We get technical

- Improve test performance with low-cost signal sources using inline filters
- Use traps to enable multiband operation with dipole antennas
- Use a global cellular radio module to quickly and securely connect IoT devices to the Cloud
- Use a compact 5G MIMO antenna for optimum connectivity

DigiKey



contents

Editor's note

Welcome to the DigiKey eMagazine Volume 26 – Wireless.

This edition will explore the dynamic and ever-evolving world of RF and wireless technology. It brings together a diverse set of articles designed to inform, inspire, and empower engineers, designers, and tech enthusiasts navigating the complexities of modern wireless connectivity.

We begin by highlighting some of the latest innovations in RF solutions with features on Nordic RF products and Qorvo RF technologies – two key players driving performance and integration in next-generation wireless systems. For readers looking to decode technical specifications, our deep dive into IoT antenna datasheets offers practical guidance for making informed design choices.

This issue also shines a spotlight on practical design techniques. Discover how low-cost signal sources combined with inline filters can improve test performance, or how traps can enable multiband operation in dipole antennas, offering elegant solutions to complex challenges.

In keeping with the pulse of connectivity, we examine the role of compact 5G MIMO antennas in delivering both high performance and sleek aesthetics – essential for modern device integration. We also explore how a global cellular radio module can accelerate the path from prototype to deployment by connecting IoT devices securely to the cloud.

As always, we aim to strike a balance between technical depth and practical insight, and we hope this edition offers you valuable takeaways for your projects and professional journey.

Ultra-low-power and high performance: Nordic's nRF54L15 redefines wireless IoT design

Battery life remains the persistent challenge in wireless IoT product development. Devices often need to run for months or years on coin cells while handling increasingly complex protocols and security requirements. Nordic Semiconductor's nRF54L15 Series SoCs meet these needs with a combination of advanced process technology, architectural efficiency, and flexible memory configurations that allow designers to balance performance and power budgets in ways previous generations couldn't support.

The nRF54L15 is Nordic Semiconductor's transition to a 22nm process node, moving from the established nRF52 Series architecture that has defined Bluetooth Low Energy implementations across consumer and industrial markets. This shift delivers measurable improvements: power consumption drops 30 to 50% in common Bluetooth LE use cases compared to the nRF52 Series, while processing capability increases substantially. The device achieves 503 CoreMark with an efficiency rating of 193 CoreMark/milliampere at 3.0 V, providing triple the processing efficiency of its predecessor while operating from the same battery chemistry.

Dual-core processing architecture

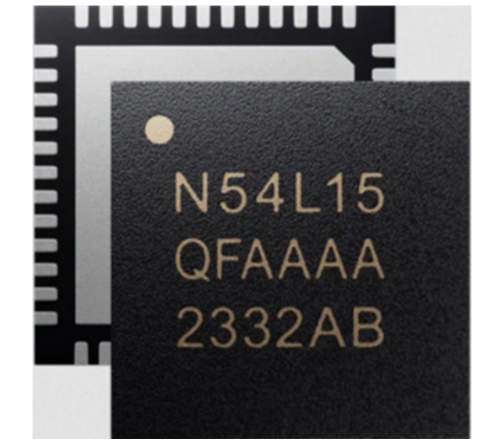
Under its hood, the nRF54L15 integrates a 128 MHz Arm Cortex-M33 processor with TrustZone security extensions and a 128 MHz RISC-V co-processor. This dual-processor arrangement serves specific design purposes rather than just general parallelism. The RISC-V core handles time-critical wireless protocol operations, implements custom protocol stacks, and enables what Nordic terms soft peripherals; software-defined peripheral functions accelerated with hardware support. For product designs that might otherwise require a separate microcontroller to handle sensor interfaces or custom communication protocols, the RISC-V coprocessor absorbs those functions within the wireless SoC.

Memory configurations scale across three pin-compatible variants. The nRF54L15 provides 1.5 MB of RRAM non-volatile memory and 256 KB RAM. The nRF54L10 reduces these to 1.0 MB NVM and 192 KB RAM, while the nRF54L05 offers 0.5 MB NVM and 96 KB RAM. All three variants share identical footprints in QFN packages, which means that designers can develop a single PCB layout and select memory configurations based on application requirements and cost targets.

Multiprotocol radio capabilities

The nRF54L15 features a 2.4 GHz radio that provides configurable transmit power ranging from -10 dBm to a maximum of +8 dBm (CSP package) or +7 dBm (QFN package), adjustable in 1 dBm increments. This granular control allows designers to balance transmission range against current consumption based on specific application requirements. Receive sensitivity is from -96 dBm at 1 Mbps BLE data rates, while the IEEE 802.15.4 reception reaches -102 dBm sensitivity. This radio supports multiple wireless protocols within the 2.4 GHz band.

Bluetooth Low Energy (BLE) modes for the nRF54L15 include LE Coded PHY for longer range, LE 1M for standard operation, and LE 2M for higher throughput. Channel Sounding capability, introduced in Bluetooth Core 6.0, also enables centimeter-level distance measurement between

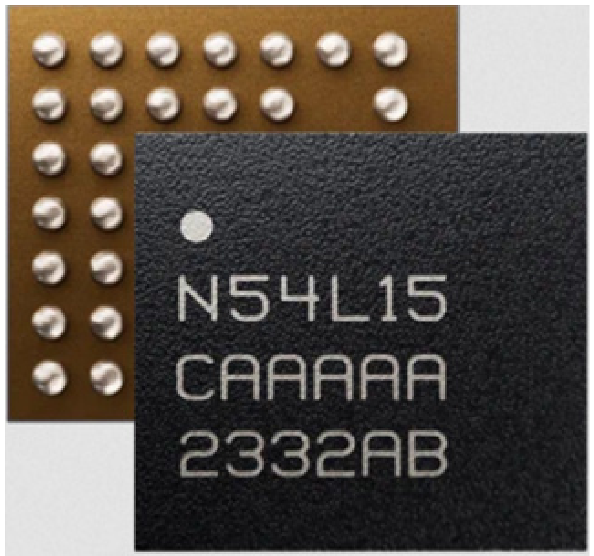


Nordic's nRF54L15 ultra-low-power wireless SoC in a QFN package.
Image source: Nordic

devices. Moreover, IEEE 802.15.4-2020 support at 250 kbps provides the foundation for Thread, Zigbee, and Matter protocol applications. Proprietary 2.4 GHz GFSK modulation operates at 1 Mbps, 2 Mbps, or 4 Mbps for a broad range of applications that require custom protocols with specific latency or throughput features. The nRF54L15 also utilizes a NFC-A listening device for near-field communication, supporting tap-to-pair functionality or proximity-based configurations.

Power consumption

Nordic understood that battery life constraints affect every wireless IoT design decision, and the nRF54L15's power characteristics reflect this reality. During radio reception, the device draws 3.4 mA at 3.0 V supply voltage, which is half what the nRF52840 consumes when operating from a 1.8 V supply.



Nordic's nRF54L15 ultra-low-power wireless SoC in a WLCSP package.
Image source: Nordic

Also, transmit current at 0 dBm output power is 4.8 mA. These improvements matter because most wireless devices spend the majority of their operational life receiving rather than transmitting, which makes receive current the dominant factor in battery longevity calculations.

When not actively communicating, sleep mode currents range from 0.7 μA to 2.9 μA, depending on which peripherals remain powered and how much RAM retains its contents. The Global RTC peripheral continues to operate in system OFF mode while drawing just 0.8 μA, which eliminates the need for external real-time clock components that would otherwise occupy board space, add to bills of materials, and consume their own supply current. For products typically spending months in storage or containers before activation, hibernation mode lowers consumption below 50 nanoamperes, allowing shelf life to be measured in years rather than months.

Security architecture

Connected devices operate in hostile environments where physical access and network-based attacks can pose real threats to users' data and device integrity. Nordic designed the nRF54L15 to meet PSA certified level 3, the highest security certification level for IoT devices that protects against both software and hardware attack vectors.

Security starts with Arm TrustZone isolation, which partitions the system into secure/non-secure domains at the hardware level. Critical operations like cryptographic key storage/authentication run in the secure domain where even compromised application code cannot access them. The cryptographic accelerator also handles encryption operations and protects against side-channel attacks that might attempt to extract keys by analyzing timing variations or power consumption patterns during cryptographic operations.

Secure boot uses an immutable boot partition that cannot be modified after manufacturing. Two independent watchdog timers monitor secure and non-secure domains separately, preventing one domain from disabling protection in the other.

Peripheral complement and package options

GPIO count is from 31 to 35 depending on package selection, organized across three ports with different speed capabilities. Port 2 supports 64 MHz high-speed operation while Ports 0 and 1 operate at 8 MHz. The nRF54L15's serial interfaces include four configurable SPI/TWI/UART peripherals plus an additional high-speed SPI/UART combination. A 14-bit ADC (upgraded from 12-bit resolution on the nRF52840) provides eight channels with resolution that trades against sample rate: 14-bits at 31.25 ksps oversampled, 12-bits at 250 ksps, or 10-bits up to 2 Msps. Other peripherals include an I2S audio interface, PDM for digital microphones, PWM, a quadrature decoder, comparators, and a temperature sensor.

Memory configurations scale across three pin-compatible variants. The nRF54L15 provides 1.5 MB of RRAM non-volatile memory and 256 KB RAM.

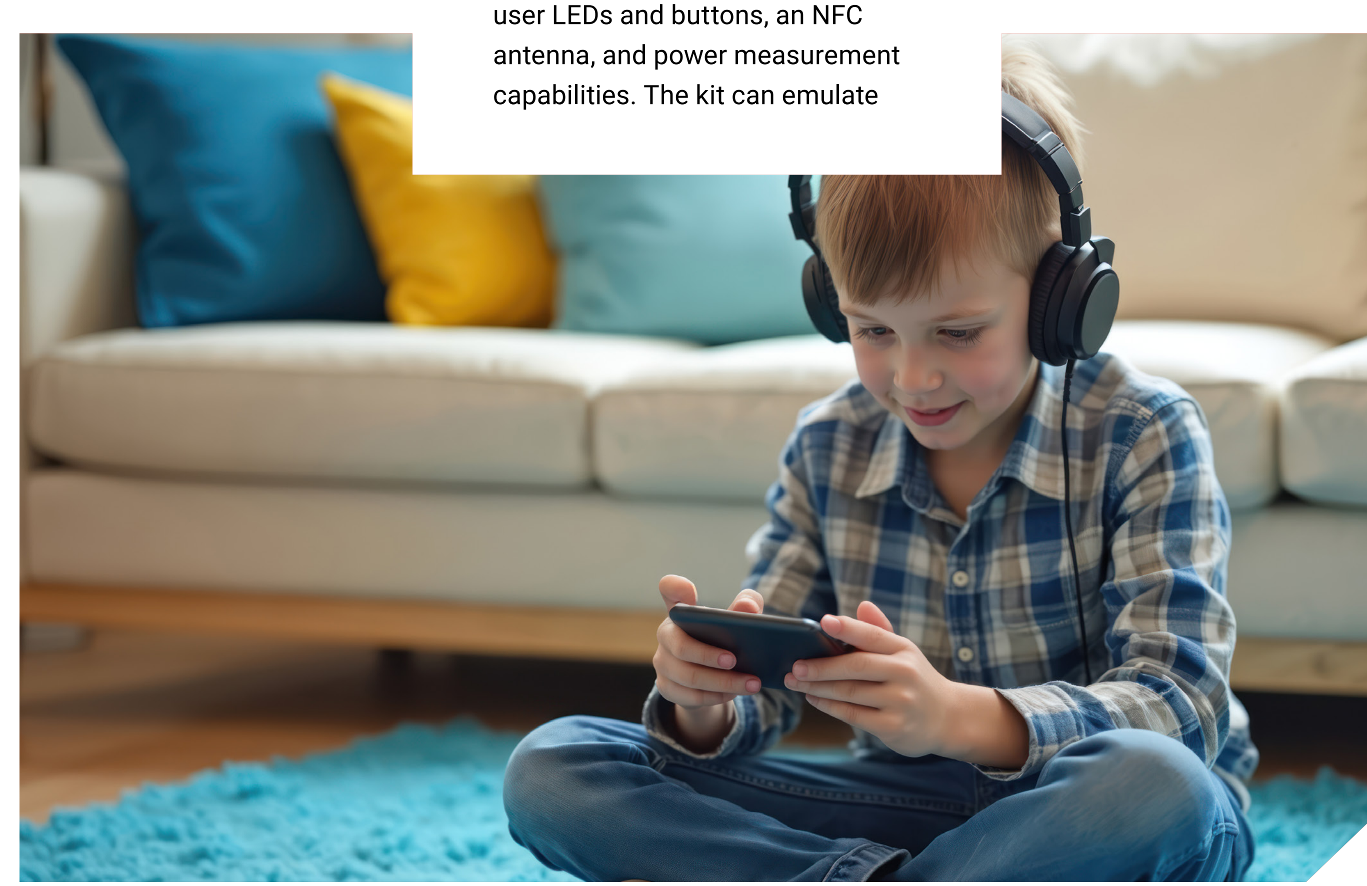
Nordic offers the nRF54L15 in two package formats for different design priorities. The QFN 6x6 mm 48-pin package has 31 GPIO and full peripheral access in a conventional surface-mount format. The WLCSP 2.4 x 2.2 mm chip-scale package is ideal for compact product designs like smart rings and wearables. The operating temperature is from -40°C to +105°C and the supply voltage ranges from 1.7 V to 3.6 V.

Development resources and use cases

The nRF54L15-DK development kit provides the QFN48-packaged SoC, 64 Mb external flash, an onboard SEGGER J-Link debugger, four user LEDs and buttons, an NFC antenna, and power measurement capabilities. The kit can emulate the nRF54L10 and nRF54L05 models, allowing developers to try out other budget-friendly memory configurations without purchasing additional hardware. Software development uses the nRF Connect SDK built on Zephyr RTOS. Nordic also offers a bare-metal development option independent of Zephyr for simpler BLE applications that don't require a full RTOS.

Nordic focuses on medical devices, smart home solutions, industrial IoT, VR/AR accessories, PC peripherals, gaming controllers, wearables, smart rings, electronic shelf labels, asset trackers, and beacons as key applications.

For more information, please visit nRF54L15 Development Kit



Qorvo's high-performance RF amplifier powers the next generation of wireless applications

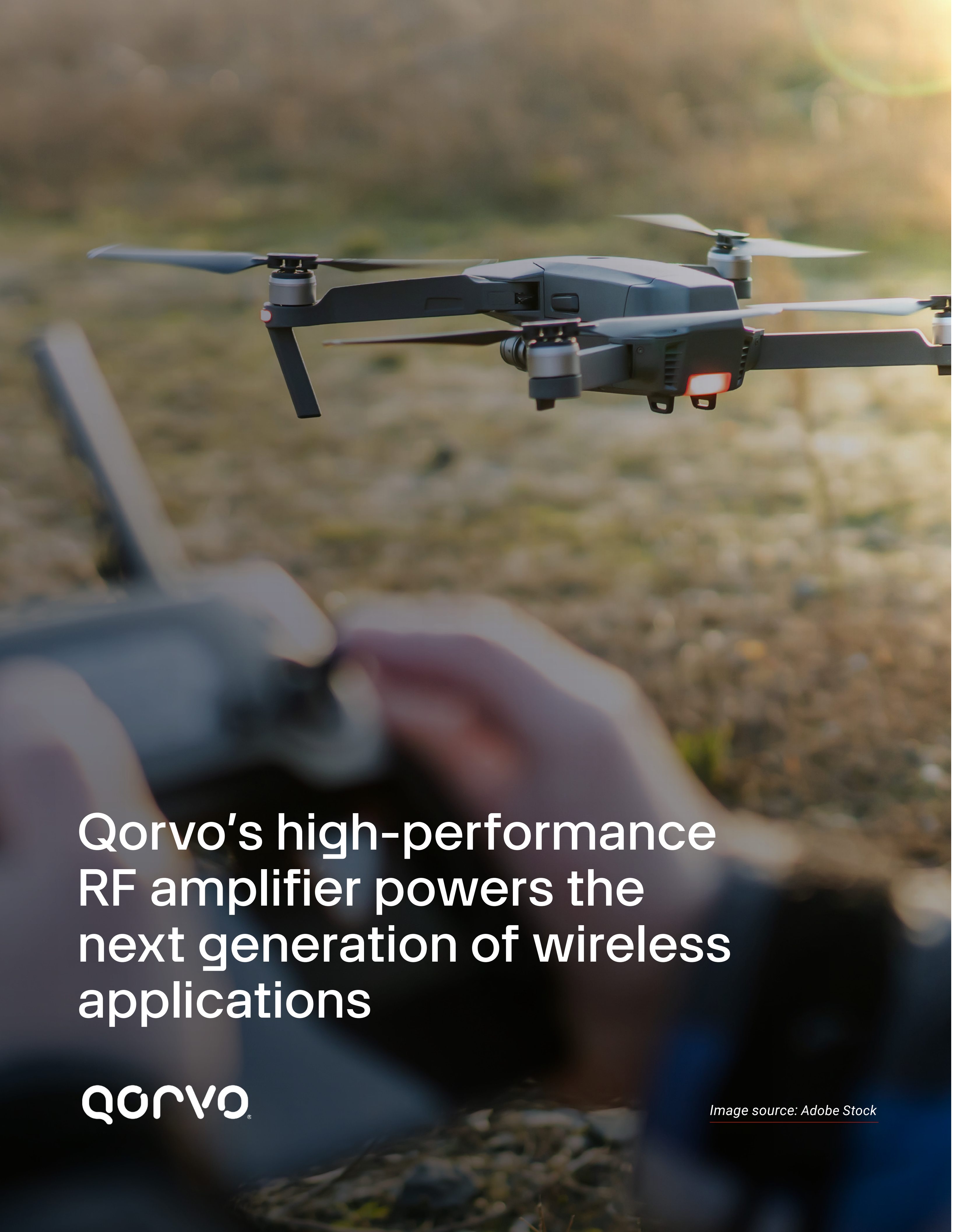


Image source: Adobe Stock

Wireless connectivity is expanding into applications once thought impossible. Drones deliver packages to remote locations, satellites provide cellular service from low Earth orbit (LEO), and utility meters communicate autonomously across entire cities. However, behind these breakthroughs is a key challenge: such applications require RF components that can deliver reliable performance across a range of frequencies and under harsh operating conditions.

