the timeline. The goal for the early deployment of 6G has been set for around 2030. In my experience, transitioning a filter technology from a research prototype to production takes 5 to 7 years. So, in practical terms,

I would expect pre-commercial trials and niche deployments to become visible between 2028 and 2029, with the first commercial networks appearing between 2029 and 2031, and meaningful device penetration beginning in 2032. If the industry’s business case is driven more by enterprise/industrial automation, sensing-integrated communications, or “AI-native” network operations than by consumer applications, that could accelerate deployments.


I am not suggesting that solving these challenges will be impossible. I’ve spent my entire career solving problems that initially seemed intractable. However, the industry needs to make hard decisions about investment and realistic performance assumptions now. If we wait, 6G may fail to deliver its promised capabilities on schedule. 

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S-band 150-W Power Amplifier

The CMPA2935150S-AMP1 GaN MMIC S-band power amplifier is designed for use in defense and aerospace systems. It covers a frequency range of 2.9 to 3.5 GHz and delivers saturated output power of 150 W with a large-signal gain of 18 dB for pulsed and CW operation. The amplifier is fabricated using GaN-on-SiC technology to support high power density, efficiency, and thermal performance, and is internally matched to 50 ohms at the RF input and output. It operates from a nominal 50 V drain supply and includes integrated bias circuitry to simplify system implementation. The amplifier is well-suited for radar transmitters, electronic warfare systems, and RF subsystems where bandwidth and repeatable performance are required.

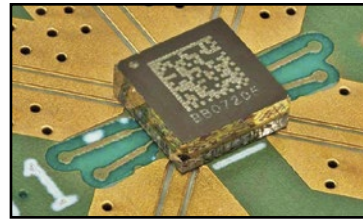
MACOM



C-band 2.4-kW SSPA

The RRP56572K4-24 solid-state power amplifier module for C-band radar and defense systems operates from 5.6 GHz to 5.7 GHz and delivers 2.4 kW of output power with a gain of 24 dB when driven from a 50 VDC supply. It supports CW and high-duty-cycle operation typical in surveillance and weather radar systems and uses GaN-on-SiC transistor technology to combine high power density with thermal performance. It is supplied as a packaged amplifier assembly that includes internal RF matching and bias circuitry, allowing system designers to integrate it into radar transmit chains with defined performance parameters for output power, gain, and efficiency. The amplifier is intended for use in ground, maritime, and fixed radar installations.

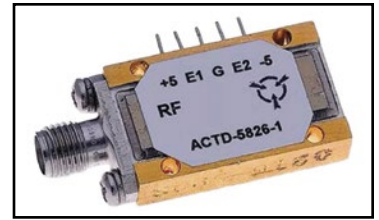
RFHIC



DC to 26 GHz SP4T MEMS Switch

The MM5130 is a broadband SP4T RF switch intended for signal routing and front-end protection in radar front ends, wideband communications, EW receivers, and other defense systems where a wide frequency coverage and fast switching are required. It supports operation from DC to 26 GHz with typical insertion loss below 3 dB across much of its range and isolation values exceeding 30 dB in key bands. The device is specified for high-power standoff and handling pulse signals of hundreds of watts, with switching times in nanoseconds between states. Control is accomplished with differential logic-level voltages compatible with standard digital interfaces, and the device is supplied in a surface-mount package for board-level assembly.

MENLO MICRO



Broadband Tunnel Diode Detector

This tunnel diode RF detector is designed to convert high-frequency RF power into a proportional DC voltage for monitoring, sensing, and built-in test functions in radar, electronic warfare, and satellite communications front ends. It has fast response and stable operation over temperature extremes common in defense environments, with low video capacitance and controlled VSWR to preserve signal integrity. Tunnel diode detectors typically operate from hundreds of megahertz into the microwave range, exhibit high sensitivity suitable for detecting low-level RF signals, and provide wide dynamic range. These detectors are used in aerospace and defense systems for their precise RF level measurement, thermal resilience, and rapid pulse response.

HONEYWELL AEROSPACE TECHNOLOGIES



High-power L-band GaN Transistor

The CLL3H0914LS-700U is a GaN-on-SiC RF power transistor intended for high-power L-band systems. It operates from 900 MHz to 1.4 GHz and is internally pre-matched with a stability network for integration into external matching networks. Under pulsed conditions with a 50 VDC drain supply, it produces up to about 750 W of output power, with a gain of 17 dB and a drain efficiency of 65%, in reference designs covering 1.2 GHz to 1.4 GHz. Input return loss at rated power is on the order of -10 dB, and pulse droop at typical operating points is small. The transistor comes in a SOT502B package and is specified for both short-pulse and long-pulse duty cycles. Typical applications include EW, radar, and avionics systems where high reliability in harsh environments is critical.

AMPLEON



X-band LNA for Satcom and Telemetry

The LNA-X1000N X-Band LNA amplifier module is designed for use in receive systems operating from 7.25 GHz to 7.75 GHz that experience harsh environmental conditions. It provides a gain of 50 dB with a noise figure near 0.8 dB, and accepts a 12 VDC supply typical in ground and airborne receiver platforms. The module uses internal RF matching and bias circuitry to simplify integration at the antenna or front end. It is housed in a weatherproof enclosure with Type-N RF connectors for direct connection to 50 ohm systems. Intended for satellite communications receivers, telemetry links, and other defense and government receive chains, the LNA-X1000N improves signal sensitivity and link budget in systems where weak-signal recovery is critical.