Qorvo's QPA9442 wideband, high-linearity driver amplifier operates across a 0.6 to 5.0 GHz frequency range with optimized tuning capabilities and integrated protection features, giving system designers a solution that spans software-defined radio (SDR) systems, LEO satellite communications, RFID networks, and smart metering infrastructure.

Qorvo's strategic market approach

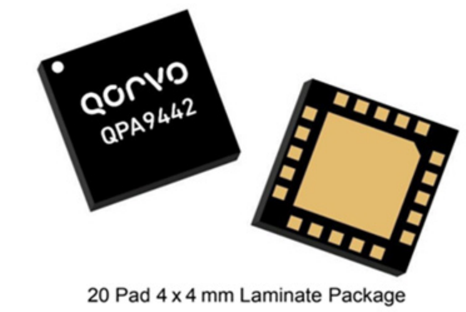
Qorvo's growth strategy rests on three interconnected facets. Firstly, it adapts its established infrastructure portfolio to serve adjacent markets, allowing mature technologies to be rapidly deployed into emerging applications. Secondly, it targets sales initiatives focused on building deep customer relationships in emerging verticals, moving beyond purely component sales to holistic signal chain solutions. Lastly, sustained investments in R&D ensure that Qorvo's portfolio evolves continuously, enabling customers to differentiate their products with access to cutting-edge RF capabilities.

Drone markets

The unmanned aerial vehicle sector is projected to climb from $36 billion in 2024 to $126 billion by 2032; a 17.3% compound annual growth rate. Military applications are dominating demand, though commercial adoption in construction, mining, and agriculture is accelerating steadily. North America and Asia-Pacific lead regional growth.

RF systems in military and commercial drones face unique constraints in terms of balancing range, data capacity, and power efficiency. Qorvo's QPA9442's wideband coverage from 0.6 to 5.0 GHz supports multiple frequency bands and modulation schemes in a single footprint, eliminating the need for multiple band-specific amplifiers in SDR architectures.

Drones operate in increasingly contested RF environments where communication range and reliability can directly impact mission success. The QPA9442 provides adequate power for beyond-visual-line-of-sight control links, while its exceptional linearity (achieving +45.0 dBm OIP3) maintains its spectral purity in crowded electromagnetic environments

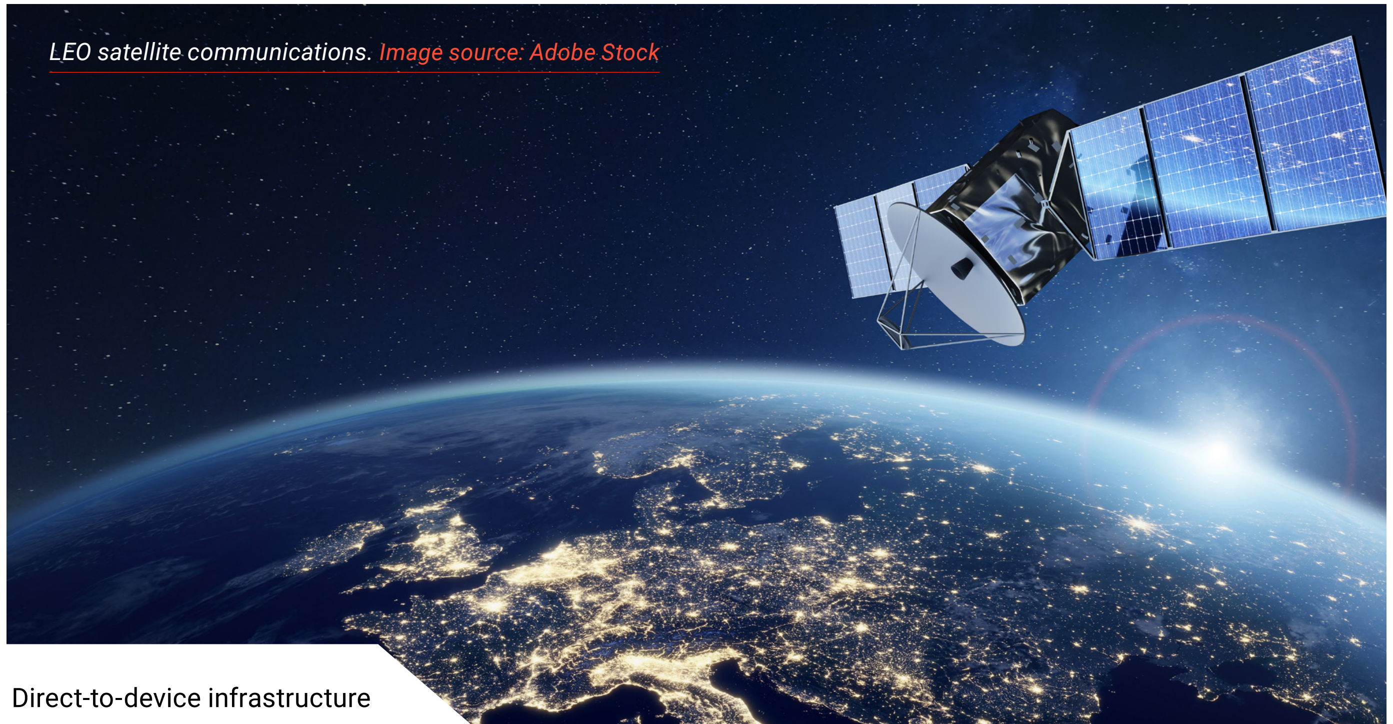


The QPA9442 wideband, high-linearity amplifier package. Image source: Qorvo

where adjacent channel interference could otherwise compromise command and control integrity. With an achievable gain of 19 dB at Band 1 and typical gain of 15.5 dB at 1840 MHz, the QPA9442 can be optimized for specific deployment cases like maximizing output power for long-range missions or improving efficiency for extended flight duration. Additionally, the QPA9442 has a DC power shutdown feature via its VPD pin that enables a drone to minimize current draw during idle periods.

LEO satellite communications infrastructure

Direct-to-device satellite connectivity promises to eliminate cellular dead zones by enabling standard smartphones to connect directly to LEO satellites without specialized hardware. The challenge lies in closing RF links across 500+ kilometers with transmit power levels that are designed for terrestrial towers just a few hundred meters away.



LEO satellite communications. Image source: Adobe Stock

Direct-to-device infrastructure requires a fundamentally different RF front-end design. Unlike stationary cell towers, LEO satellites race overhead at 7.5 km/s, creating Doppler shifts that push signals outside narrow LTE and 5G channel allocations. Devices must compensate in real-time while maintaining sufficient link margin to penetrate buildings and vehicle interiors.

Operating across 0.6 to 5.0 GHz, Qorvo's QPA9442 covers all 3GPP-defined non-terrestrial network bands, including the Band n255 (1525 - 1559 MHz downlink), Band n256 (2170 – 2200 MHz downlink), as well as Band n254 (2483.5 – 2500 MHz downlink). Its 30 dBm output P1dB provides the 20 - 30 dB link margin required to close connections with satellites hundreds of kilometers overhead, a crucial requirement lower-power amplifiers do not meet.

Moreover, the QPA9442's high linearity performance with an output IP3 of 45.0 dBm at 2140 MHz helps maintain signal integrity as satellites traverse from horizon to horizon, since path loss can vary by 20 dB or more during a single pass. Its internal RF overdrive protection and DC overvoltage protection features provide additional robustness for satellite ground station deployments operating continuously in remote locations.

RFID systems

RFID reader architectures must accommodate deployment scenarios ranging from handheld units operating at 0.3 watts to fixed infrastructure installations pushing 3 watts (a 10x power spread that typically requires multiple amplifier solutions for each application tier). However, the QPA9442 with its 0.6 to 5.0 GHz coverage and 30 dBm of output covers the entire range with a single component.

For ultra-high-frequency RFID systems operating in the 860 – 960 MHz band, the QPA9442 delivers sufficient output power for fixed reader installations to interrogate tags at distances of 10 to 15 meters, while its tunable gain optimizes for shorter-range, handheld applications where lower output power extends the battery life. This amplifier's wideband capability also makes it ideal for readers supporting both 433 MHz active RFID and 915 MHz passive RFID within a single hardware platform.

RFID readers also alternate rapidly between transmit and receive modes when broadcasting interrogation signals and listening for tag responses in milliseconds. The QPA9442's On/Off timing (0.26 µs typical) enables rapid transitions without introducing significant dead time, maximizing tag read rates in high-throughput applications, like retail inventory scanning and logistics tracking. The QPA9442's integrated power shutdown feature also minimizes current consumption during receive windows, which is critical for battery-powered handheld readers as extended operating time directly impacts productivity.

Smart meter deployments

Utility metering infrastructure worldwide is transitioning to advanced monitoring systems that enable real-time consumption tracking and improved grid reliability. The latest smart meters integrate multi-standard communication capabilities supporting NB-IoT, LTE-M, 5G, Wi-Fi, and ZigBee protocols. The QPA9442 0.6 to 5.0 GHz coverage spans these communication standards within a single amplifier, simplifying designs that would otherwise require multiple band-specific components.

With 30 dBm output P1dB, the QPA9442 provides sufficient power for smart meters to reach neighborhood concentrators several hundred meters away, even through building walls and underground vault installations. Simultaneously, optimized power dissipation (1.15 W typical at +10 dBm output) is critical since many gas and water meters operate on battery power for 15 - 20 year deployments where current consumption directly impacts replacement costs.

Meters typically transmit for just seconds per hour, spending the majority of time in receive or sleep modes. The QPA9442's 2 mA maximum OFF-state current and 0.26 µs typical, 1 µs maximum ON/OFF timing allows the meters to minimize average current consumption while maintaining rapid response to network commands.

An example of a smart meter. Image source: Adobe Stock

Conclusion

With wireless communications expanding into drones, satellites, smart meter infrastructure, and more, high-performance amplifiers are more critical than ever. Qorvo's QPA9442 shows that a well-designed amplifier can meet the needs of multiple applications, allowing system designers to address multiple markets with a single, proven component architecture.

Amphenol RF AUTOMATE Mini-FAKRA: small footprint interconnects for automotive systems

Amphenol® RF

Advanced Driver Assistance Systems (ADAS), 360-degree camera arrays, autonomous driving sensors, and other automotive systems generate several terabytes of data daily, exceeding what typical automotive RF connectors can handle. The Amphenol RF AUTOMATE Mini-FAKRA Series meets this constraint with connectors that are significantly smaller than standard FAKRA and support data speeds up to 20 Gbps across two tiers. This next-generation interconnect technology is already enabling the transition to software-defined vehicles and zonal architectures.

Standard FAKRA connectors have hit their limits

Connector infrastructure in modern vehicles is hitting a limit and requires an upgrade to keep up with automotive system protocols. For example, an 8 megapixel forward-looking ADAS camera operating at 60 frames per second generates up to 8 Gbps of raw data, consuming nearly the entire bandwidth capacity of a single FAKRA connection. High-resolution surround-view camera systems ramp this up even further by maintaining four or more simultaneous feeds. Meanwhile, camera link protocols, such as MIPI A-PHY v2.0, require up to 32 Gbps downlink speeds, while automotive Ethernet can reach up to 10 Gbps.

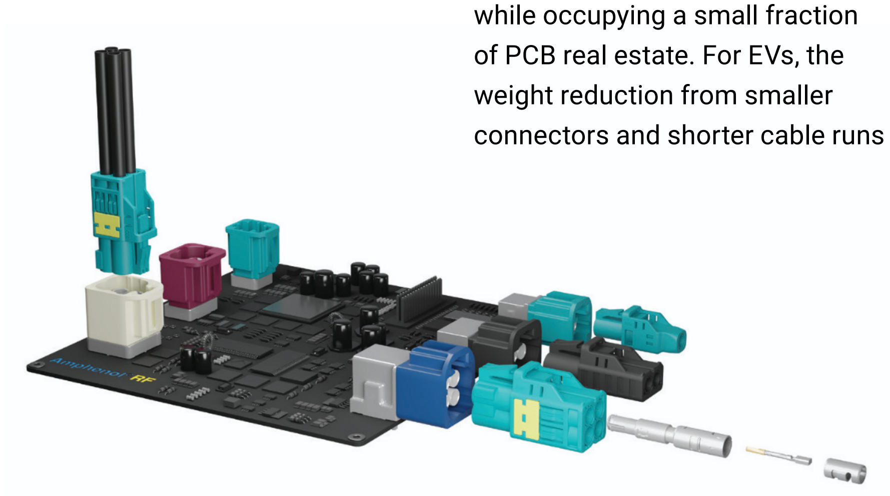
FAKRA connectors have served the automotive industry for decades, delivering frequencies up to 6 GHz and data rates up to 8 Gbps. The Amphenol AUTOMATE RF FAKRA line is an enhanced version of the FAKRA connector. They also meet USCAR standards with 14 different mechanical and color codes and a minimum of 100 mating cycles.

Type A for automotive applications

Type A of the Amphenol RF AUTOMATE Series offers a frequency range from DC (0 Hz)

to 9 GHz and supports up to 20 Gbps data transmission in single-port, dual-port, or quad-port configurations. The Type A connectors are designed using a zinc alloy with a matte tin finish and feature gold-plated copper-nickel alloy contacts. The cable assemblies deliver a minimum of 500 mating cycles and work with TFC-302LL, RG-174, Dacar 302, and RTK-031 cable types.

Type A features color-coded housings with key codes A through E plus the universal Z code, which ensures intermateability with all other key configurations. Its Terminal Position Assurance (TPA) secondary locking mechanism ensures secure mating, while mechanical keying prevents connector mis-mating during assembly in high-volume automotive manufacturing environments.



Straight and right-angle versions available for Type A connectors in single, dual and quad-port configurations for PCB and cable-mount designs. Image source: Amphenol RF

Space savings improves automotive system architecture

Modern vehicles contain close to 40 different harnesses with roughly 700 connectors and over 3,000 wires. If taken apart and laid end-to-end, these wires would exceed 4 kilometers in length and weigh approximately 60 kg. S&P Global Mobility predicts that 38% of vehicles produced by 2034 will feature zonal architectures, up from 2% in 2022.

Due to this architectural shift, automakers need more compact, high-bandwidth connectors that can aggregate data streams at zone boundaries. Compared to standard FAKRA connectors, Amphenol RF AUTOMATE has an 80% smaller footprint, reducing installation space. This means that a single quad-port Mini-FAKRA connector replaces four discrete legacy connections while occupying a small fraction of PCB real estate. For EVs, the weight reduction from smaller connectors and shorter cable runs can meaningfully contribute to efficiency targets.

Key applications

Camera systems and visual processing

360-degree-view cameras are one of the most bandwidth-intensive applications in automobiles. These systems typically deploy four or more cameras to simultaneously capture high-resolution video feeds that must reach central processing units with minimal latency. Designers can utilize a quad-port Mini-FAKRA connector to aggregate camera feeds into a single compact interface point, eliminating the need for four separate legacy FAKRA connections. The 20 Gbps throughput capacity provides headroom for higher resolution sensors and increased frame rates as camera technology improves. The 80% space savings is especially valuable in smaller areas near bumpers and side mirrors where camera modules are mounted.

ECUs and compute modules

Unlike legacy power architectures utilizing distributed processing across dozens of small ECUs, modern zonal architectures concentrate computing power into a handful of domain controllers and zone modules. These processors are intended to handle simultaneous inputs from multiple sensor types, including cameras, radar, lidar and ultrasonics coming in through RF connections. The compact housing of AUTOMATE connectors allows designers to route more connections in constrained board spaces.

Infotainment and displays

Instrument clusters render 3D graphics, overlaying navigation instructions, ADAS warnings, and vehicle status information simultaneously. High-definition displays (4K and beyond) require reliable high-bandwidth connections to graphics processors. Similarly, infotainment head units streaming multiple audio and video sources also process touchscreen inputs, voice commands, smartphone integration, etc. With 20 Gbps capacity, the AUTOMATE Series can aggregate data streams via a single connection point. Their -40°C to +105°C operating temperature range also ensures reliability in a wide range of thermal conditions inside vehicle cabins and dashboards.

Unlike legacy power architectures utilizing distributed processing across dozens of small ECUs, modern zonal architectures concentrate computing power into a handful of domain controllers and zone modules.

Conclusion

As zonal architectures proliferate and camera resolutions increase, the combination of compact form factor, high-frequency performance and industry compatibility positions the AUTOMATE connectors as critical components of next-generation automotive electrical systems.

Amphenol RF's AUTOMATE Mini-FAKRA connectors provide higher throughput and significant space savings over standard FAKRA solutions. The Type A variant serves applications up to 9 GHz across flexible port configurations.

For more information, please visit Amphenol RF Automotive Solutions

Understanding the nuances of an IoT antenna datasheet

Written by Steven Keeping

When you're designing a wireless Internet of Things (IoT) product, you'll need to get to grips with antennas and their role as the sole interface between the product and the outside world. With the wrong choice of antenna, your final product may communicate, but its performance will be so compromised that users might give up on it and turn elsewhere.

The problem for many designers is that there seems to be a staggering array of antenna solutions, making the selection process somewhat daunting. So, how do you narrow down the best antenna choice for your design?

Some decisions are easier than others. Start by looking for an antenna optimized for your design's operating band. For example, if the product uses LoRa connectivity and targets the U.S. market, the antenna should be optimized to operate in the 902 to 928 megahertz (MHz) band. If the device supports dual-band Wi-Fi, the antenna should be optimized to operate in both the 2.4 gigahertz (GHz) and 5 GHz RF bands.

Next, consider the form factor of the final product. For example, if a Bluetooth Low Energy (LE) enabled sensor needs to be highly compact, then a good option could be Amphenol's ST0147-00-011-A, a 2.4 GHz surface-mount chip antenna. It measures just 3.05 x 1.6 x 0.55 millimeters (mm) and is mounted directly on the device's PC board. An example of a much larger device is a Wi-Fi access point (AP). It offers plenty of space for the antenna while satisfying the demand for good range and high throughput. A good option here is Amphenol's ST0226-30-002-A external whip antenna (Figure 1).

Figure 1: The ST0226-30-002-A external whip antenna suits applications such as dual-band Wi-Fi access points.
Image source: Amphenol

After operating bands and form factors, things get a little more complex. Selecting an antenna that meets power consumption, reliability, range, and throughput specifications demands a reasonable understanding of the datasheet.

Under the hood

Take a typical datasheet, such as that for Amphenol's ST0224-10-401-A (Figure 2). This is a Wi-Fi trace RF antenna that suits smart meter and Industrial IoT (IIoT) applications and can be mounted internally. The datasheet includes information about the device's radiation pattern, maximum power transfer, frequency response, gain, and efficiency. Let's consider the meaning of each of these parameters.

Figure 2: The ST0224-10-401-A Wi-Fi trace RF antenna can be mounted internally and suits smart meter and IIoT applications.
Image source: Amphenol

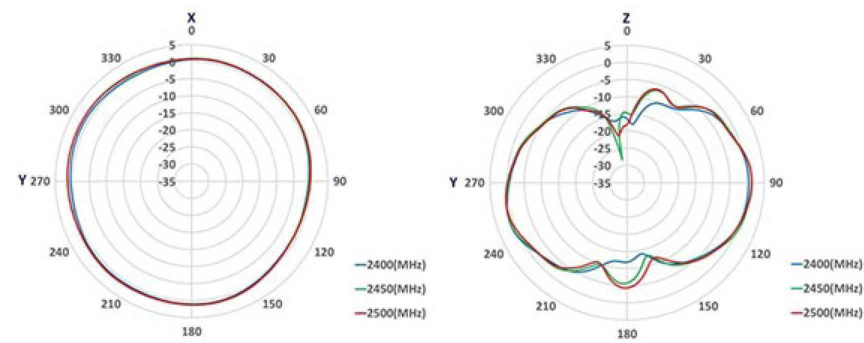
Radiation pattern: this graphically defines how the antenna radiates (or absorbs) radio-frequency (RF) energy in 3D space. The datasheet typically shows two or three slices through the 3D radiation pattern, one showing peak radiation in the XY plane and the other showing the peak in the ZY (and/or ZX) plane (Figure 3). Often, the plane patterns are referred to as the 'azimuth' (XY plane) and the 'elevation' (orthogonal to the XY plane, for example, across the ZY plane) when the antenna is mounted as it is intended to be used in the final product.

An omnidirectional antenna, such as a dipole antenna, is one that radiates or receives radio energy relatively equally in all directions. This suits many IoT applications because the developer often needs to ensure connectivity between devices in any orientation relative to each other. The datasheet for the Amphenol ST0224-10-401-A antenna shows that it is an omnidirectional device.

The downside of an omnidirectional antenna is that transmission energy is dissipated across the surface of an expanding sphere, attenuating the signal strength exponentially and impacting range. In contrast, directional antennas use techniques such as beamforming to focus radio energy in a specific direction, boosting range.

Maximum power transfer: this occurs when the impedance of the transmission line (Z0) equals that of the antenna (Za). Even with well-designed impedance matching circuitry, some power is typically reflected by the antenna back along the transmission line. A common measure of how well the Z0 and Za impedances are matched is the voltage standing wave ratio (VSWR). A VSWR of 1 indicates no

Figure 3: Shown are the peak radiation patterns for a Wi-Fi trace antenna in the XY plane (left), and the ZY plane (right). Image source: Amphenol



impedance mismatch loss, while higher numbers indicate increasing losses.

For example, a VSWR of 3.0 indicates about 75% of the power is delivered to the antenna. The power ratio of the reflected wave to the incident wave is called the return loss (RL). This indicates the reduction in decibels (dB) of the reflected wave power below that of the incident wave. A VSWR below 1.5 (an RL of ≈ 14 dB) is a satisfactory match. The Amphenol ST0224-10-401-A-10 antenna features an RL of -10 dB when operating in the 2.4 and 5 GHz frequency bands.

Because RL is also dependent on radio frequency, the developer should check the frequency response of the antenna to ensure RL is minimized in the intended operating band (Figure 4).

Gain and efficiency: gain describes how much power is transmitted in the direction of peak radiation and is usually given in dB referenced to an isotropic antenna (dBi). Gain is related to the antenna's directivity and efficiency. Directivity measures the directional nature of the antenna's radiation pattern. For example, a perfectly omnidirectional antenna has zero directionality and a directivity of 1 (or 0 dB). Directivity is usually quoted as the peak value according to the radiation pattern (Dmax). Gain is more commonly quoted in an antenna's specification sheet than directivity because it takes into consideration VSWR mismatch and energy losses.

Efficiency (η) is the ratio of total radiated power (TRP, or Prad) to input power (Pin). TRP is calculated by integrating the power emitted across the entire radiation pattern. To calculate η, use the formula η = (Prad/Pin) * 100%. The antenna peak gain is then Gainmax = η * Dmax.

The antenna is a critical part of an IoT product. The wrong choice can dramatically impact the performance of the wireless device.

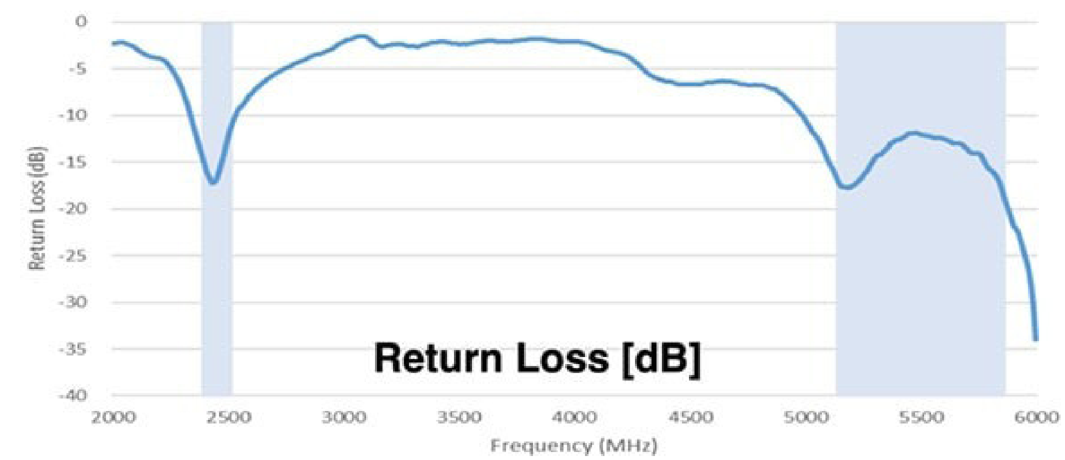


Figure 4: RL is dependent on frequency. The developer should ensure the antenna offers minimum RL at the intended operating frequency. Image source: Amphenol

A transmitting antenna with a gain of 3 dB will radiate twice the power of a lossless isotropic antenna with the same input power. A lossless antenna is one with an efficiency of 0 dB (or 100%). Similarly, a receive antenna with a peak gain of 3 dB would receive twice as much power as a lossless isotropic antenna. For our Amphenol example, the peak gain is 2.1 dBi in the 2.4GHz band and 3.1 in the 5GHz band.

High gain is not always a good thing. If the direction of the incoming signal is unknown, then it's better to have a low gain (low directivity) antenna to ensure a satisfactory response to signals from all directions. An example is the antenna on a smartphone. This needs to be low gain because the incoming and outgoing signals to the nearest cellular basestation come and go in an arbitrary direction.

Conclusion

The antenna is a critical component of an IoT product. The wrong choice can dramatically compromise the performance of the wireless device. Some parts of the selection process, such as matching the antenna to the operating frequency and selecting an antenna that fits the space available, are straightforward. The key to choosing the correct antenna is understanding the terms used in the datasheet and paying particular attention to radiation pattern, maximum power transfer, frequency response, and gain.

Video spotlight

Samtec Precision RF

As a manufacturer of a broad line of electronic interconnects, Samtec also offers full RF solution capabilities. These include micro high-frequency U.FL and W.FL, 50 Ω and 75 Ω cable assemblies, cable connectors and board level interconnects, ganged and high isolation cable systems, 100 Ω shielded twisted pair cable assemblies, micro-mini interconnects and non-magnetic RF solutions.

Learn More

Selecting a Wireless Connectivity Solution

So, you want to go wireless and but you are not sure which technology to embrace. The key factors and limitations are demonstrated in this video to help in selecting which is right for your project. Factors such as cost, range, security and ease of implementation are covered to pare down the wide array of options. There was a time when remote control still involved a cable tether to pass signals from the user to a device such as a toy car, television or telephones which were bulky and usually attached to a wall or placed on a desk with long, unsightly cords to drag around. The latest technologies broadcast signals everywhere while targeting specific receivers that do not rely on line-of-sight methods.

Learn More

The first car radio – Motorola's Sound in Motion

Written by David Ray,
Cyber City Circuits

Motorola

Sound in Motion

Motorola has played a long and vital role in the twentieth century. From the first marketed car radio to the first lunar lander, Motorola, like Bell Laboratories, became an industrial research laboratory with applied science research, development, and manufacturing all under one 'roof.' This led to the creation of two-way radios, police radios, pager systems, satellite systems, and even unique discrete semiconductors, microprocessors, and other components, but it all really started with a car radio.

This is the story of Bill Lear and the first Motorola radio.

Bill Lear

Our story begins with the inventor. William Powell Lear was born in Missouri in 1902. He spent much of his time at his church on the other side of town, 'Moody Tabernacle.' At a young age, Bill dropped out of high school. He worked a few different jobs as an 'office boy.' While working for the American Multigraph Company, he served as a low-level assistant to the boss, Warren B. Houghton. Lear sat in the corner of the room while Houghton dictated memos to his secretary, made business phone calls, and handled various tasks. He says that this had a significant influence on his life.

Once, he sat in on a job interview for a new assistant manager. The


Bill Lear – six years old

salary, nine hundred dollars a year, was an extraordinary sum for the time. The applicant seemed ideal, answering every question with confidence. Houghton was ready to hire him on the spot. But when the man hesitated and said, "I can't accept the job before I talk it over with my wife," Houghton's tone changed instantly.

"In that case, forget the offer," Houghton said. "I can't hire both of you. If you can't make decisions yourself, I'll find someone who can."

From his corner, young Lear was stunned. The applicant's hesitation had cost him a once-in-a-lifetime chance. Lear understood that fearfulness and reliance on others could damage a man's future as much as a lack of knowledge. He decided that if such a moment arose again, he would act without hesitation, without delay, and would make his own decisions instead of letting others do so. This lesson, learned quietly at Multigraph, became a fundamental rule guiding his career.

The next summer he went to Oklahoma to live with his father and grandfather. His parents had split several years earlier. Each day, his father would give him a silver dollar, and within a short time, he was able to buy his first automobile, a used Model T. The car was in rough shape, but Lear stripped it down and rebuilt it to the bare minimum to drive around. Like teenagers today, he even cut off the muffler, making it sound like a race engine zooming around Tulsa.

Running away and joining the military

When he returned home to Chicago, he and his mother had a fight, and he 'ran away' from home. He took all his money and tried to head west to California, walking most of the way. He ran out of money in Denver, and there were no jobs available. It seems he didn't reach California, but instead, he lied about his age and joined the US Navy. He hoped the Navy would take him to California, but ironically, they sent him back to Chicago to the Great Lakes Naval Training Station to train as a wireless operator.

Lear was already very knowledgeable about wireless radios. Reading newsstand magazines like 'Radio News' and

'Electrical World,' he kept up with the latest innovations of the early 1900s and even built his own crystal radio set with twenty-five-cent parts he ordered. Eventually, he made friends with a young boy named Shawgo, whose father worked for the local city utility. He visited Shawgo's home and found the basement filled with treasures he had only read about in black ink on cheap paper. Leyden jars, Tesla coils, batteries, relays, everything. He even had his own transmitter, but they had to take it down because he didn't want to be suspected of being in contact with an enemy

While in the Navy, he started his first business, the Laso-Rael Company, in his neighbor's basement. The two of them would manufacture radio couplers and isolation transformers by hand to sell to Warshawsky's, the local war surplus store that sold radio equipment. During this time, he was involved in building Chicago's first radio broadcast station, with his Navy commander, Eugene F. McDonald Jr, who later became the president of Zenith Radio Corporation just a couple of years later.

Lear demonstrated so much skill that the Navy saw fit to make him an instructor, meaning he would actually stay in Chicago with the Navy. He stayed with the Navy for some years before setting off on his own again. Knowing that he could reach the life he wanted through hard work, honesty, and discipline, he was heavily influenced by nineteenth-century author Horatio Alger, who wrote rags-to-riches novels for young men.

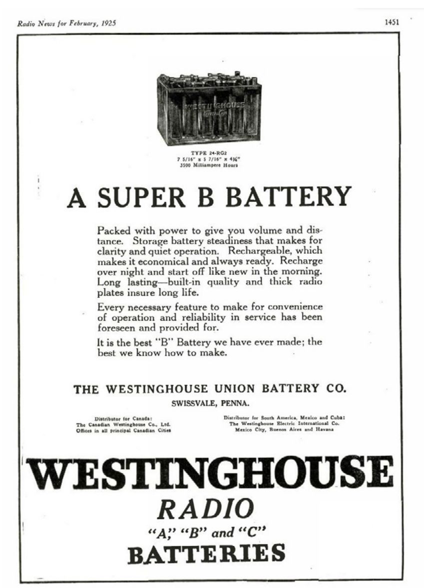
Cyber City Scuttlebutt: many retellings of Lear's story claim that he was a decorated Navy test pilot. The writer could find no evidence of this, but his son, John Lear, was indeed a decorated Navy pilot, earning every FAA certificate and license available, flying over 190 different types of airplanes, and setting several world records in flight.

Rags to riches determination

He decided to start fresh by walking to Quincy, Illinois. As he passed an auto parts store, he noticed some radio paraphernalia hanging in the front window. Lear walked into the store and told the owner that today was his lucky day. He boastfully explained that no one in Quincy knew as much about radios as he did, which is certainly true. He got a job, a home, and married his wife, Ethel Peterson.

Things were going very well until their infant son, William Lear Jr., died asleep in bed. This was devastating for both of them. They packed up and moved to Tulsa, Oklahoma, to live with Bill's father and grandfather. Here, he worked at a local hardware store and helped found the community's Christian radio station. During this time, he decided to re-enroll in high school to earn his diploma, working at night repairing radios at his home.

Within a few years, both Tulsa and his wife Ethel had exhausted him. He soon made his way back to Illinois in a battered Ford with a new wife, Madelaine. He got a ride to the local radio station and ran into an old friend from his time in Quincy, who was able to introduce him to the local industry.



Needing a 'B' battery was a problem that many broadcasters and distributors had problems dealing with.

Retro Electro sidenote: the friend's name is Howard Sams, but the writer isn't sure if it's THE Howard W Sams from Sams Photofacts fame. It would be pretty amazing if it was.

Paul Galvin (left) and his brother Joseph, circa 1930

Early broadcasters had a problem. They needed a 'B' battery for the high-voltage plates on their vacuum tubes, and this battery had to be changed often. Needless to say, wireless broadcasters of the day had good relationships with battery suppliers, and this is how Lear met R.D. Morely with Universal Battery Company. In a remarkably audacious move, he informed Morey that he could build a 'B' battery eliminator, enabling the transmitter's main power to replace the battery. Morey replied that a man who could do away with the 'B' battery could write his own ticket, and he hired Lear at $125 a week, and in 1924, "only sultans and bootleggers made that kind of money."

Lear radio laboratories

He quickly rose through the ranks of Chicago's radio industry jumping from company to company. As many others attempted to replicate Lear's battery eliminator, they consistently produced subpar products. They allowed noise from the power system to enter the transmitters, rendering the entire system useless. He spent the next several years building radio sets for several different companies, but when his short-term business partner, Ernie Tyrman, died from ulcers, he started his own business. Lear Radio Laboratories.

The wisdom of the day was that a coupling coil had to be two and a quarter inches in diameter to be any good. Lear's problem was that he didn't know that. He reasoned that if he used very thin wire, wrapped many more times than a standard coil, he could make them much smaller than anybody else. Unable to find someone who trusted it would work, he built a Rube Goldberg machine to wind these coils in his basement by himself.