MARKI MICROWAVE



SAW Voltage-controlled Oscillators

The 101765 voltage-controlled SAW oscillator is a precision timing component designed for radar, test and measurement, and other mission-critical RF systems. It uses a surface-acoustic-wave resonator to support coherent frequency generation and timing in phase-locked loop (PLL) circuits and local oscillator applications. Models in this family include versions at 320 MHz and 400 MHz that achieve a phase noise of -166 dBc/Hz at a 10 kHz offset and a noise floor of -180 dBc/Hz. The typical supply voltage range is 4.75 VDC to 15.75 VDC, with a current consumption of 111 mA. The oscillator delivers single-ended sinewave output with power levels of +18 to +10 dBm. Devices are hermetically sealed in a 1 x 1 x 0.2 in. package with options for MIL-PRF-38534 screening.

MICROCHIP TECHNOLOGIES



SAW Filter for GPS Systems

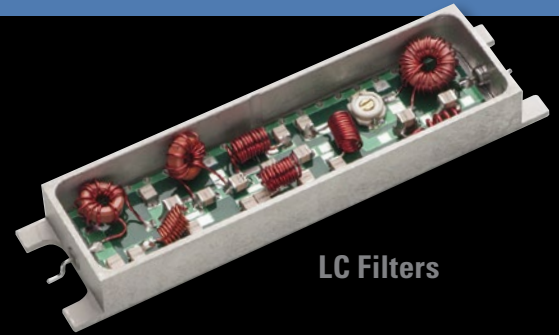
The QPQ1060 is an L1 GPS band-pass surface acoustic wave filter designed to pass signals around the GPS L1 frequency while rejecting out-of-band energy in navigation and communication front ends. It has a bandwidth of 31 MHz centered on 1575.42 MHz and a typical insertion loss of 1.3 dB, and presents a 50 ohm interface without external matching components. The filter is housed in a 1.4 x 1.2 x 0.84 mm surface-mount package and provides high isolation and rejection of unwanted signals, with typical out-of-band attenuation levels suitable for general-purpose GPS receive architectures. It supports power handling compatible with low-power transmitters and is intended for integration in GPS timing, navigation, and communications receivers.

QORVO

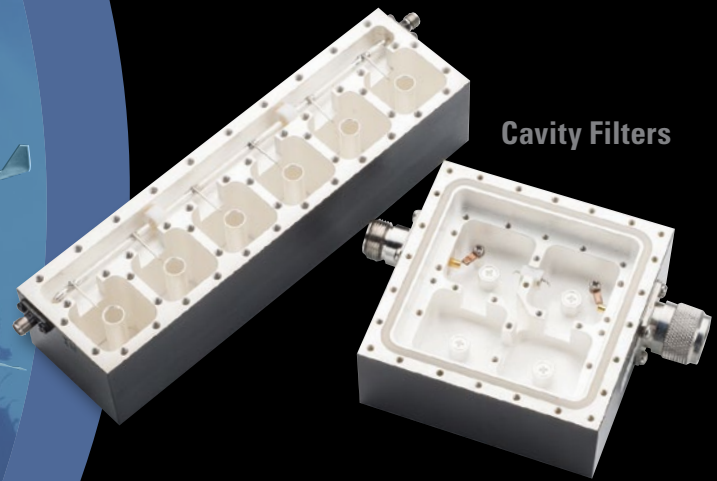
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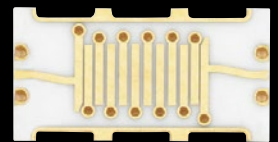
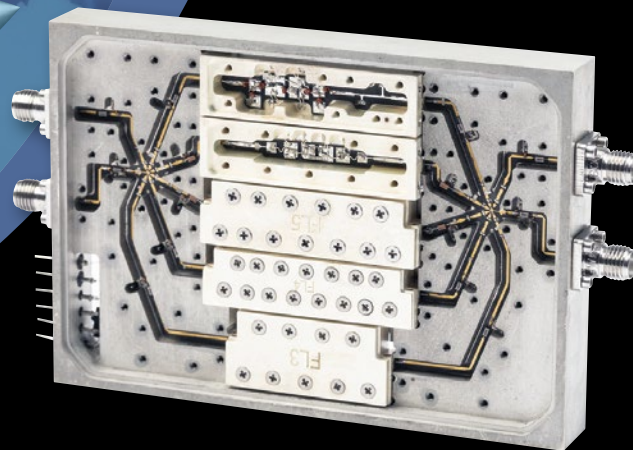


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High-rel EMI Filters for Military and Aerospace Systems

by Johanson Technology

When electronic devices are exposed to strong electromagnetic fields, unwanted electric currents can be induced in the circuit, interfering with intended operations. In military and aerospace systems, such failures can compromise mission performance, put multimillion-dollar assets at risk, and even cost lives

EMI filters are one of the first lines of defense against these disruptions. EMI filters are passive electronic components designed to suppress high-frequency noise and prevent electromagnetic interference from disrupting sensitive systems.

Unmanned aerial vehicles, advanced radar installations, satellites, and aircraft all rely heavily on high-frequency communications for navigation, real-time situational awareness, target detection and tracking, remote control, and secure coordination.

They also concentrate a significant volume of electronics close together, including high-speed digital circuits, switching power supplies, communication modules, and RF transmitters. They also frequently operate

alongside sensitive GPS receivers, navigation units, and camera or radar payloads. If strong EMI suppression measures are not in place, the subsystems may interfere with one another, degrading performance or leading to failure. EMI filters play a critical role in ensuring high-frequency signals remain clean enough for reliable transmission and reception.