Retro Electro fun fact: Lear brought his staff over to Galvin Manufacturing with him, including Elmer Wavering, who thirty-two years later became president of Motorola.

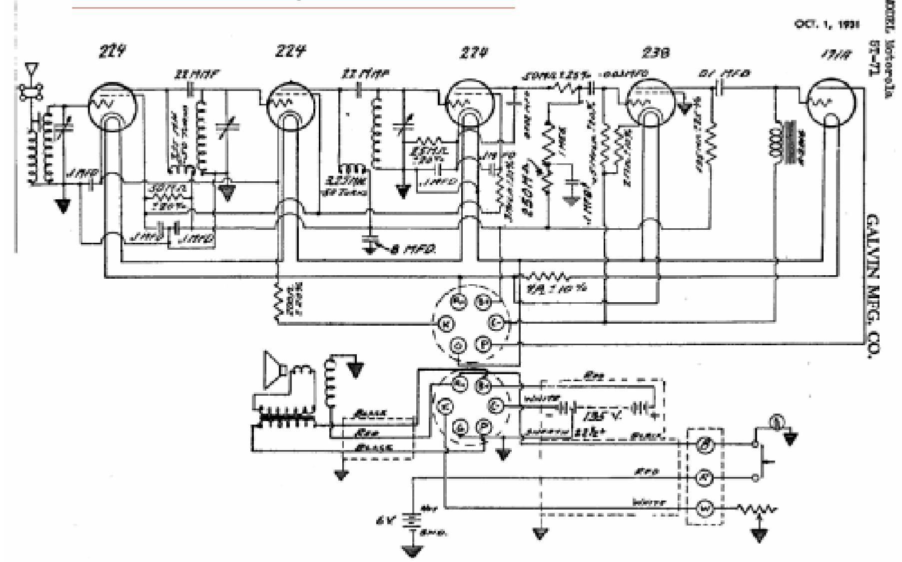
When he called his former Navy commander, Eugene McDonald, out for a demonstration, he was so impressed that Zenith Radio Corp ordered fifty thousand of them. Afterward, he rented space in a downtown building and renamed Lear Radio Laboratories to Radio Coil and Wire Corporation. He did very well, and in 1928, a new company moved into the same building. He soon traded his business for a one-third stake in that company, Galvin Manufacturing Corporation, which continued to produce coils and battery eliminators.

The Galvin Manufacturing Corporation

The Galvin Manufacturing Corporation began in 1928 in Chicago with five employees working on the ground floor of 847 Harrison Street. After a couple of earlier business attempts, such as the Galvin & Stewart Battery Company (1921), the Galvin brothers were going to try their hand at working on battery eliminators, initially simply performing warranty service for units sold through Sears & Roebuck, along with manufacturing 'white-labeled' radio sets for about twenty different distributors.

The building at 847 Harrison Street where Bill Lear and the Galvin brothers met. Galvin would later take over all six floors of the building.

Schematic for the original Motorola radio.

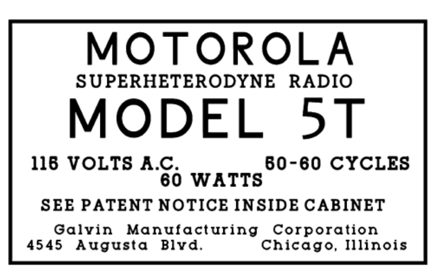


The Motorola radio

As the reader can probably deduce, the main issue in automobiles both then and now is noise. Everything in a 1930 Ford generated electrical noise, which made a radio powered from the engine so noisy that it was useless. Using these coils, he thought he could place a radio receiver in a car and it would work fine. Working with a colleague, Howard Gates, he built two radio sets for installation in cars. He took one and placed it on the desk of his business partner, Paul Galvin, Founder of Galvin Manufacturing.

"What's that?" Galvin asked.

"An automobile radio,"



"Well, I think it's a bunch of crap," Galvin said. "They'll never be allowed in cars. There'll be laws against it."

"You know what I think about what you think about automobile radios?" Lear sneered.

"What?"

"Nothing! You're just as wrong as you can be. A radio in the car will be a relaxation to the driver. Instead of bothering him, it'll make him less nervous – give him a chance to listen to his favorite program when he gets caught in a traffic jam. It won't be legislated against." (It would take states another 75 years to begin passing distracted driving laws.)

Then, a couple of weeks later, Galvin came back, asking, "Did you run a bill of material on that automobile radio set you made?"

"Yes."

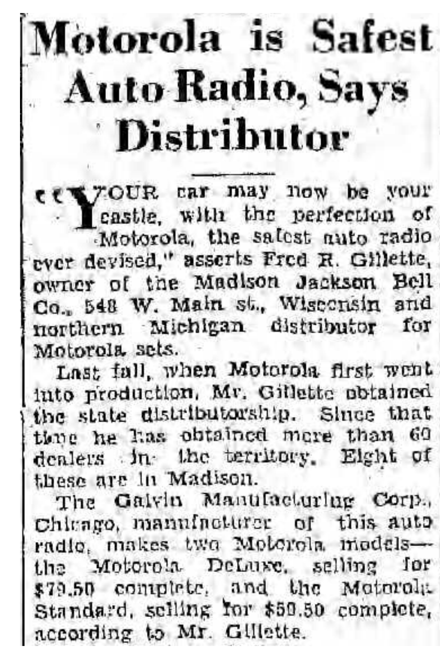
"How much did it run?"

"Twenty-two dollars."

"Let's see – if we sell it for five and a half times $22, that would be approximately $122. Less $50 and 10 per cent discount, that would come to about $50, and we'd be able to make 'em for about $35, so we'd make $15 apiece. Let's make a couple of hundred."

On a trip across the country, listening to one of the first car radios ever made, Lear and Galvin tossed around several names, agreeing on one compounded from 'motor' and 'victrola'. Motorola

Retro Electro fun fact: to get an idea of what the music was like coming out of this speaker, the reader can find recordings of broadcasts from the time period.



Motorola is Safest Auto Radio, Says Distributor

"YOUR car may now be your castle, with the perfection of Motorola, the safest auto radio ever devised," asserts Fred R. Gillette, owner of the Madison Jackson Bell Co., 548 W. Main st., Wisconsin and northern Michigan distributor for Motorola sets.

Last fall, when Motorola first went into production, Mr. Gillette obtained the state distributorship. Since that time he has obtained more than 60 dealers in the territory. Eight of these are in Madison.

The Galvin Manufacturing Corp., Chicago, manufacturer of this auto radio, makes two Motorola models—the Motorola DeLuxe, selling for $79.50 complete, and the Motorola Standard, selling for $50.50 complete, according to Mr. Gillette.

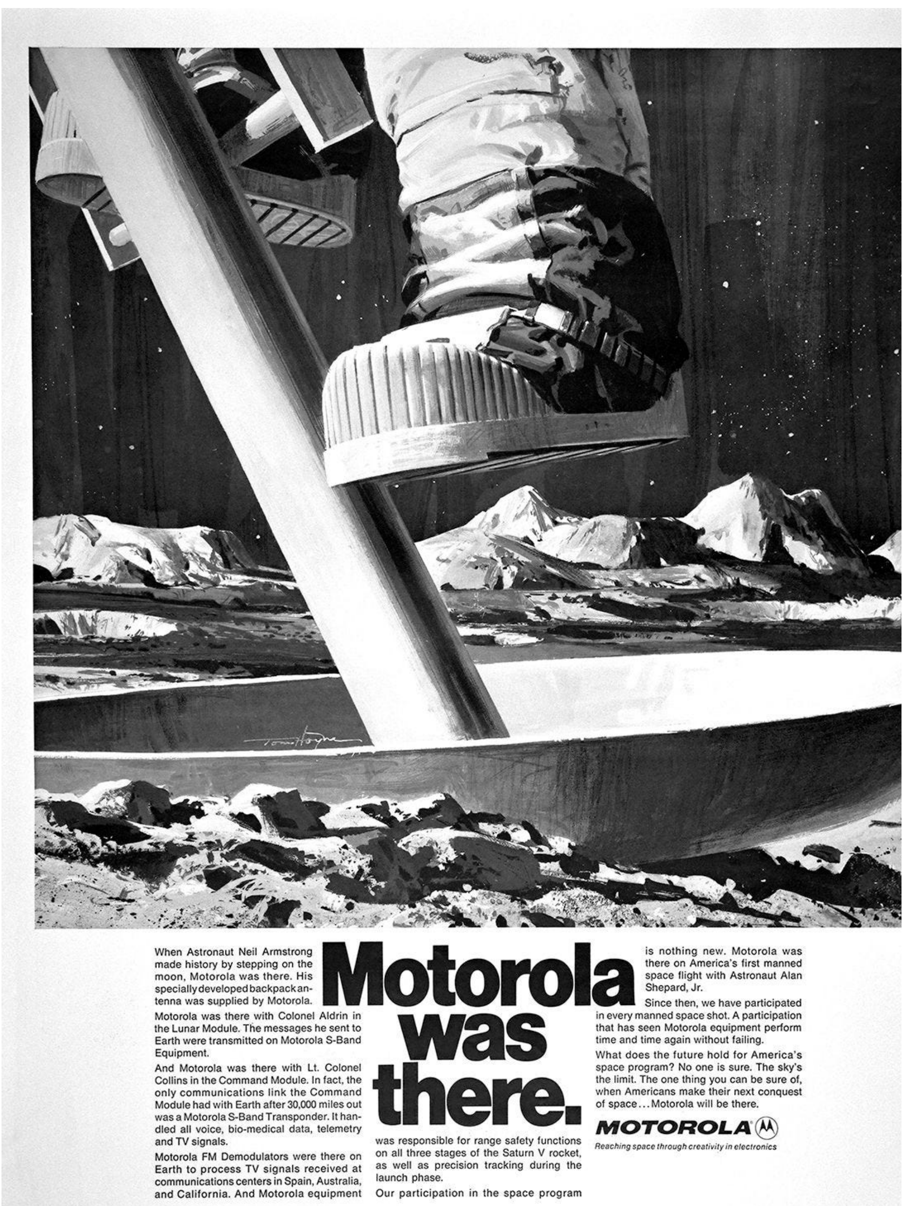
Lear would go on to create many inventions, including the 8-Track player system.

The story goes that this trip was to the Radio Manufacturer's Association conference in Atlantic City, NJ. When they arrived, they couldn't get a table, so they parked Galvin's Studebaker, with a loudspeaker mounted under the hood, and blasted the radio into the conference from outside. This drew many people, and with that, they started selling the Motorola car radios.

Lear after Motorola

With his income from Galvin and other business dealings, Lear earned $35,000 in 1931, making him very wealthy during the early depression era. He used this money to start several other businesses, including Lear Developments Inc., which supplied aviation systems, including the first auto-pilot systems, to the military during WWII. He later created the Lear Jet Corporation and invented the 8-Track cassette and player.

Retro Electro fun fact: NXP Semiconductor essentially started its life as Signetics, before it was acquired by Phillips, later being rebranded as NXP. Learn more about the Signetics story in the Retro Electro Article, "Five-Five-Five: The Story of Interdesign Inc."

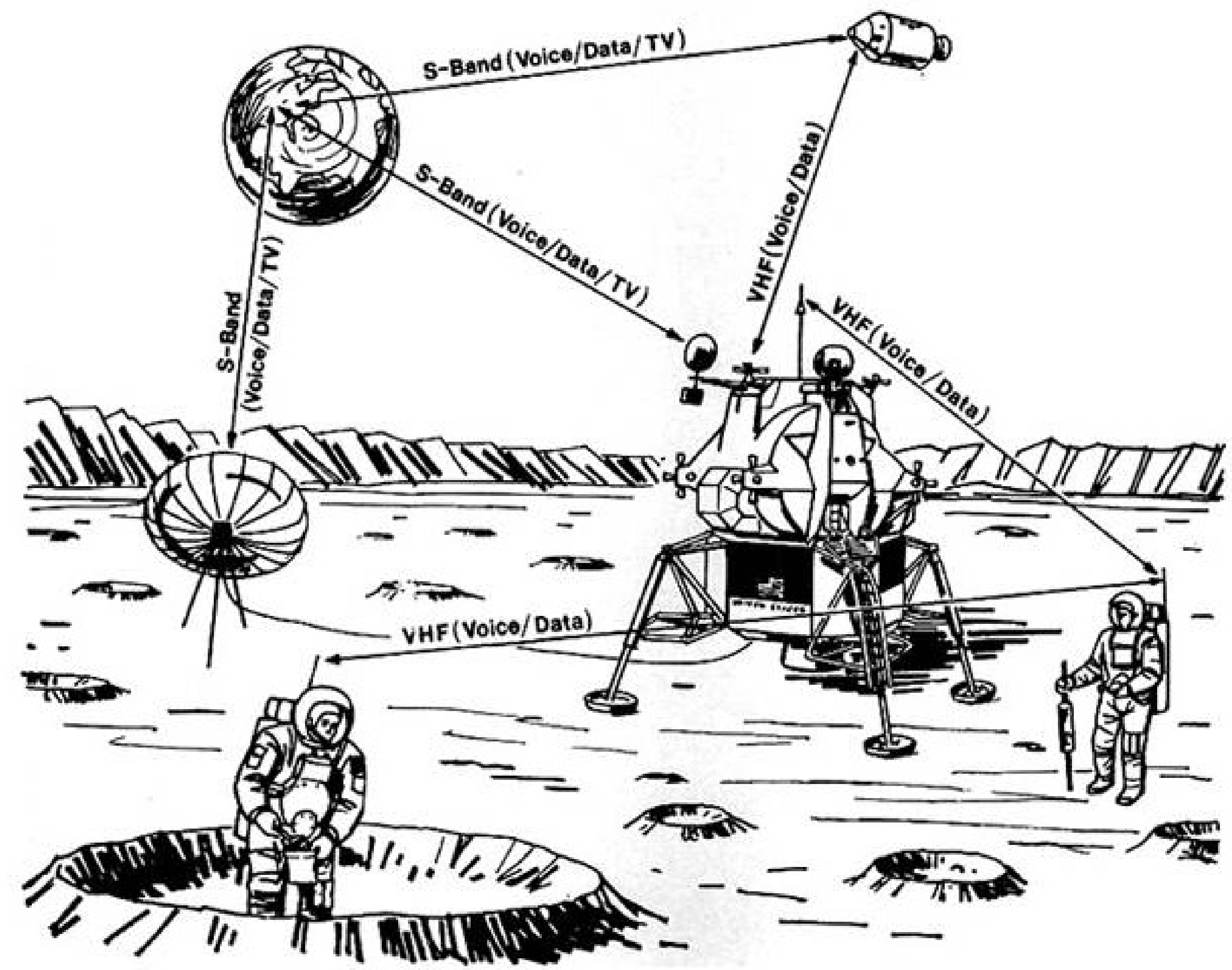


Galvin Manufacturing after Lear

The Galvin family would continue the Galvin Manufacturing Corporation for many years. They would enter into a contract with Ford Motor Company in 1932, putting a Motorola in the driveway of much of the nation.

Following the success of the car radio, they released the Motorola Police Cruiser Receiver (1936), which was specially tuned to specific police frequencies. A few years later they released the first two-way police radio, creating the slogan 'YOU CAN'T OUTRUN MOTOROLA'.

They were instrumental to success during World War II with the SCR-536 (1940) and SCR-300 (1943), producing the first man-portable 'handie-talkie' radio sets. The company rebranded as Motorola in 1947 and continued to innovate, eventually producing your favorite



transistor, the 2N2222, as well as the radio transceivers used on Apollo. It also developed satellite communication systems, early microprocessors with the 68000, and contributed to the development of the mobile cell phone.

Motorola would 'spin-off' their discrete components division, creating the company ON Semiconductor, today onsemi. The microcontroller divisions later became a company named Freescale, which later merged with NXP Semiconductors.

Suggested reading

1. "The History of Motorola" by Abort Retry Fail
2. "1930: The First Motorola Brand Car Radio" by Motorola Solutions
3. "First company to mass-produce car radios is incorporated" by History
4. Elmer H Wavering Obituary in Chicago Tribune
5. "First Words From the Moon" by Motorola Solutions
6. "Galvin Manufacturing Company in World War Two" by David D Jackson
7. Daniel Noble in Engineering and Technology History Wiki
8. "The Said It Couldn't Be Done: The Incredible Story of Bill Lear" by Victor Boesen
9. The Founder's Touch: The Life of Paul Galvin of Motorola" by Harry Mark Petrakis

1902
William Powell Lear is born in Hannibal, Missouri.

1918
Lear drops out of high school and works odd jobs as an "office boy" in Chicago, including at the American Multigraph Company under Warren B. Houghton.

1919
Lear lies about his age to join the U.S. Navy, where he trains as a wireless radio operator and later serves as an instructor at the Great Lakes Naval Training Station.

1920
Lear assists his commander, Eugene F. McDonald Jr., in building one of Chicago's first radio broadcast stations.

1923
Lear starts his first business, the Laso-Rael Company, making radio couplers and isolation transformers to sell to Warshawsky's Radio Supply Store in Chicago.

1924
Lear meets R.D. Morley of Universal Battery Company and invents a "B-battery eliminator," allowing radios to run directly from main power. Morley hires him at $125 a week — a small fortune in 1924.

1927
After his partner Ernie Tyrman dies, Lear continues the business alone and designs miniature coupling coils that outperform traditional large ones.