High Reliability Filters

High reliability refers to the design and manufacturing of systems, com-

By maintaining clean, interference-free power and signal pathways, EMI filters allow drones to perform extended missions with precise navigation, secure communications, and high-fidelity data transmission, even in environments saturated with electromagnetic challenges.

ponents, or processes that must operate consistently under mission-critical or extreme conditions such as extreme heat, vibration, or radiation. These principles apply to satellites, missile guidance systems, and aircraft avionics, where false targets, momentary GPS positioning errors, unstable radar tracking, and corrupted data can compromise mission performance.

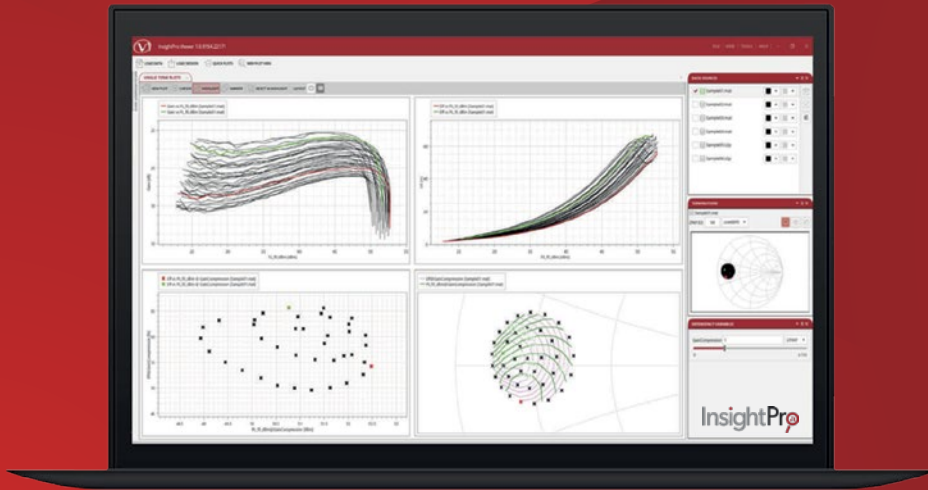
When drones malfunction due to interference, for example, there is no option for human intervention. Momentary glitches can trigger a fail-safe mode, force an early return, or cause a crash. For long-range drones operating beyond visual line of sight, uninterrupted data flow can be the difference between completing a reconnaissance mission and losing the asset.

Military drones also operate in electromagnetic environments that may be intentionally hostile, with adversaries attempting to jam, spoof, or use high-powered radar signals to disrupt operation. By maintaining clean, interference-free power and signal pathways, EMI filters allow drones to per-

continued on page 12

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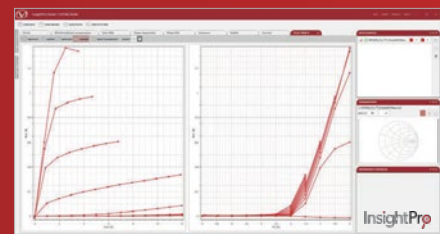
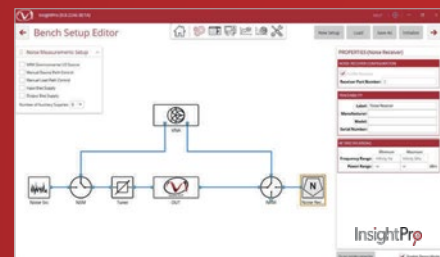
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continued from page 10

form extended missions with precise navigation, secure communications, and high-fidelity data transmission, even in environments saturated with electromagnetic challenges.

Radar systems face similar challenges. These systems generate and process very weak signals that EMI from external sources, such as communication equipment, power electronics, or even nearby radar systems, can easily corrupt. EMI filters are required to ensure that radar receivers can detect and process genuine signals without distortion or degradation, thereby improving the accuracy of target detection, tracking, and identification. For phased-array radars, EMI filters also help preserve phase and amplitude consistency across hundreds or thousands of T/R modules, ensuring precise beamforming.

EMI filters typically consist of passive components, such as capacitors and inductors, connected to form circuits that shunt unwanted high-frequency energy to ground, suppressing high-frequency noise and preventing electromagnetic interference from corrupting sensitive RF, timing, and control circuits.

The inductors allow DC or low-frequency currents to pass through, while blocking the harmful, unwanted high-frequency currents. The capacitors provide a low-impedance path to divert high-frequency noise away from the filter input, either back into the power supply or to ground, effectively removing it from the signal or power line.

Unlike filters used in commercial applications, high-rel EMI filters must operate flawlessly despite rapid thermal cycling, constant vibration, high

humidity, and rapid changes in atmospheric pressure. A failure in the filter, whether from degraded capacitors, saturated inductors, or broken connections, can allow noise to bypass suppression measures.

To maintain performance under these stresses, military and aerospace-grade versions are manufactured with stable dielectric materials that maintain capacitance and balance, minimizing parasitics. EMI filters also undergo stricter manufacturing controls, often with 100% visual and electrical inspection and traceability for every material lot.

Components are encapsu-

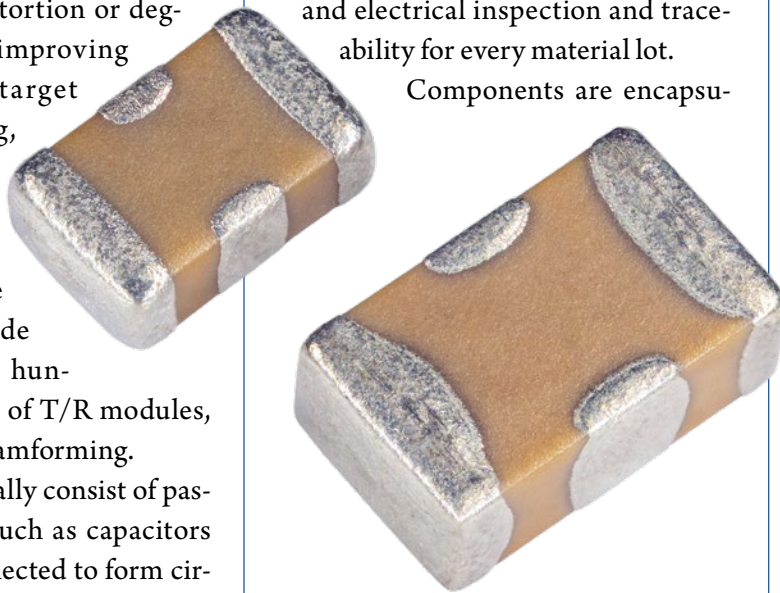


Figure 1—Johanson’s monolithic EMI filter is designed to provide both EMI suppression and power decoupling in a single, compact surface-mount device. The filter features ultra-low parasitic inductance resulting in a wide filter stop-band.

lated, potted, or housed in metal enclosures to resist mechanical shock and provide effective shielding. Temperature-compensated ferrites, thin film coatings, and ceramic capacitors further improve performance and reliability.

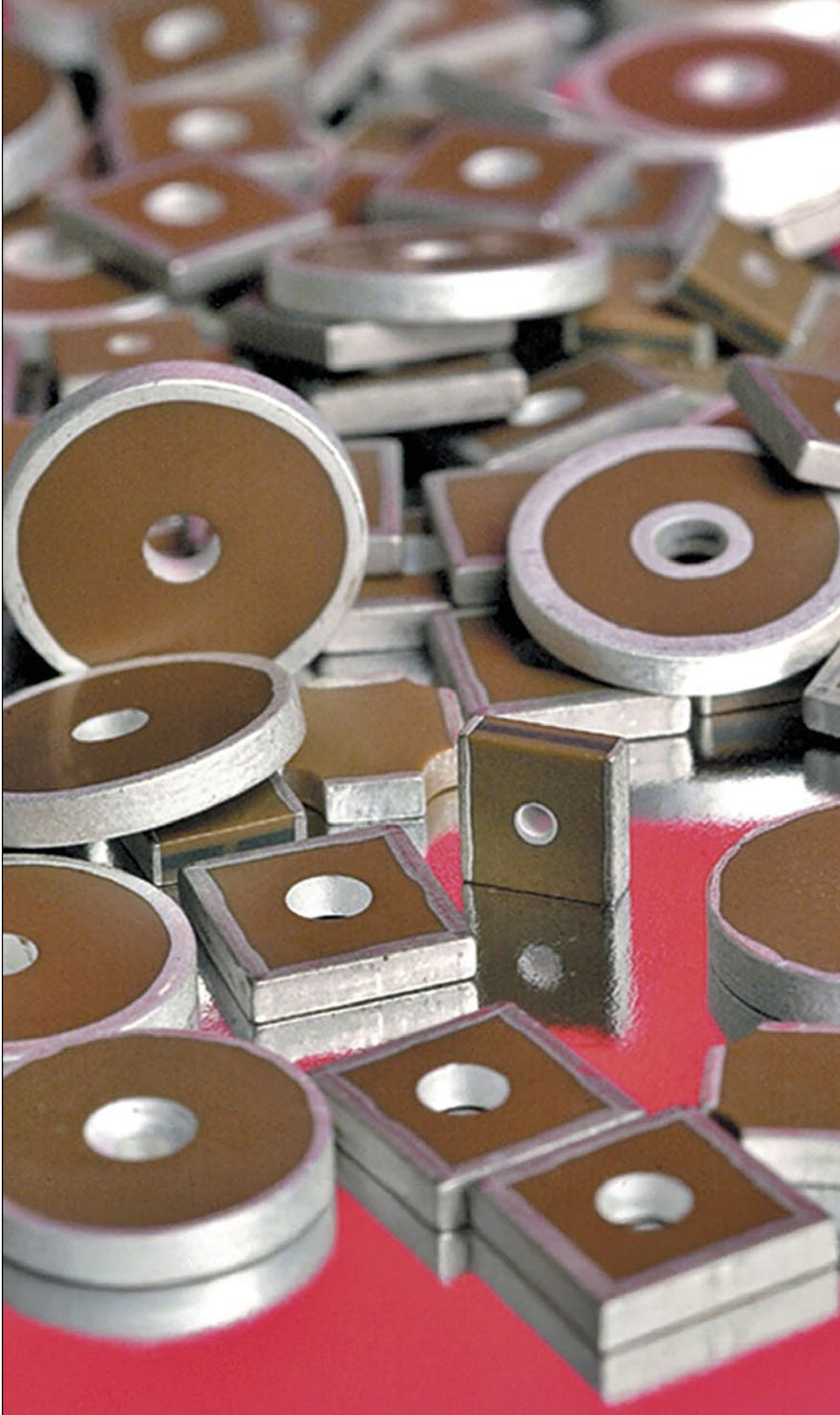
Military-grade electronics undergo environmental stress screening and redundancy measures to ensure continued operation even if one conversion stage fails. Components may also be tested to MIL-STD-461 standards for electromagnetic compatibility.