1928
Lear demonstrates his new coil design to Eugene McDonald of Zenith Radio Corporation, who orders 50,000 units. Lear renames his firm Radio Coil and Wire Corporation.
Paul and Joseph Galvin found Galvin Manufacturing Corporation in Chicago with five employees and a $63 weekly payroll.

1929
Lear merges his company into Galvin Manufacturing, trading it for a one-third stake and bringing along his staff.

1930
Lear develops a car radio that filters ignition noise. Paul Galvin and Lear demonstrate it outside the Radio Manufacturers Association convention in Atlantic City, broadcasting from a Studebaker. The radio goes into production as the Motorola Model 5T71 — the first commercially successful car radio.

1931
Lear leaves Galvin Manufacturing to start Lear Developments Inc., building aviation radios and autopilot systems.

1933
Ford Motor Company begins offering factory-installed Motorola car radios.

1936
Galvin Manufacturing releases the Police Cruiser Receiver, the first police car fleet radio.

1940
Galvin Manufacturing develops the SCR-536 "Handie-Talkie" — the first portable AM two-way radio.

1943
Galvin Manufacturing introduces the SCR-300 "Walkie-Talkie," the first FM backpack radio used by Allied forces in World War II.

1947
Galvin Manufacturing Corporation is renamed Motorola, Inc., as it begins manufacturing television sets.

1962
Engineer Jack Haenichen designs the 2N2222 silicon transistor at Motorola, becoming the most widely used discrete transistor in the world.

1969
Motorola's S-band transponders carry Neil Armstrong's voice and live video from the lunar surface during the Apollo 11 mission.

1980
Motorola releases the 68000 microprocessor, powering computers such as the Apple Macintosh, Amiga, and Atari ST.

1999
Motorola spins off its discrete components division to form ON Semiconductor (now onsemi).

2004
Motorola spins off its microcontroller and embedded systems division to form Freescale Semiconductor.

2015
NXP Semiconductors acquires Freescale, merging both product portfolios under the unified NXP Semiconductors name.

Improve test performance with low-cost signal sources using inline filters

Written by Art Pini

Do you need a pure sine wave for a test but only have an arbitrary function generator with a high harmonic level available? Perhaps you're mixing the outputs of two signal generators and must select the upper sideband component at the mixer output. How can you do this? The solution is to use inline RF filters, such as Crystek Corporation's CLPFL-0200 (Figure 1, see next page) with an SMA connector and CLPFL-0021-BNC (Figure 1, see next page) with a BNC connector.

RF filters clean up signals by selectively attenuating unwanted frequencies while passing desired frequency components. Inline filters, intended for use with coaxial lines, are designed with a 50 ohm (Ω) nominal impedance. These filters reduce noise by reducing the signal bandwidth. They also control the signal spectrum to reduce harmonics, images, and interfering signals.

Figure 1: Inline coaxial filters, such as the CLPFL-0200 with an SMA connector (left) or the CLPFL-0021 with a BNC connector (right), can reduce signal harmonics and noise on signal sources. Image source: Crystek Corporation

Types of filters

There are several types of inline filter configurations, including low pass, high pass, and bandpass (Figure 2).

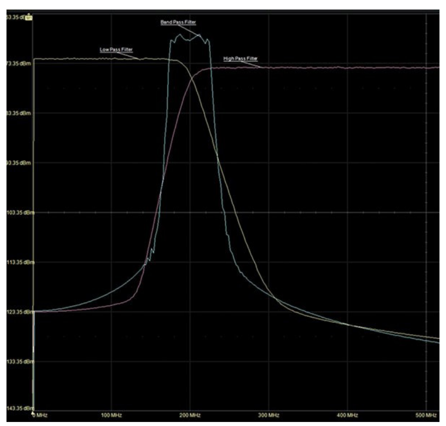


Figure 2: Shown are the frequency responses of low-pass, high-pass, and bandpass filters. Image source: Art Pini

Low-pass filters pass frequencies below a fixed cutoff and can eliminate the harmonics of a signal with the cutoff set just above the fundamental frequency. High-pass filters pass frequencies above a fixed cutoff and can eliminate an interfering signal with the cutoff set above the power line frequency. Bandpass filters attenuate unwanted signals by passing frequencies within a desired band and can be employed as a preselector for an RF front-end. The region where the signal is transmitted with little loss is called the passband, and the region where the signal is highly attenuated is the stopband. The region(s) between the passband and the stop band is the transition region(s).

Selecting the right filter

Filters are designed for specific frequency response characteristics. These include the sharpness of the transition from the passband to the stopband, the flatness of the passband and the stopband, and the phase response as a function of frequency. There are several classic designs shown in Figure 3.

The Butterworth filter has a flat passband response and a moderate roll-off rate. The Bessel filter has the most linear phase response but the slowest roll off; it would typically be used when a band-limited pulse waveform must be transmitted with minimum distortion. The Chebyshev filter has a fast roll off but has ripple in the passband. The inverse Chebyshev filter has a flat passband response and a fast roll off but exhibits ripple in the stop band. The Butterworth and the Chebyshev are two of the most widely used inline filters.

The roll-off characteristics of any filter type are affected by its order. The order is derived from the filter's transfer function and indicates the number of poles in the design. In general, the higher the filter order, the faster the roll off (Figure 4).

Crystek's CLPFL-0200 is a 7th-order Butterworth low-pass filter with a passband of DC to 200 megahertz (MHz) and an insertion loss of 2.2 decibels (dB) at a frequency of 210 MHz. This filter could be used to clean up the output of a signal generator when making an effective number of bits (ENOB) measurement on an 8-bit analog-to-digital converter (ADC) (Figure 5).

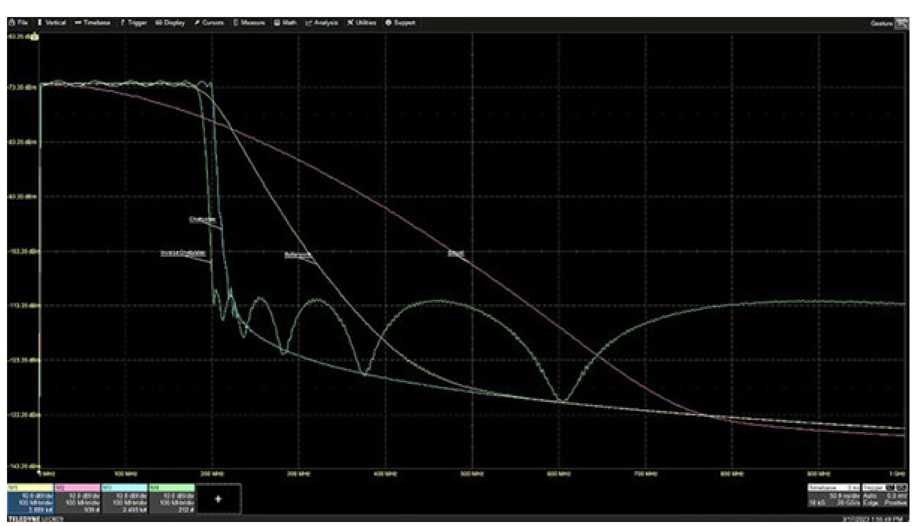
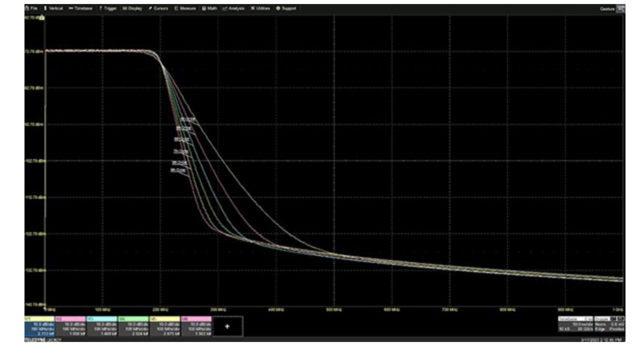


Figure 3: The frequency response of several types of classic filters shows the differences in roll-off and flatness characteristics. Image source: Art Pini

Figure 4: Shown is a comparison of a Butterworth low-pass filter response for a filter with orders of 5 through 9. The higher the filter order, the faster the roll off in the transition region. Image source: Art Pini



The upper trace shows the signal generator output spectrum with a second harmonic only 22 dB below the fundamental. With the filter (lower trace), the second harmonic is down over 70 dB, and other harmonics are below the noise floor. Note also that the noise floor above the filter cutoff frequency is lowered by better than 40 dB.

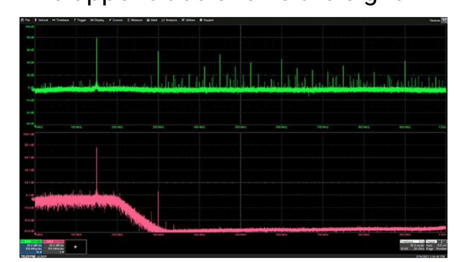


Figure 5: Shown is the result of a 200 MHz low-pass filter being used to remove harmonics and noise from a signal generator. The filtered signal (lower trace) has significantly reduced noise and harmonic levels. Image source: Art Pini

High-pass filters eliminate interfering signals with a lower frequency than the desired signal (Figure 6).

In Figure 6, a high-pass filter attenuates a 13MHz interfering signal and passes the 30MHz signal of interest. The interfering signal's effect can be seen in the time-domain view (upper left) as an amplitude variation of the signal peaks. The filtered signal (lower left) has flat peak amplitudes.

A filter such as Crystek's CHPFL-0025-BNC, a 7th-order 25 MHz Chebyshev high-pass filter with BNC connectors, could attenuate the interfering signal.

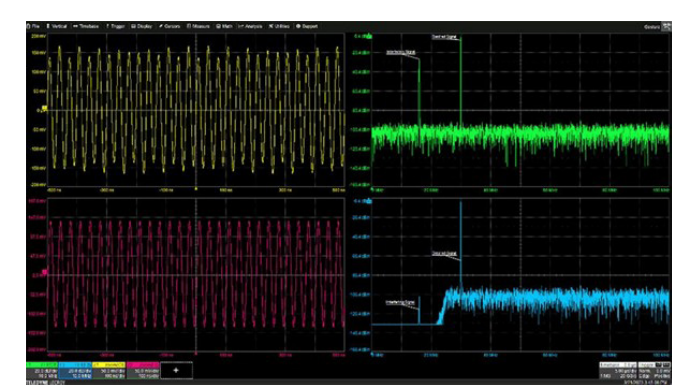


Figure 6: Shown is a high-pass filter being used to eliminate a 13 MHz interfering signal from the desired 30 MHz signal (upper trace). The filtered signal appears in the lower trace. Image source: Art Pini

Crystek filters are offered in up to 9th-order configurations. For example, the CLPFL-0021-BNC mentioned earlier is a 21MHz Chebyshev response, 9th-order, low-pass filter. It delivers a transition region that rolls off at about 55 dB per octave.

Bandpass filters typically require more components than low or high-pass filters, which take up space and add to the BOM. Crystek addresses this using surface acoustic wave (SAW) technology to allow its bandpass filters to fit in the same package as low-pass or high-pass filters. An example SAW bandpass filter is the Crystek CBPFS-0915 with SMA connectors and a 26MHz bandwidth centered on 915MHz.

Conclusion

Inline RF filters improve test performance by eliminating harmonics, noise, and interference from signal sources. Companies like Crystek offer a wide range of inline filters to match your signal-conditioning needs.

Use traps to enable multiband operation with dipole antennas

Written by Bill Schweber

The historically significant long-wire dipole antenna may seem like an anachronism in these days of compact, highly mobile wireless devices operating in the gigahertz spectrum, but that's not the case. Due to its many virtues, it is still widely used by the military, emergency services, broadcasters, and amateur radio enthusiasts (hams) for long-distance, worldwide point-to-point links, and wide-area broadcasting.

Among these virtues are flexibility, ease of set-up, adjustable radiation pattern, low visibility to others, and small packing/carrying size. It is primarily used at frequencies below 30 megahertz (MHz) (10 meter (m) wavelength) in what historically was designated as the high-frequency (HF) band spanning 3 to 30MHz, as well as lower frequencies/longer wavelengths. As a further benefit, a single dipole antenna can serve multiple bands simultaneously via the addition of simple resonant LC circuits called traps in both arms of the dipole.

This blog will provide a brief overview of the long-wire (dipole) antenna principle, point out some theory versus real-world

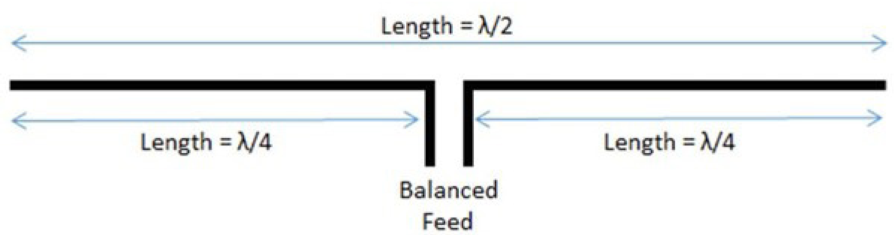


Figure 1: The basic, classic dipole antenna has two quarter-wavelength arms and appears as a 73 Ω balanced resistive load at its resonant operating frequency. Image source: MicrowaveTools

considerations, and explain how traps can extend their usefulness to function as a multiband antenna. (Some of these considerations apply to other dipole configurations, such as the well-known folded dipole, but there are important differences there as well.)

Why use a long-wire dipole antenna?

Given that so many of today's antennas are short (in most cases, on the order of a meter or less) or nearly invisible such as the chip resonator or planar inverted-F antenna (PIFA) inside a smartphone, the long-wire dipole may seem to be an antique or curiosity. However, Maxwell's equations and wave theory show that an effective dipole radiator/receiver must have a primary dimension of one-half the wavelength of interest. This classic dipole antenna is ungrounded and presents a balanced, symmetrical load to the transmitter power amplifier and the receiver front-end amplifier (Figure 1). (The nominal impedance of an ideal dipole is 73 Ω but is often cited as 75 Ω; the difference is negligible.) If the antenna is connected to the common 50 Ω feedline, a modest impedance matching arrangement is needed between feedline and antenna.

If thin wire is used for the dipole, the bandwidth will typically be around 5% of the center frequency; thicker wire will increase the bandwidth by as much as 20%, but it will affect other performance attributes. If the connection to

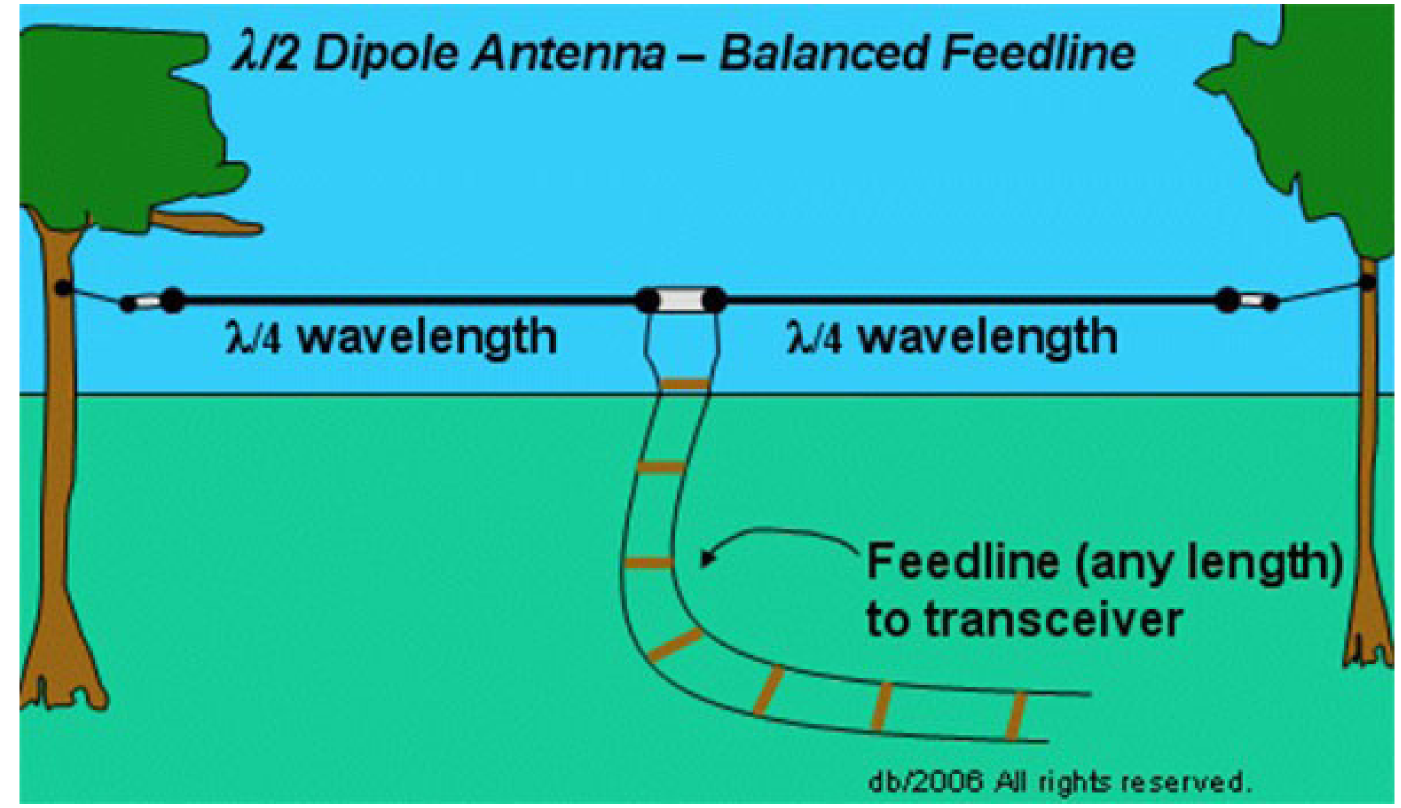


Figure 2: The dipole is usually attached to its supports via insulators (white) and wire lengths that allow the dipole arm lengths to be maintained independently of the distance between the supports. Image source: Physics Forums

the transmitter or receiver is via a grounded circuit and uses coaxial cable as the feedline, a balun transformer may be needed. However, a coaxial cable can also be used directly in many cases as long as the impedances are suitably matched.