To meet these requirements, components are typically sourced from aerospace or military-certified suppliers, such as Johanson Technology. For more than 60 years, the company has designed and manufactured multi-layer ceramic capacitors, EMI filters, and other critical components for high-reliability applications. While manufacturing is performed in North America to support scalable production, expedited lead times, and ITAR compliance, all high-reliability testing and design to standards such as MIL-PRF-31033, MIL-STD-202, and MIL-PRF-55681 is conducted in the U.S.

To meet the diverse requirements of military and aerospace applications, Johanson Technology offers EMI filters in a variety of configurations and form factors. Depending on the application, filters can employ differential-mode and common-mode elements, transient suppression, and shielding techniques. They may be integrated into power entry modules, cable assemblies, or engineered as custom solutions for compact avionics and mission-critical systems. In many cases, some degree of customization is required.

One example of a high-rel configuration unique to Johanson Technology is its monolithic EMI filter (**Figure 1**), a multilayer ceramic component designed to provide both EMI suppression and power decoupling in a single, compact surface-mount device. The filter features ultra-low parasitic inductance, resulting in a wide filter stop-band.

Unlike standard capacitors with limited filtering, these EMI filters are engineered to simultaneously suppress noise in both differential and common modes, making them exceptionally effective in crowded, noisy environments.



Compared with traditional single capacitors and simple feedthrough filters, monolithic filters offer improved broadband attenuation, lower parasitic inductance, and better high-frequency characteristics. Because of this, they are often chosen for filtering on power/data lines and high-speed signal paths where space efficiency and EMI compliance are critical.

The filter's innovative electrode architecture delivers superior per-

Figure 2—Disoidal filters are capacitors frequently installed into EMI filter assemblies to provide feed-through protection against high-frequency interference.

formance compared to conventional multilayer capacitors. Unlike conventional capacitors that use two electrodes, the X2Y structure incorporates a third shield electrode that surrounds the other two.

Because of this balanced structure,

the monolithic filter functions as a pair of matched shunt capacitors to ground. The opposing current paths naturally cancel inductance, yielding extremely low equivalent series inductance (ESL). This allows the device to perform broadband EMI filtering, typically effective from around 100 kHz up to well beyond 17 GHz.

The EMI filters are specialized multilayer capacitor arrangements with tightly matched impedances. Therefore, they exhibit very low noise-mode conversion, resulting in massive improvement in both conducted and radiated emission performance. Compared to typical common-mode chokes, the X2Y EMI filters exhibit 17 dB better noise-mode conversion.

By combining differential-mode and common-mode suppression in a single element, the EMI filter can often replace several discrete capacitors and inductors that would otherwise be required. By some estimates, this can reduce costs by 50% and reduce size by 80%.

Planar and disoidal filters incorporate built-in filtering components directly into the connector body to suppress unwanted EMI or radio frequency interference (RFI) as signals or power pass through the connection point. These connectors are commonly used in environments where cables and interconnects act as antennas, picking up or radiating interference, such as high-speed data lines, control signals, or DC power converters.

Disoidal filters (**Figure 2**) are ring-shaped capacitors frequently installed in EMI filter assemblies to provide feed-through protection against high-frequency interference in radar systems, secure communications, and power units for aircraft and drones.

continued on page 14

continued from page 13

Johanson Technology's X7R discoidal filters, for example, feature multilayer ceramic construction and a geometry that enable dramatically lower equivalent series resistance (ESR) and equivalent series inductance (ESL), critical for high-frequency decoupling and filtering.

Circumferential grounding provides an infinite number of paths to ground, ensuring optimal filtering performance. The durable substrate construction protects against damage caused by thermal and mechanical stresses.


Often used in sensors and transducers, planar filters (**Figure 3**) employ a flat, layered structure that integrates many filter lines into a single, thin unit, ideal for high-density

connectors. They provide superior filtering performance, mechanical strength, and are more compact than discrete solutions such as tubular capacitors.

All these filters address a key concern for military and aerospace applications: the ability to miniaturize passives allows engineers to meet strict size, weight, and reliability demands while increasing capability and lowering cost.

Miniaturization also improves survivability, since smaller components tolerate vibration and g-forces better than bulky ones, reducing the risk of fatigue failures in high-stress flight conditions. Small, high-quality passives also handle the thermal extremes, radiation, and vacuum of

space more reliably when designed with stable materials and geometries.

In military and aerospace applications where failure is not an option, EMI can be a threat to mission success and safety. As the first line of defense against electromagnetic challenges, high-reliability EMI filters serve as a critical safeguard, preserving the integrity of power and signal pathways against disruptive noise. By ensuring clean, interference-free operation, EMI filters safeguard the precision of military and aerospace systems, protect secure communications, and preserve critical data integrity, even in environments saturated with electromagnetic noise. 

• JOHANSON DIELECTRICS •

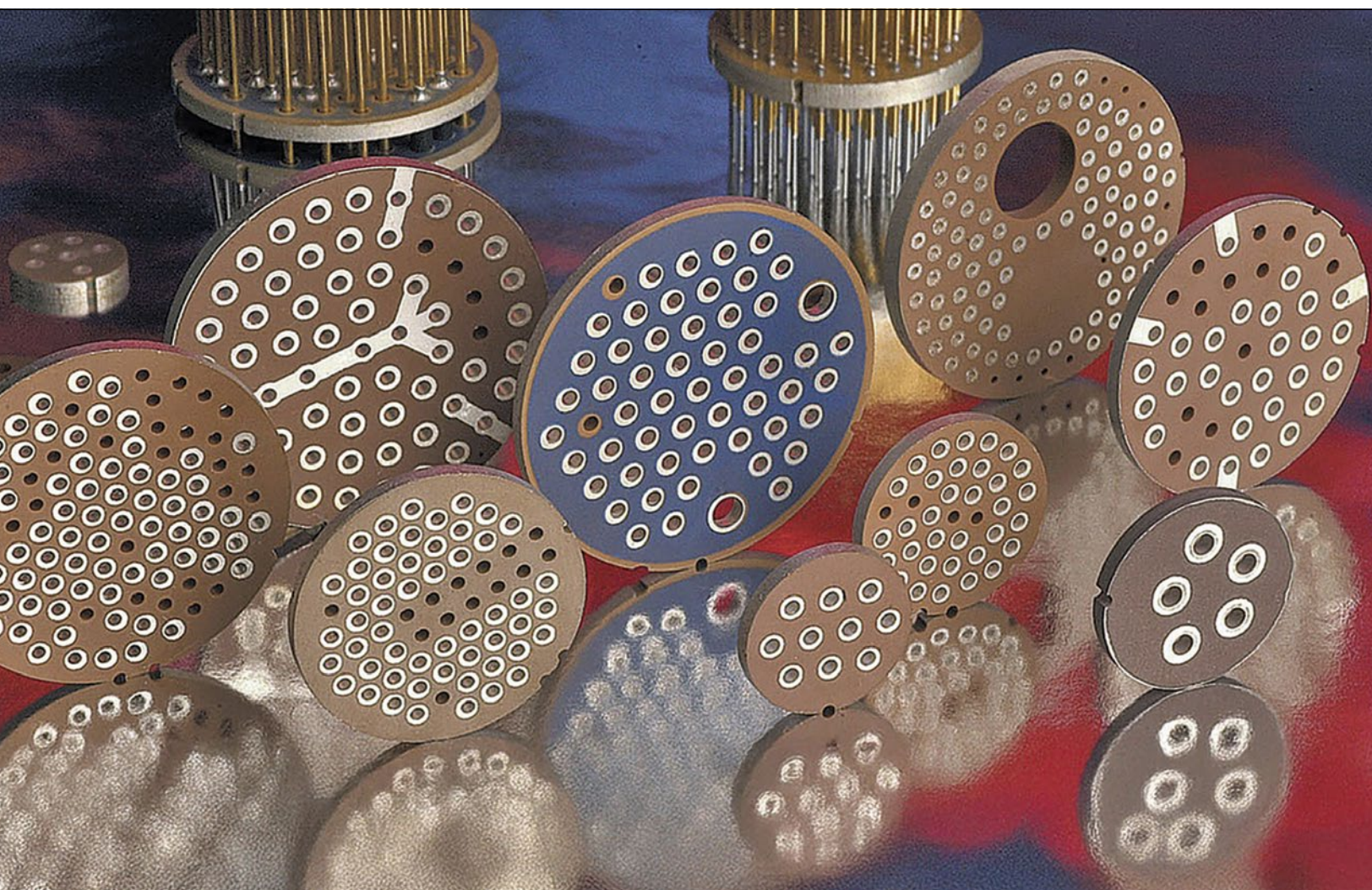


Figure 3—Planar filters employ a flat, layered structure that integrates many filter lines into a single, thin unit, ideal for high-density connectors.