Given its simple design, it's easy to see the attraction of the long-wire dipole antenna. All it requires are two equal lengths of wire and a way to attach them to trees, buildings, signposts, or whatever is handy. The antenna is usually not connected directly to those supports; instead, a length of wire and insulators are generally used as attachment 'standoffs' (Figure 2).

In practice, the actual antenna length for optimal performance will likely need to be adjusted to accommodate the fact that the wire has a finite thickness and other deviations from theory but this adjustment is usually less than five percent. Even if not adjusted, performance is usually quite good, and the voltage standing wave ratio (VSWR) is usually below a generally acceptable 1.5:1.

In those cases where there is a significant antenna impedance shift or mismatch, the VSWR will rise to an unacceptable level, and performance will suffer. In such instances, an adjustable antenna tuner is used in the feedline to compensate and implement a transition.

The theoretical gain of the dipole is around 2 dBi (dB relative to isotropic). Its radiation pattern is simple and often characterized as a torus or donut (Figure 3).

The user can adjust the antenna orientation to direct maximum transmitter energy/receiver sensitivity toward the intended radio transceiver, often located thousands of miles away. There are many documented cases of successful communication at

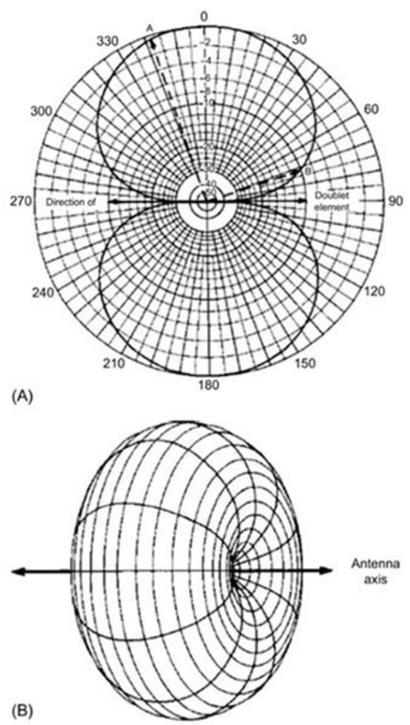


Figure 3: The radiation pattern for the dipole as viewed from above in the vertical plane (A), and from the side in the horizontal plane where it resembles a torus or donut (B).
Image source: Science Direct

these distances using a dipole at 20 and 40m with transmit power well below a watt and under suitable atmospheric propagation conditions, as its efficiency and radiation pattern are that good.

Multiband operation extends versatility

In many real-world HF communication situations, it is necessary to try to establish a contact in more than one band at the same time or switch bands at different hours, since connectivity is a function of many variables such as sunspots, atmospheric noise, daytime versus nighttime operation, and constantly varying propagation conditions. As a result, a single-band dipole antenna may be insufficient.

The obvious solution is to set up multiple dipole antennas, one for each band/wavelength of interest. However, doing so has practical difficulties for rigging, tangling, managing, and switching between multiple feedlines. In some cases, an RF splitter/combiner could be used to enable a single feed line to connect to two antennas, but this introduces losses and new impedance matching issues.

Fortunately, there's a better solution that, like the dipole, has been in use since the earliest days of wireless: the 'trap'. (It's unclear when this term was first introduced or by whom; the word is not used on the 1941 US Patent 2,229,865 that presents the technique.) A trap is a simple, parallel-connected inductor-capacitor (LC) combination which is self-resonant between two bands of interest.

One trap is inserted into each arm of the dipole to make the antenna have two electrical lengths but one physical length. At frequencies below the resonant frequency, the trap's reactance will be inductive; above the resonant frequency, it will be capacitive. Traps act like a switch, electrically cutting off the rest of the antenna at the trap's design frequency and functioning as a loading coil below the antenna's resonant frequency.

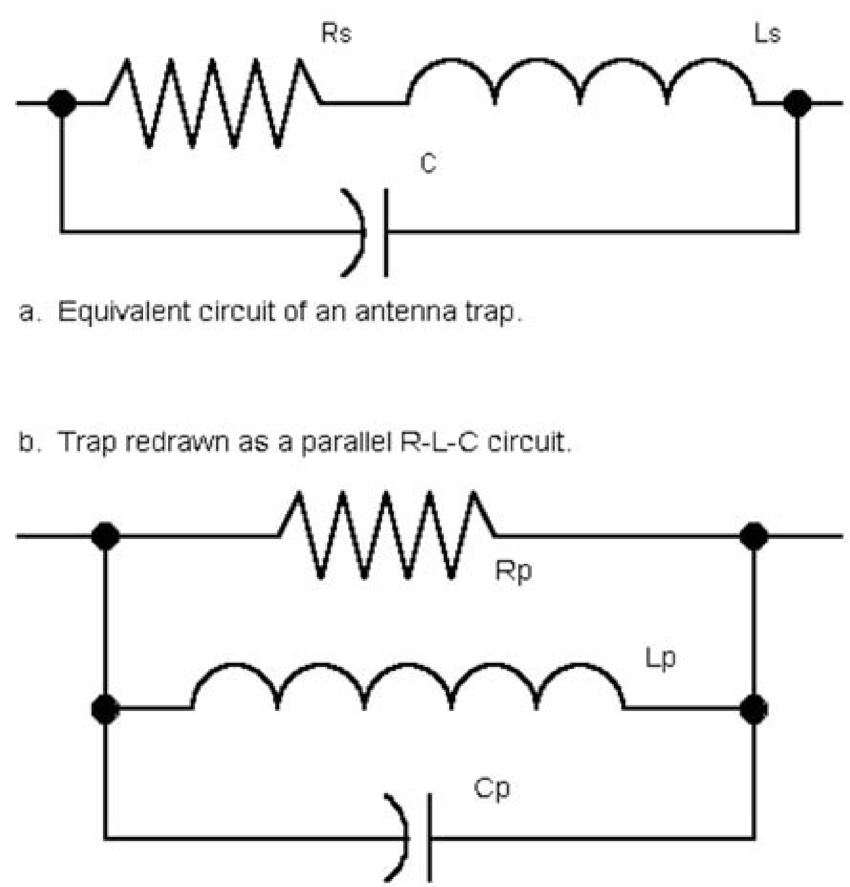


Figure 4: The trap is a simple resonant LC circuit with some undesired, unavoidable resistance which can be modeled in series (a), or as a parallel RLC circuit (b).
Image source: AntenTop

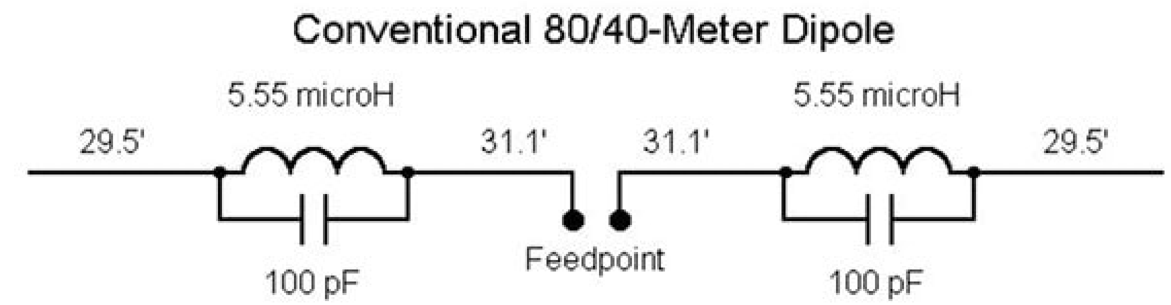


Figure 5: The component values shown and the dipole linear dimensions (in feet) are a good starting point for an 80/40m multiband dipole. Image source: QSL Net

A simplified electrical model of the trap shows the physical inductor and capacitor and a small parasitic resistance (RP) (Figure 4).

Traps can have a reputation for being lossy, which would be a concern for both transmit and receive modes. However, a properly designed and tuned trap will impose a modest loss on the order of 1 dB, and that is usually acceptable in exchange for the convenience that it provides.

Selecting the trap component values

Mathematically, there are an infinite number of LC pairings that will result in a desired resonant frequency. However, many of these would require an extremely small (or large) inductor matched with an extremely large (or small) capacitor, respectively. Such a pairing would be excessively affected by parasitics and physical size issues, and also have a Q-factor (quality factor) that was too narrow or broad for the band of interest.

Fortunately, there is considerable literature available on sizing traps based on theory, implementation, and hands-on field experience. For example, a trap using a 5.55 microhenry (μH) inductor paired with a 100 picofarad (pF) capacitor is a good starting point for an 80/40m dipole (Figure 5).

Selecting trap components is about more than just determining suitable L and C values, as there are some very practical issues of power handling and ruggedness. For receive-only antennas, almost any inductor or capacitor can handle the very small amount of received power, which is on the order of milliwatts, and often less. However, transmitters often provide power levels ranging into the tens,

Figure 6: This homemade 80/40 m trap uses a hand-wound inductor around a PVC pipe as its core support. Image source: www.vk4adc.com

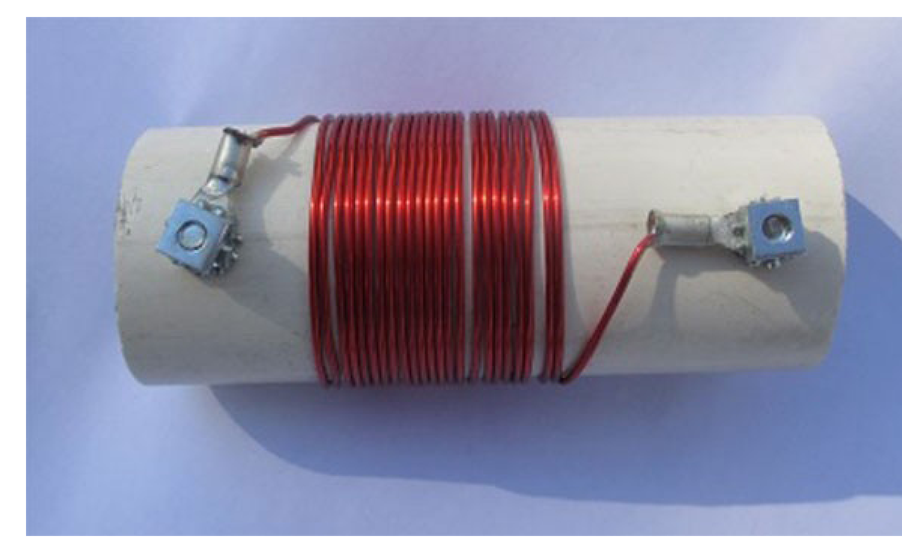


Figure 7: Traps can be used for three-band operation on basic dipoles as well as on more complex multiband antennas such as this 20/15/10 m Yagi design; shown (left to right) are the antenna director, driven, and reflector elements, each with two traps on each arm. Image source: OnAllBands

hundreds, and even more watts, so the trap components must be rated for those power levels.

Traps are also exposed to the weather. While some dipole antennas are located in benign environments such as an attic or wooden barn, most are outside and thus must endure rain, wind stress, temperature extremes, condensation, and more. Therefore, the trap and its connection must be either completely sealed, have some sort of drainage and venting arrangement, or be constructed with weather-resistant materials. Even if the connections remain intact, any water intrusion or corrosion can affect component values and thus shift the resonant frequency.

Trap construction usually requires encapsulating its components by sealing them in a plastic case, using conformal coating, or using some sort of weather-resistant exposed construction (Figure 6). Low-cost PVC pipe is often used as the core of a wound inductor; in other cases, a PVC pipe with tight end caps is used as the enclosure with watertight access holes.

There's another practical issue to consider: tuning and trimming the trap components. While calculating the component values is a necessary first step, these ideal values are often not quite close enough due to parasitics, wire diameter, and inductor winding imperfections, to cite but a few real-world factors.

For this reason, most homemade traps and many commercial ones allow the user to make some adjustments to the L and C values in the field to achieve the desired performance, which is usually done with a VSWR meter. This fine-tuning can be a frustrating, iterative process, especially with DIY implementations; again, there are many websites with practical suggestions for simplifying the process.

The use of traps is not limited to solely using a long-wire dipole over two bands. It is possible to build three and even four-band dipole antennas using a series of traps. However, doing this requires additional adjustments and some performance compromises and tradeoffs in antenna radiation pattern, gain, bandwidth, and other parameters.

Not limited to simple dipoles

While traps are usually associated with basic long-wire dipoles, they are not limited to that antenna design. For example, a multiband, directional, high-gain Yagi-Udi antenna (often simply called a 'Yagi') is constructed using an array of active and passive dipole elements. This form of Yagi uses traps in its director, active drive, and reflector elements so it can function across multiple bands (Figure 7).

It is possible to build your own dipole, and many one-off users do just that. But they are also available as standard commercial units such as the KGI825 from PulseLarsen Antennas. This basic quarter-wavelength dipole with 2 dB gain is designed for operation from 806 to 896 megahertz (MHz), centered at 851MHz (Figure 8).

The KGI825 can handle up to 60 watts of transmit power and offers convenient magnetic mounting inside a window between 0.138 and 0.158 inches thick (3.5 to 4 millimeters). It comes with a 14 foot (4.25m) RG-58/U coaxial cable to which the user adds the desired connector.

Conclusion

The humble, modest, low-tech, long-wire dipole antenna has served the wireless world for over a century. It continues to do so due to its simplicity, adaptability, portability, and effectiveness. By using passive traps, its ability to function can be extended across two or even more bands in the high-frequency part of the electromagnetic spectrum.

Related content

1. Understanding Antenna Specifications and Operation, Part 1
2. Understanding Antenna Specifications and Operation, Part 2
3. Antennas: Design, Application, and Performance
4. The Use of Baluns for Measurements
5. Understanding the RF Balun and its Transformative Function
6. Use PIFAs to Solve the Small-Product, Smaller-Antenna Dilemma

External references

1. H.K. Morgan, U.S. Patent 2,229,865, "Radio Antenna System"
2. MicrowaveTools, "Dipole Antenna"
3. Science Direct, "Antenna Fundamentals: Radiation Pattern"
4. On All Bands, "Antenna Traps—A Way to Cope With Limited Space"
5. QSL Net, "Tuned Circuits and Traps"
6. AntenTop, "Modeling Trap Antennas"
7. AntenTop, "Multirange Trap Antennas"
8. VK4ADC's web, "Low Cost Antenna Traps"
9. SOTABeams, "Using Antenna Traps"

Figure 8: The KGI825 is a quarter-wavelength dipole antenna with 2 dB gain and a center frequency of 851 MHz. Image source: PulseLarsen Antennas

Use a compact 5G MIMO antenna for optimum connectivity and aesthetics

Written by Stephen Evanczuk

5G network deployments are accelerating globally for faster data rates, increased capacity, and seamless connectivity. Multiple-input multiple-output (MIMO) antenna technology is crucial for delivering on the promises of 5G, including simultaneous transmission and reception of multiple data streams, enhanced spectral efficiency, and overall network performance.

Although many antenna options exist, many applications require small, low-profile MIMO antennas that designers can fit into space-constrained systems or place in discreet locations in security, residential, retail, and other applications.

This article briefly discusses the challenges facing designers of small and discreet 5G devices. It then introduces a compact 5G/4G MIMO antenna from Taoglas that meets designers' needs while providing wide spectrum coverage, global compatibility, and ease of use.

Applications and challenges for compact, low-profile 5G MIMO antennas

The discreet installation of small, low-profile 5G MIMO antennas can provide the data rates and coverage required in many applications. Consumer electronics and security system designers want to deliver 5G performance without compromising aesthetics. In transportation and industrial applications, compact antennas can eliminate the distracting visual impact that larger conventional antennas might have on vehicle or equipment operators. Compact antennas allow designers to add 5G connectivity more easily in smaller, self-contained applications such as digital signage, point-of-sale kiosks, and network appliances.

For applications in industrial process systems and the Internet of Things (IoT), designers can easily add small 5G MIMO antennas to provide 5G network connectivity for remote locations or serve as a backup connectivity option for existing communications networks.

The use of multiple antennas and the associated processing allows individual data streams to be multiplexed to improve link reliability and compensate for signal loss to maintain high data rates. MIMO antennas counter

Figure 1: Designed to be easily and discreetly installed with magnetic or adhesive mounting, the MA322 5G MIMO antenna measures only 80 x 18.1mm. Image source: Taoglas

signal degradation due to high path loss in millimeter-wave communications and multipath fading exacerbated with small cell deployments widely used in 5G networks.

Although MIMO technology offers significant benefits, it also poses implementation challenges. These challenges include minimizing mutual coupling and maximizing isolation among the elements of a MIMO antenna to ensure optimal radiation performance.

Earlier MIMO antenna designs addressed these concerns by increasing the physical distance between the antennas. This left users coping with the installation of large antenna systems. As designers look to accommodate space-constrained installations, the physical space for placing multiple antennas in a MIMO antenna design becomes much more limited. As a result, effects like mutual coupling and reduced efficiency become more pronounced.