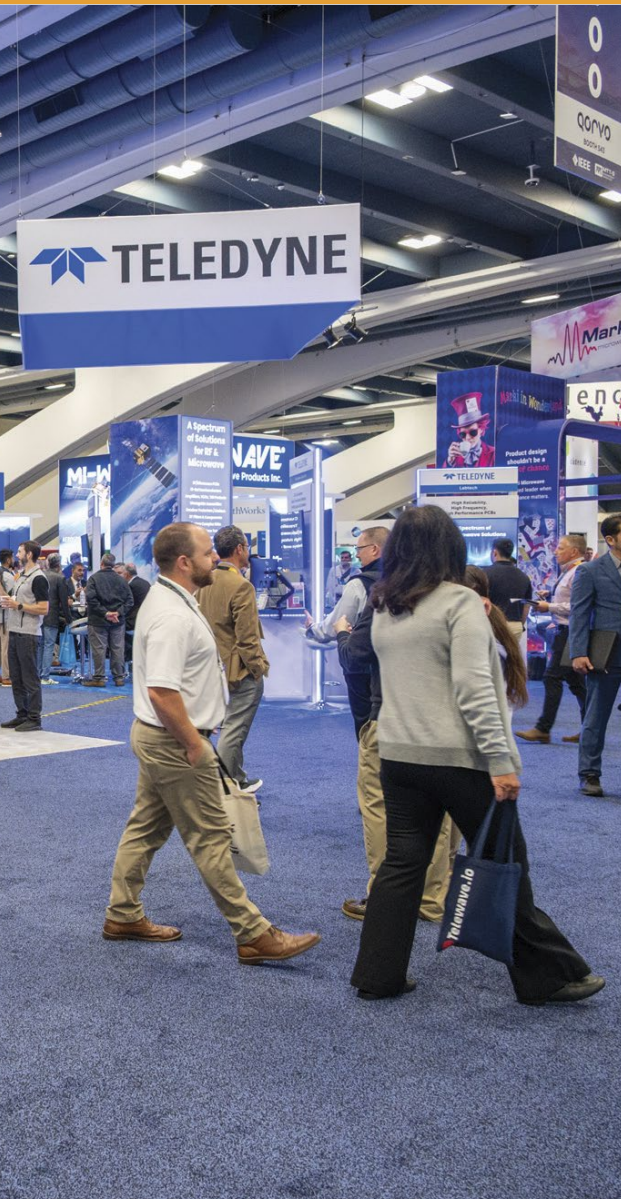


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The Orbital Environment Is Getting Crowded, and the Math Is Getting Ugly

by Barry Manz, Editor

When the International Telecommunication Union processed the first satellite filings of the space age, the assumption was that geostationary orbit would remain the center of gravity for commercial space. Half a century later, that assumption has not proven accurate, as spacecraft have moved into low Earth orbit, and there are enormous numbers of them. If current filings are even reasonably accurate, the number of satellites in orbit will become effectively unmanageable, even with the best efforts at maneuvering, de-orbiting, and technological advances. So, let's look at the numbers themselves.

The reason operators stuck to GEO for five decades was that the GEO geostationary slot at 35,786 km covers roughly a third of the Earth from a single spacecraft. A LEO platform at 500 km sees perhaps a few hundred kilometers of useful footprint before geometry and link budget push the user outside the beam. To deliver continuous global coverage from LEO, operators need thousands of satellites with extremely low latency.

SpaceX alone now operates more than 10,000 Starlink satellites, or about two-thirds of those in orbit. The next-largest operator, OneWeb, has fewer than 700.

Between 2017 and 2022, national regulators collectively filed requests with the ITU covering more than a million satellites across 300-plus constellation systems. Rwanda alone filed for 337,320. In January, SpaceX filed a notification for roughly a million orbital data-center spacecraft, compute platforms intended to run AI workloads



in orbit. Blue Origin followed up with a 50,000-satellite data center filing, so the projected satellite population for 2040 sits around half a million.

Every active LEO broadband satellite consumes downlink bandwidth in Ku, Ka, and, increasingly, V-band, alongside feeder-link allocations that must coexist with terrestrial fixed-service and radio-astronomy users. The ITU coordination process assumes a

manageable number of operators negotiating in good faith. It was not designed for a regime in which a handful of players propose cumulative spacecraft populations exceeding the historical total by two orders of magnitude.

The result is that interference disputes have become routine, with radio astronomy sites documenting out-of-band emissions from LEO spacecraft at levels that compromise observations across portions of the 10.7 to 12.7 GHz band. The massive Square Kilometer Array project has raised these concerns, and SpaceX has cooperated by adjusting antenna patterns, but the electromagnetic brightness of the sky will continue to climb.

As Ukraine has ably demonstrated, military use of Starlink has been a crucial element for fighting off Russian advances. It uses Starlink for drone operations, artillery correction, and tactical communications. The broader principle — that a commercial constellation can function as wartime communications infrastructure — is now a fixed assumption in defense planning.


Not to be outdone, Russia has been developing counterspace systems intended to produce orbital debris clouds against LEO targets, and it tested a direct-ascent ASAT against its own Kosmos-1408 spacecraft in November 2021. That single event produced more than 1,500 trackable fragments and forced the ISS crew to return to their capsules. That pales in comparison to China’s 2007 Fengyun-1C test, which involved more than 3,000 tracked pieces, an estimated 150,000 smaller fragments, and a debris cloud at 865 km that will persist for decades.

The orbital data center filings from SpaceX and Blue Origin are another possible achievement, and with them, some very big challenges. For instance, a compute platform in orbit must get data in and out, which means either extremely high-throughput feeder links to ground stations or dense optical inter-satellite links into an existing broadband constellation. There’s also a thermal problem: while terrestrial AI data centers have well-understood water- and air-cooling requirements, in LEO the only heat-rejection mechanism is radiation. So, it’s limited by available surface area so for a platform dissipating megawatts of power, it must carry radiator panels that can measure 170 m, according to Elon Musk.

Fortunately, Starlink-heavy altitudes of 500 km have one saving grace: atmospheric drag eventually eliminates smaller fragments within 5 to 8 years. Spacecraft debris in higher orbits doesn’t have this ability on any useful timescale, so if an event occurs at 800 to 1,000

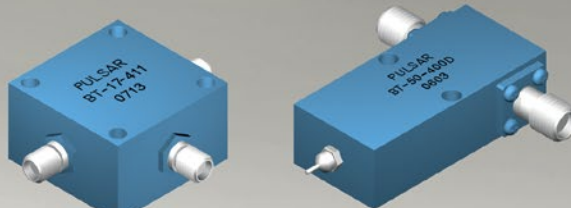
km, where the Fengyun-1C debris still exists, the resulting debris will effectively be permanent.

There are also environmental factors to consider, as a 550-lb. satellite releases about 66 lb. of aluminum oxide nanoparticles during reentry. Multiply that across projected annual deorbit rates, and aluminum oxide injection into the mesosphere and upper stratosphere becomes a major problem. There are also potential issues with lithium, copper, and carbon-fiber combustion products that researchers are just beginning to model.