Overcoming these challenges requires new approaches involving more advanced materials, decoupling methods, miniaturization, and optimized ground-plane design.

A simpler solution to 5G antenna installation

An excellent example of the application of new approaches is the Taoglas MA322.A.001 Comet series MIMO antenna (Figure 1). This device delivers 5G MIMO performance in a puck-like, low-profile form factor measuring 80 x 18.1 millimeters (mm) and weighing 113 grams (g).

The MA322's form factor and weight enable its use in applications where large and heavy antennas are not practical or desired. It is also designed for a magnetic or adhesive mount, providing 5G connectivity in existing applications where drilled mounting holes are undesirable. These include applications like first responders and emergency services vehicles that need upgraded 5G communications. To simplify the antenna's connection to the users' application, each of this antenna's MIMO 1 and 2 connections comes with a 2-meter (m) low-loss cable with high-frequency subminiature version A (SMA) connectors.

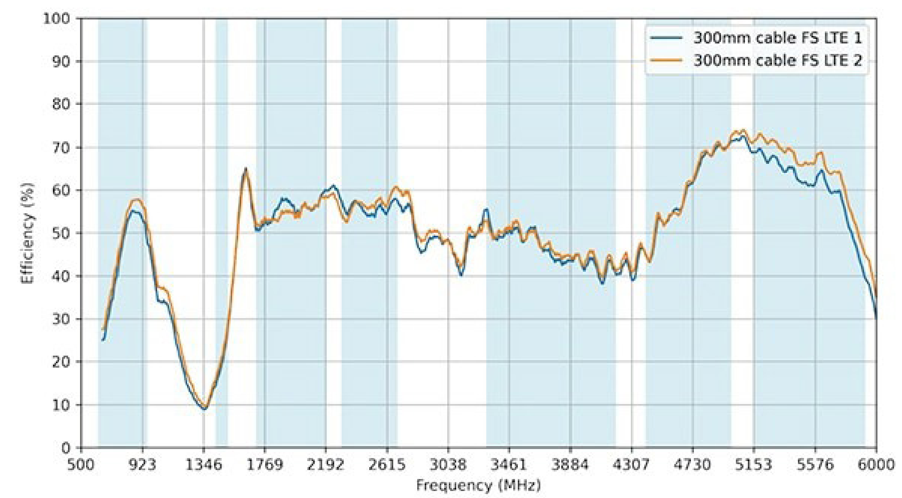


Figure 2: An innovative design allows the MA322 to deliver efficiency levels previously unobtainable in similar-sized puck-shaped antennas.
Image source: Taoglas

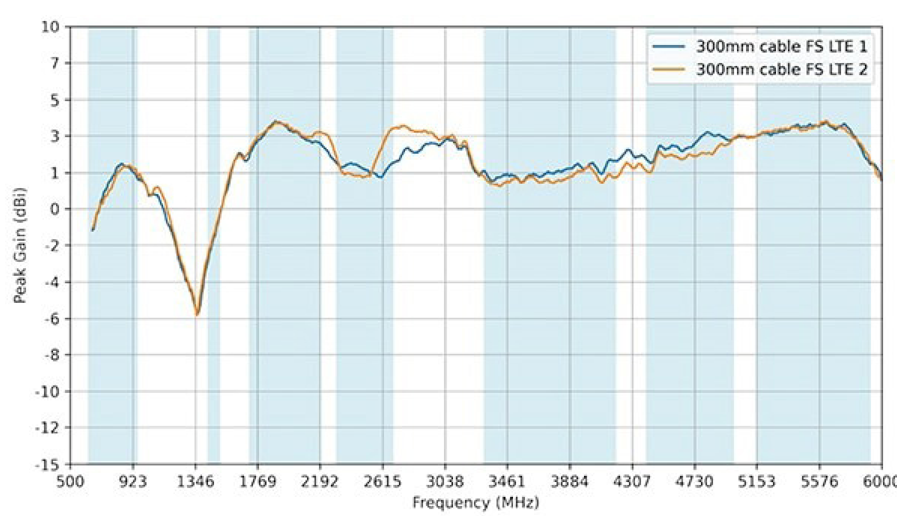


Figure 3: The MA322 meets the demand for stable peak gain, achieving a specified maximum peak gain of 4.2 dBi. Image source: Taoglas

Suited for indoor or outdoor installation, the antenna enclosure has an operating temperate range of -40 to +85°C and is IP67 rated, providing dust-tight protection and protection against water ingress when immersed in up to 1m of water. Its enclosure is fabricated with acrylonitrile styrene acrylate (ASA) plastic to provide the ultraviolet (UV) stability needed for long-term outdoor installations. A separate 3M foam pad is also included, enabling adhesive mounting on non-magnetic surfaces.

The antenna complies with European Union (EU) Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) regulations and EU Restriction of Hazardous Substances (RoHS) legislation.

High performance with worldwide cellular frequency support

Designed with two high-performance 5G/4G antennas, the MA322 supports worldwide 5G cellular frequencies and 4G, 3G, and 2G bands from 617 megahertz (MHz) to 5925 MHz. It does so while delivering performance characteristics typically lacking in small antennas.

With its low return-loss characteristics and voltage standing wave ratio (VSWR) specification value of zero, the MA322 antenna operates at typical small-antenna efficiency levels without sacrificing signal performance (Figure 2).

Designed to meet designers' long-range communications and path-loss mitigation requirements, the MA322 antenna achieves stable peak gain levels (Figure 3) and excellent omnidirectional radiation patterns (Figure 4) across its entire operating frequency range. Its maximum peak gain is 4.2 decibels relative to isotropic (dBi), and its operating frequency range includes the 3550MHz frequency band, which lies within the 5G bands frequently used in the United States and Europe.

With its stable performance and easy installation, the MA322 antenna offers designers a ready 5G installation solution for an expanding array of applications.

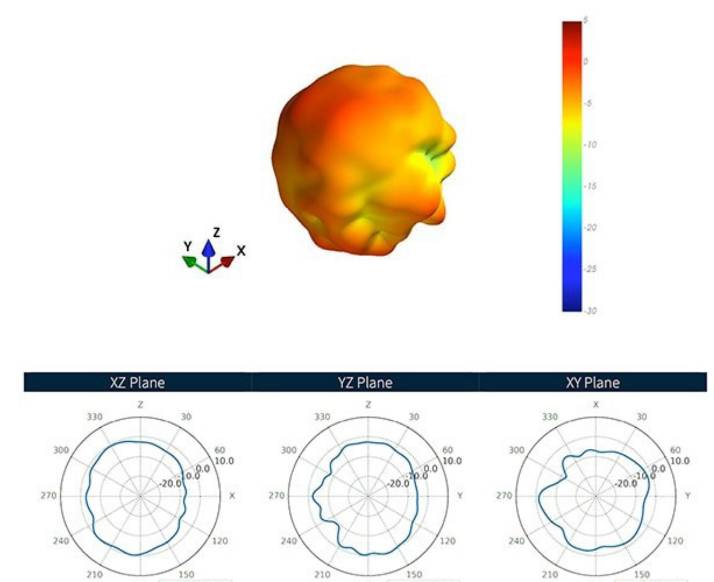


Figure 4: The MA322 offers highly uniform radiation patterns across its operating frequency range, including at the 3550MHz frequency band shown here.
Image source: Taoglas

Conclusion

The availability of more advanced materials and design methods has enabled the development of small MIMO antennas from Taoglas that can achieve the levels of gain and efficiency required for 5G operation. This compact, low-profile device allows designers to add 5G connectivity to applications with limited space where security, aesthetics, and ease of use are required.

Use a global cellular radio module to quickly and securely connect IoT devices to the Cloud

Written by Jens Wallmann

To connect portable or remote network end devices to the Internet of Things (IoT), or to control machines remotely using machine-to-machine communication (M2M), a mobile radio connection for data exchange via the Cloud is a good option. However, this option presents hurdles for the developer, such as determining which wireless networks can support the required data throughput worldwide and which protocols the wireless modem must be able to handle. System scalability, data security, cost, time to market, and the acquisition and operating costs incurred by the user must also be considered.

This article briefly explains what LTE Cat 1 offers developers of IoT and M2M applications. It then introduces radio modules from u-blox's LARA-R6 series that provide universal connectivity and reliable performance. The article concludes by showing how developers can use an evaluation board (EVB) to easily configure and control the modules via AT commands and generate AT command strings via library functions.

LTE Cat 1 compared to LTE Cat 1bis, LTE Cat M, and LTE Cat NB

While LTE cellular radio now achieves gigabit transmission rates, low-power, wide-area (LPWA) protocols like LTE Cat 1, LTE Cat 1bis, LTE Cat M, and LTE Cat NB are designed to be particularly efficient in terms of energy consumption, network resources, and cost. This is critically important for IoT devices.

Providing up to 20 megahertz (MHz) channel bandwidth in full duplex, LTE Cat 1 achieves download data rates up to 10 megabits per second (Mbps) and upload data rates up to 5 Mbps. Two antennas enable receiver (Rx) diversity for better performance (Table 1). LTE Cat 1bis uses a single antenna.

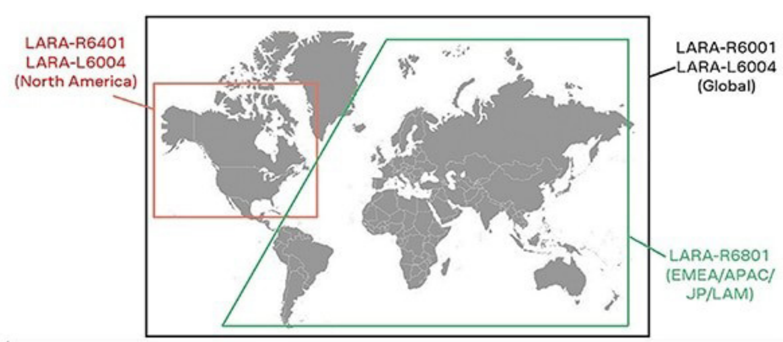
LTE Cat 1 mobile radio for global availability

u-blox's LARA-R6 series is comprised of robust cellular radio

	LTE Cat1/Cat1bis	LTE Cat M1	LTE Cat NB1
3GPP Release	Release 8	Release 13	Release 13
Downlink peak rate	10 Mpbs	1 Mbps	26 kbps
Uplink peak rate	5 Mbps	1 Mbps	66 kbps (multi-tone) 16.9 kbps (single-tone)
Latency	50 ms to 100 ms	10 ms to 15 ms	1.6 s to 10 s
Number of antennas	2 (LTE Cat 1) 1 (LTE Cat 1bis)	1	1
Duplex mode	Full duplex	Full or half duplex	Half duplex
Device receive bandwidth	1.4 MHz to 20 MHz	1.4	180 kHz

Table 1: Performance comparison of LPWA protocols. LTE CAT 1 uses two antennas for Rx diversity; LTE Cat 1bis uses one antenna. Image source: Wikipedia, Jens Wallmann

Figure 1: Three regional variants of the LARA-R6 modules cover the globe. Image source: DigiKey, modified by author



modules designed for the radio access technology (RAT) LTE Cat 1 frequency division duplex (FDD) and time division duplex (TDD) standards. They support 3G UMTS/HSPA and 2G GSM/GPRS/EGPRS as a fallback solution. These modules are an excellent solution for global/multi-regional coverage and come in a small LGA form factor measuring 26 x 24 millimeters (mm).

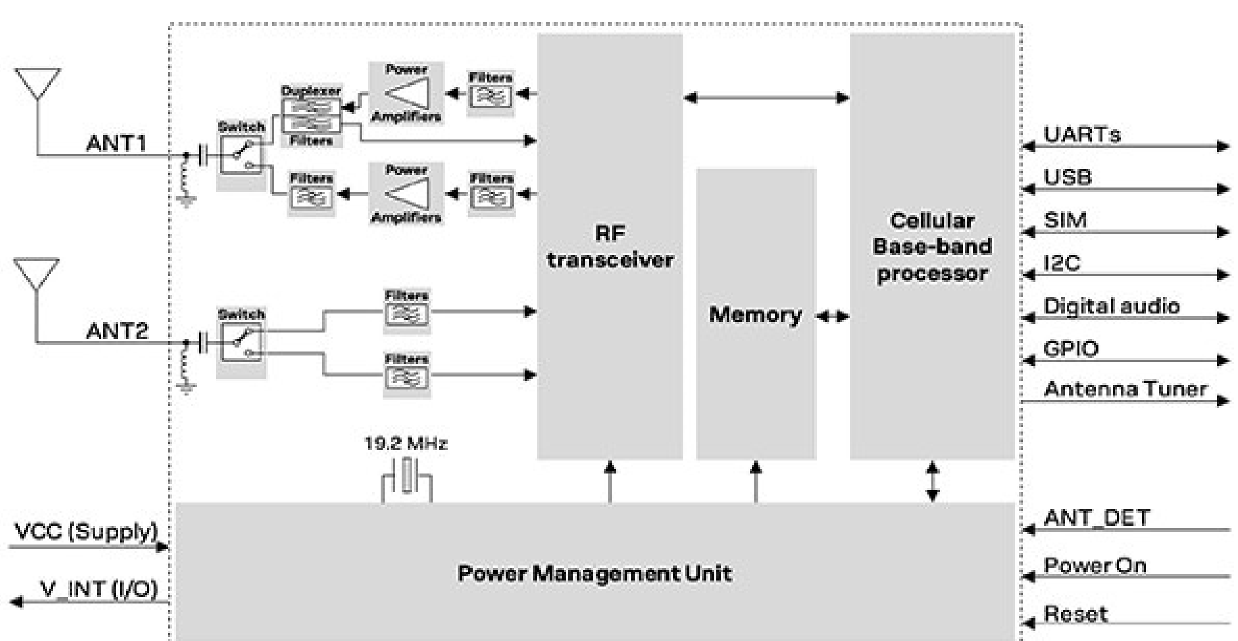
Equipped with versatile interfaces, a wide variety of features, and multiband and multimode capabilities, LARA-R6 modules are suitable for applications that require medium data speed, seamless connectivity, excellent coverage, and low latency. Such applications include asset tracking, telematics, remote monitoring, alarm centers, video surveillance, connected health, and point-of-sale terminals.

All modules support Rx diversity for reliable performance in difficult coverage conditions or when voice over LTE (VoLTE) is required. Programmers can take advantage of the embedded IoT protocols (LwM2M, MQTT) and security features (TLS/DTLS, secure update, and secure boot) to implement various functions, including device management, remote device control, and secure firmware over-the-air (FOTA) updates.

The LARA-R6 series supports LTE Cat 1 according to 3GPP Release 10 and achieves global coverage with three regional variants:

- The LARA-R6001-00B (data and voice) and LARA-R6001D-00B (data only) modules support 18 LTE FDD/TDD frequency bands plus 3G/2G fallback for global connectivity
- The LARA-R6401-00B (data and voice) and LARA-R6401D-00B (data only) modules provide an ideal LTE Cat 1 solution for North America, supporting LTE bands from AT&T, FirstNet, Verizon, and T-Mobile
- The LARA-R6801-00B (data and voice) and LARA-R6801D-01B-01 (data only) modules are designed for deployments in the following regions: Europe and the Middle East (EMEA), Asia Pacific (APAC), Japan (JP), and Latin America (LATAM) (Figure 1)

Figure 2: Internal structure of a LARA-R6 module. Image source: u-blox



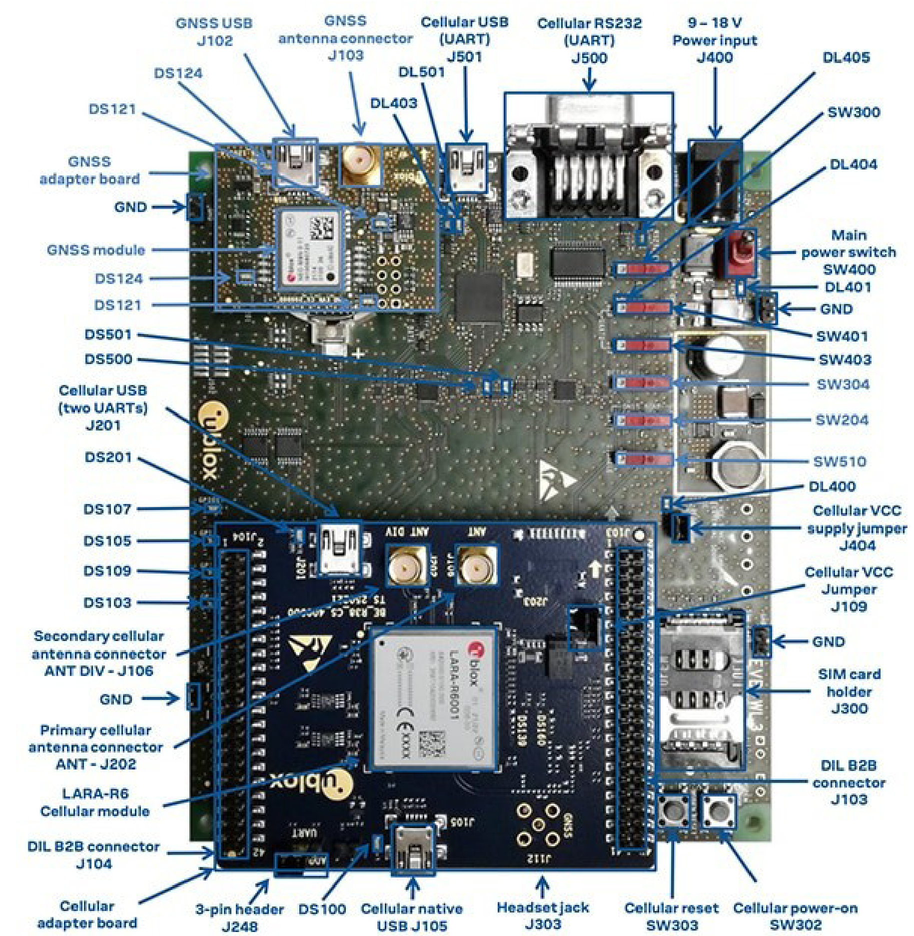


Figure 3: LARA-R6 EVB (EVK-R6) with an attached LARA-R6 adapter board (bottom) and a GNSS board (top left). Image source: u-blox

LARA-R6 special features at a glance

LARA-R6 modules integrate a cellular baseband processor with external interfaces, an RF transceiver with amplifiers and filters, memory, and a power management unit (Figure 2).

The RF transceiver operates in the frequency bands 700MHz, 800MHz, 850MHz, 900MHz, 1.7GHz, 1.8GHz, 1.9GHz, 2.1GHz, and 2.6GHz. All data transfer protocols of the cellular baseband processor can be controlled and configured via AT commands using the external UART and USB interfaces.

Protocols

- Dual stack IPv4 and IPv6
- Embedded TCP/IP, UDP/IP, FTP, and HTTP
- Embedded MQTT and MQTT-SN
- Embedded LwM2M
- eSIM and Bearer Independent Protocol (BIP)

LARA-R6 modules require a supply voltage of 3.1 to 4.5 volts and have an idle current consumption of around 1.1 milliamperes (mA). In 2G operation, individual TDMA time slots can reach peak transmission powers of over 33 decibels referenced to 1 milliwatt (mW) (dBm) (> 2.0 watts), and all other RAT reach levels of over 24 dBm (> 0.25 watts).

An excellent antenna sensitivity of less than -100 dBm, corresponding to signal powers of less than 0.1 picowatts (pW), enables stable radio connections at the edge of the mobile network.

Evaluating and programming

The quickest way to start evaluating and programming a LARA-R6 module is to use an R6 EVB (EVK-R6) and a plug-in LARA-R6 adapter board (ADP-R6)

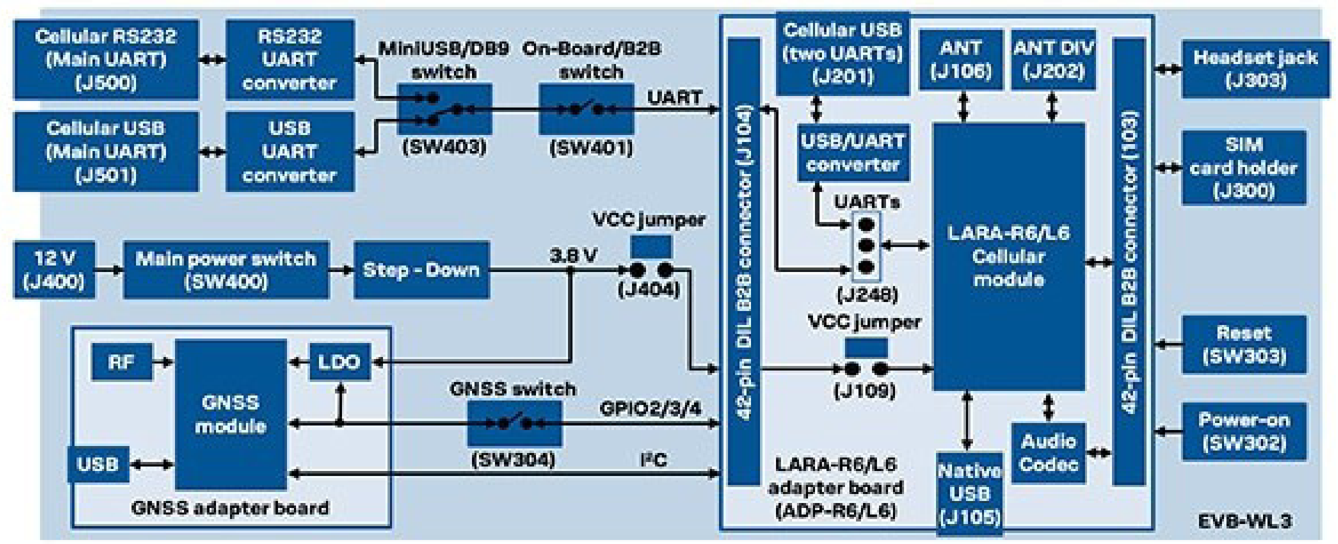


Figure 4: Functional block diagram of the R6 EVB with GNSS and LARA-R6 adapters plugged in. Image source: u-blox

for the corresponding region. For example, the EVK-R6001-00B for global applications includes the plug-in adapter board ADP-R6001-00B (voice + data) and a GNSS adapter board (Figure 3).

The EVK-R6401-00B variant for North America includes the ADP-R6401-00B adapter, while the EVK-R6801-01 for EMEA/APAC/JP/LATAM includes the ADP-R6801-00B adapter. The three adapter boards already mentioned for voice and data transmission are also available separately, as are versions for data transmission only, including the ADP-R6401D-00B (North America) and ADP-R6001D-00B (global).

The R6 adapter board extends the LARA-R6 module with two antennas and two MiniUSB connectors. The R6 EVB adds a GNSS module, a SIM card slot, additional plug-in connections, jumpers, switches, and a power supply to the module peripherals (Figure 4).

Each kit contains one EVB with an attached LTE Cat 1 LARA-R6 adapter board and a GNSS module from u-blox, one USB cable, two LTE mobile radio antennas, a GPS/GLONASS antenna, and a power supply unit.

Command sent by DTE (user)	DCE response (module)	Description
AT+CREG?	+CREG: 0,1 OK	Verify the network registration
AT+COPS=0	OK	Register the module on the network (AT+CREG? returns 0,0).
AT+COPS?	+COPS: 0,0,"I TIM",7 OK	Read the operator name and radio access

Table 2: AT registration commands. Table source: u-blox, modified by author

Table 3: 'POST data' is HTTP command number 5 and is formatted as shown. Table source: u-blox, modified by author

Type	Syntax	Response	Example
Set	AT+UHTTPC=<profile_id>,5, <path>,<filename>,<data>, <HTTP_content_type> [,<user_defined_content_type>]	OK	AT+UHTTPC=0,5,"/path/file.html", "responseFilename","data",0 OK

Commissioning of the EVK

The easy-to-use, powerful EVK-R6 kit from u-blox simplifies the evaluation of multimode LTE Cat 1 / 3G / 2G cellular modules. A Windows PC with the LARA-R6 USB driver installed controls the LARA-R6 modem via the USB connector and simplifies the connection setup via the system settings. To get started, the developer needs to:

1. Insert the SIM card and connect both cellular antennas and the GNSS antenna
2. Carefully configure the jumpers and switches of the EVK
3. Apply the supply voltage and turn on the main switch SW400 on the EVB
4.
    1. For operation as a low data rate modem via the 'Main UART' interface, connect the PC to the MiniUSB jack J501 or RS232 jack J500 on the EVK
    2. For operation as a low data rate modem via 'Two UARTs', connect the PC to the cellular USB jack J201 interface on the ADP
    3. For operation as a high data rate modem via 'Native Cellular USB', connect the PC to the MiniUSB jack J105 on the ADP
5. Press the Cellular Power-On button SW302 on the EVB
6. Run a terminal application software (such as m-center), go to the COM port setup menu, choose the AT port corresponding to 4a, 4b, or 4c, and set these values: Data rate: 115,200 bps; Data bits: 8; Parity: N; Stop bits: 1

The m-center tool helps evaluate, configure, and test u-blox cellular products, and it includes an AT command terminal.

Simple Internet connection using a Windows PC

By connecting a Windows PC to the EVK, the user can establish a wireless Internet connection in two ways:

1: A low-speed packet data connection: this uses the TCP/IP stack of the Windows PC via the UART interface of the LARA-R6 module. The PC and EVK are connected according to method 4a. The developer must select Phone and Modem > Modems > Add using the Windows Control Panel. The

For the global networking of low-power IoT and M2M applications, LTE Cat 1 multi-mode radio modules from the LARA-R6 series are efficient and cost-effective.

next step is to pick the 'Don't detect my modem' checkbox, select 'Standard 33.6 kbps Modem', and allocate a COM port. If necessary, the developer can add Properties > Advanced > Extra initialization commands.

2: A high-speed packet data connection: this accesses the Internet using the TCP/IP stack of the Windows PC via the cellular native USB interface of the LARA-R6 module. The PC and EVK are connected according to method 4c. The developer must select Network and Sharing Center > Set up a new connection or network via the Windows Control Panel and click "Connect to the Internet". The next step is to select 'Dial-up' and one of the AT USB Ports. The final step is to enter dial-up parameters (Dial-in number, provider name, user ID, and password).

Registering the SIM card with the mobile operator

Once the SIM card and MNO parameter are configured, the cellular module automatically registers itself on the cellular network after power-on. If there is a problem, the registration can be checked manually using the AT commands shown in Table 2.

Communication to the remote HTTP server via AT command

The GitHub repository 'Firechip_u-blox_LARA-R6_Arduino_Library' contains an extensive library of AT commands for the LARA-R6 modules, written in C++ for Arduino controllers. Sixteen application examples, including ping tests, registration, packet switch, SMS, GNSS, and IoT Cloud, provide suggestions for custom code structures.

AT commands can also send requests to a remote HTTP server during an active connection, receive the server response, and store that response transparently in the local file system. The supported methods are HEAD, GET, DELETE, PUT, POST file, and POST data.

The Lara_R6_Example9 sends random temperatures to the RemoteHTTP-Server ThingSpeak.com using HTTP POST or GET. ThingSpeak is an IoT analytics platform service by MathWorks that helps to aggregate, visualize, and analyze live data streams in the Cloud. Table 3 shows the syntax of the HTTP command 'POST data'.

```
...
String myWriteAPIKey = "PFIOEXW1VF21T7O6"; // Change this to your API key
String serverName = "api.thingspeak.com"; // Domain Name for HTTP POST/GET
[...]

void loop()
{
  // Create a random temperature between 20 and 30
  float temperature = ((float)random(2000,3000)) / 100.0;


  // Send data using HTTP POST
  String httpRequestData = "api_key=" + myWriteAPIKey + "&field1=" +
                           String(temperature);

  Serial.print(F("POSTing a temperature of "));
  Serial.print(String(temperature));
  Serial.println(F(" to ThingSpeak"));

  // Send HTTP POST request to /update. The reponse will be written to
     post_response.txt in the LARA's file system
  myLARA.sendHTTPPOSTdata(0, "/update", "post_response.txt", httpRequestData,
                          LARA_R6_HTTP_CONTENT_APPLICATION_X_WWW);


  // Send data using HTTP GET
     ==> see original code on Github

  for (int i = 0; i < 20000; i++) // Wait for 20 seconds
  {
    myLARA.poll(); // Keep processing data from the LARA so we can catch
                   the HTTP command result
    delay(1);
  }
}
...
```

Listing 1: This main program generates a random temperature value and calls the library function sendHTTPPOSTdata every 20 seconds. Code source: Firechip on Github

This example can be programmed on an Arduino host controller, which controls the LARA-R6 module on an EVK board via AT commands. Additionally, a configured SIM card is required.

The programmer must create a ThingSpeak user account and set field 1 for the random temperature measurement value via the menu item Channels > My Channels > New Channel. The corresponding 'Write API Key' is entered in the main program, 'LARA-R6_Example9_ThingSpeak.ino' in the variable myWriteAPIKey.

The C++ main program generates a random temperature value, forms the Cloud-specific data string, and calls the library function sendHTTPPOSTdata every 20 seconds (Listing 1).

Generate the AT command string calling library functions

The library header 'Firechip_u-blox_LARA-R6_Arduino_Library.h' forwards the function call sendHTTPPOSTdata to the library procedure 'Firechip_u-blox_LARA-R6_Arduino_Library.cpp', where the fully formatted AT command string is generated and sent (Listing 2).

Listing 2: This C++ library procedure generates and sends the fully formatted AT command string (line 12). Code source: Firechip on Github

```
...
1  LARA_R6_error_t LARA_R6::sendHTTPPOSTdata(int profile, String path,
                                  String responseFilename, String data,
                                  LARA_R6_http_content_types_t httpContentType)
2  {
3    LARA_R6_error_t err;
4    char *command;
5
6    if (profile >= LARA_R6_NUM_HTTP_PROFILES)
7     return LARA_R6_ERROR_ERROR;
8
9    command = lara_r6_calloc_char(strlen(LARA_R6_HTTP_COMMAND) + 24 +
                                      path.length() + responseFilename.length()
                                      + data.length());
10   if (command == nullptr)
11     return LARA_R6_ERROR_OUT_OF_MEMORY;
12   sprintf(command, "%s=%d,%d,\"%s\",\"%s\",\"%s\",%d",
             LARA_R6_HTTP_COMMAND, profile, LARA_R6_HTTP_COMMAND_POST_DATA,
             path.c_str(), responseFilename.c_str(), data.c_str(),
             httpContentType);
13
14   err = sendCommandWithResponse(command, LARA_R6_RESPONSE_OK_OR_ERROR,
                                     nullptr, LARA_R6_STANDARD_RESPONSE_TIMEOUT);
15
16   free(command);
17   return err;
18 }
...
```

The library procedure LARA_R6::sendHTTPPOSTdata (Listing 2) uses the passed parameters of the function call myLARA.sendHTTPPOSTdata() (Listing 1) and additionally declared variables from the library header to generate the complete HTTP command string according to Table 3. Finally, the LARA-R6 modem sends the resulting AT command string to the ThingSpeak RemoteHTTP server:

AT+UHTTPC=0,5,"/update","post_response.txt","api_key=PFIOEXW1VF21T7O6&field1=21.54",0

Conclusion

For the global networking of low-power IoT and M2M applications, LTE Cat 1 multi-mode radio modules from the LARA-R6 series are efficient and cost-effective. As shown, developers have ready access to all interfaces using the EVK and can easily configure and control the protocols and functions of the module via AT commands. This provides simple options for operating as a PC modem, sending data to the Cloud, and generating AT command strings via library functions.

This month in history

1882

January 12

First power station

The Edison Electric Light Station in London commenced operations, becoming the first coal-fired electric power station for public use and paving the way for the modern era of electrification. This was the kick-off of the 1882 Crystal Palace Electrical Exposition.

Edison's Electric Light Station at 57 Holborn Viaduct, London, opened in 1882.

1919

January 14

Nathaniel Rochester's birthday

Nathaniel Rochester was an American computer scientist and electrical engineer best known for designing IBM's first commercial computer, the IBM 701. He was also one of the organizers of the 1956 Dartmouth Conference, which launched the field of artificial intelligence.

Nathaniel Rochester became the engineer who brought IBM into the computer age with its first digital electronic computer, the IBM-701.

1949

January 20

Inauguration of President Truman

Harry S. Truman takes the oath of office on January 20, 1949, beginning his second term as President of the United States, the first inauguration ever televised live to the American public.

The second inauguration of President Truman became the first presidential inauguration to be televised.

1977

January 3

Formation of Apple Computers

Apple Computer, Inc. was officially incorporated by Steve Jobs, Steve Wozniak, and Mike Markkula in Cupertino, California. The incorporation marked the company's transition from a garage startup into a formal business entity. The team met with Chuck Peddle a few months earlier to talk about the new 6502 processor and how to use it in their computers.

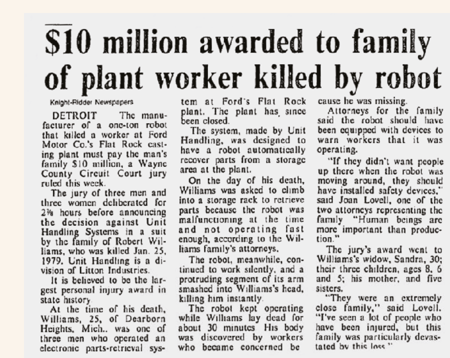
This case is said to be Steve Wozniak's first Apple 1 computer.

1979

January 25

First death by robot

This day in 1979, a Michigan auto worker was killed by a robot, marking the first recorded time someone died in a robot related industrial accident.



$10 million awarded to family of plant worker killed by robot

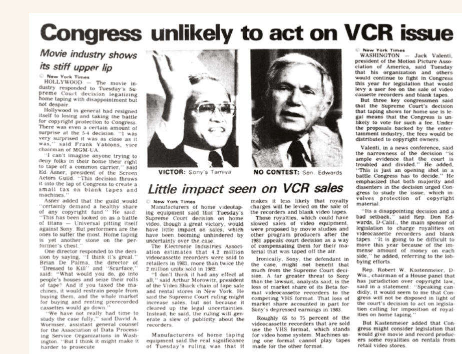
In 1979, Ford worker Robert Williams became the first known person killed by an industrial robot when a malfunctioning arm struck him at the company's Flat Rock plant.

1984

January 17

Video tape recording decided legal

In 1984, the U.S. Supreme Court ruled 5-4 that recording TV shows on a VCR for personal use is fair use, not copyright infringement. This decision shaped home video history and pushed the legal uses of 'fair use.'



Congress unlikely to act on VCR issue

Movie industry shows its stiff upper lip

Little impact seen on VCR sales

The news about home recording was on the cover of newspapers and magazines across the country.