It is important to keep in mind that the announced numbers—a million satellites, orbital data centers, hundred-thousand-spacecraft national constellations are only filings that must undergo review. History suggests the number of satellites deployed may be far less than this, but even if it is, space is going to become a very crowded place in the decades to come. 


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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
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continued from page 3

IoT is no longer about proving that devices can be connected. That question was settled years ago. What matters now is whether large numbers of networked systems can be operated safely, maintained over long lifetimes, and trusted to interact with physical processes without constant intervention. Sensors and controllers now influence power grids, factories, transportation systems, medical equipment, and public infrastructure. When these systems fail, the impact is measured in downtime, safety risk, and cost, and not lost packets or dashboard alerts.

Today's IoT environment reflects that shift. It is best understood as a systems architecture that spans hardware, networking, software, and operations rather than as a standalone technology. Modern deployments are designed around how data is generated, processed, and acted upon across distributed locations. Connectivity is assumed. The harder problem is coordinating sensing, computation, communication, and control in ways that remain predictable under real-world constraints.

At the device level, IoT hardware covers a wide range of capabilities.

Some nodes are still built around small microcontrollers that perform a single function and transmit limited data. Others resemble embedded computers, running full operating systems and hosting multiple applications. Many devices now integrate multi-core processors,

common for local device networks. These are often paired with Ethernet or fiber in fixed installations, and with cellular connectivity for wide-area coverage. LTE-M, NB-IoT, and increasingly 5G are used where managed connectivity and predictable service levels are



radios that support multiple standards, and cryptographic hardware. Power management continues to shape nearly every design decision. Duty cycles, sleep states, and radio behavior are tuned carefully, particularly in deployments where battery replacement is costly or impractical.

Networking reflects similar diversity. Short-range wireless technologies based on IEEE 802.15.4, Bluetooth Low Energy, and sub-GHz radios remain

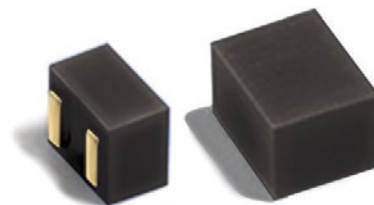
required. In practice, most systems rely on gateways that sit between these networks and IP backbones, handling routing, security, and traffic control while insulating constrained devices from upstream complexity.

Communication protocols have been settled into patterns shaped by device limitations and network behavior. Lightweight protocols such as MQTT and CoAP are widely used for telemetry and command exchange,

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while HTTPS is often reserved for configuration and management. Data formats are chosen to balance size, processing overhead, and interoperability. Issues such as clock drift and timestamp alignment still surface, especially in systems that combine data from multiple locations or attempt to close control loops across networks.

Cloud infrastructure remains central to many IoT deployments, but its role has become more defined. Telemetry is typically aggregated into time-series databases and processed through stream-based pipelines that support filtering, correlation, and event detection. These platforms also handle device provisioning, configuration management, and integration with enterprise systems. At the same time, few large deployments rely exclusively on continuous cloud connectivity. Cost, latency, and reliability concerns have pushed designers to be more selective about what data is transmitted and when.

That shift has made edge computing a standard part of IoT system design. Functions such as data reduction, local analytics, and control logic are increasingly executed at or near the source. Edge nodes often run containerized workloads or lightweight virtual machines, allowing software updates without replacing hardware. This distributed model reduces dependence on centralized infrastructure but intro-

duces coordination challenges, particularly around identity, configuration, and monitoring across devices, edge, and cloud layers.

Modern systems assume that devices may be physically accessible, intermittently connected, and deployed for many years. Device identity is often rooted in hardware, with keys or certificates provisioned during manufacturing or enrollment. Secure boot mechanisms prevent unauthorized firmware from executing, and encrypted communication protects data in transit. Because these systems persist for long periods, update mechanisms and vulnerability management are now part of the baseline design rather than optional features.


Operational management has emerged as one of the most demanding aspects of IoT. Large fleets include devices with different hardware versions, firmware levels, and connectivity conditions. Operators rely on monitoring systems to track health and performance, while logs and diagnostics support remote troubleshooting. Over-the-air updates are common, but they must be staged and controlled to avoid service disruption or excessive network load.

Looking ahead, many of the hardest challenges are tied to time rather than technology. Devices often remain in service long after operating systems, cryptographic algorithms, or cloud services have evolved. Maintaining

security while preserving compatibility across long lifecycles remains difficult. Interoperability also remains constrained by fragmented standards and inconsistent data models, complicating integration across vendors and platforms.

Network behavior will pose additional constraints as deployments grow and applications demand tighter timing guarantees. Supporting large numbers of devices with predictable latency requires coordination across access networks, backhaul capacity, and traffic management systems. Power availability will remain a limiting factor, particularly in environments where batteries cannot be replaced easily, and energy harvesting is inconsistent.

Regulatory and governance concerns are also shaping system design. Requirements related to data location, privacy, and auditability influence where data is processed and how it is shared. These constraints often conflict with centralized analytics models, pushing more logic toward localized processing and policy-aware data handling.

In short, the current state of IoT reflects a transition from experimentation to infrastructure. The success of future deployments will depend less on new connectivity options and more on the ability to operate distributed systems with defined performance, security, and maintenance characteristics over long periods. 



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PMI Planar Monolithics.....	4, 5
Pulsar.....	17

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