A reconfigurable low-band RF front-end architecture for global IoT Connectivity

Using the Forefront RF FFM51010 Front-End Module

Connectivity everywhere — but not without compromise

Cellular IoT connectivity has evolved into a fragmented, multi-standard landscape, where no single technology meets all application requirements. Instead of a linear progression from legacy cellular to LTE and 5G, developers are now faced with a broad mix of technologies depending on the use case but with trade-offs in power, bandwidth, cost and coverage.
For device manufacturers, this fragmentation introduces a new set of design challenges. Products must increasingly support multiple regional frequency allocations, operate efficiently within tight power and size limits, and remain viable across evolving network roadmaps. At the same time, RF front-end architectures must balance performance, flexibility and integration within compact form factors.

These pressures are particularly acute in the low-band spectrum (<1 GHz), where cellular IoT technologies rely on strong propagation characteristics to deliver coverage and penetration. Supporting global operation across these bands using conventional fixed, band-specific RF front-end designs leads to increased complexity, larger PCB footprints and reduced efficiency.

This application note explores how a reconfigurable low-band RF front-end architecture—implemented in the Forefront RF FFM51010 front-end module—addresses these challenges. By enabling a software-defined approach to duplexing and band support, it provides a scalable and flexible solution that works across multiple global IoT platforms.

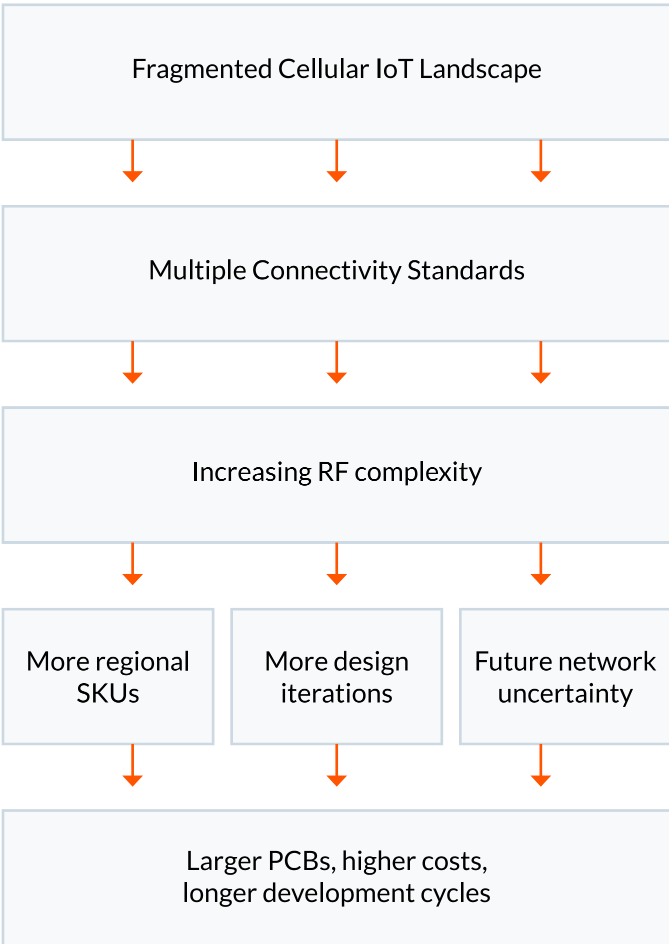


Figure 1: The Cellular IoT market has evolved into a high-fragments, multi-standard landscape

The fragmented IoT landscape

The current IoT connectivity landscape is characterised by a broad set of technologies, each developed for specific application requirements. Rather than converging on a single standard, the ecosystem has diversified into multiple connectivity approaches, reflecting differing priorities in power consumption, data rate, coverage and cost.

Within the cellular IoT domain, a wide range of standards are now deployed, including legacy 2G/3G, 4G LTE (Cat-1, Cat-1bis, Cat-4), LTE Cat-M1 (eMTC), NB-IoT (Cat-NB2), and emerging 5G RedCap and eRedCap technologies. These are all described in more detail within this Application Note.

Low power wide area network (LPWAN) technologies enable high density, long-range communication over several kilometres while maintaining low power consumption. They are optimised for small data packet transmission from battery-powered sensors and have a shelf life of up to 10 years. Typical applications include smart cities, industrial/environmental monitoring, agriculture and large-scale assess tracking, such as livestock. LPWAN devices are also operable on unlicensed spectrum, as well as via NB-IoT and LTE-M.

Short-range wireless applications including WIFI, Bluetooth, Zigbee, Thread and other protocols operate at the 2.4 GHz, 5 GHz and 6 GHz frequencies. Applications are predominantly in the home and include smart home devices, digital doorbells, home security systems, consumer electronics, lighting and sensors.

Satellite IoT is an emerging extension of the connectivity landscape, supporting both narrowband (NB) low data rate applications and direct-to-device communications using the standard cellular spectrum from space. It is particularly relevant for infrastructure limited environments such as agriculture, remote asset tracking, maritime, critical infrastructure and emergency connectivity. Together all these technologies reflect a highly fragmented connectivity landscape where no single solution can meet all requirements. As such, IoT system design increasingly involves selecting and/or supporting multiple technologies based on application-specific requirements and/or limitations.

Figure 2: Within cellular IoT, a wide range of standards are now employed

Multi-standard cellular operations

Within the cellular IoT framework, there are multiple standards in place, each with differing key features and associated costs.

These applications coexist alongside existing the 4G LTE and 5G NR network to deliver the right level of cost, complexity, bandwidth and connectivity. Table 2 demonstrates the anticipated evolution from 4G LTE to 5G in the IoT space, with 5G RedCap network operator deployment now increasing.

The sections below, as summarized in Table 2, provide further details on the specific features of the different types of cellular IoT platforms:

NB-IoT (LTE Cat NB2)

Narrowband IoT is an ultra-low-power, wide-area cellular technology optimized for simple, stationary IoT devices with minimal data needs. This makes it the ideal solution for smart meters, environmental sensors and infrastructure monitoring. Low module costs and long battery lifetimes enable massive deployment, although limited mobility support and dependence on regional operator deployment limit its suitability for globally scalable products.

LTE-M (Cat-M1)

LTE-M extends LTE into IoT applications that require mobility, moderate data rates and lower latency. With support for features such as VoLTE (voice over LTE), it enables use cases such as asset tracking, wearables and connected healthcare. It has improved indoor coverage over standard LTE and allows for voice calls – hence its deployment in some cellular connected smartwatches. However, like NB-IoT, its global availability is inconsistent, with operators often favouring one technology over the other.

LTE Cat 1 / Cat 1-bis

LTE Cat-1 and Cat1-bis offer a more pragmatic middle ground. Based on earlier LTE standards, they provide moderate data rates and global coverage leveraging on the existing 4G network infrastructure. Cat-1bis further reduces complexity through single-antenna operation. As 2G and 3G networks are phased out, they are increasingly used in applications such as payments, telematics and industrial IoT, where a balance of cost, performance and availability is required.

High Cost & Complexity High bandwith: 50 Mbps – 2 Gbps	4G LTE Cat 3 – Cat 20 ↓ 5G NR
Medium Cost & Complexity Low-medium bandwidth: 1 – 10 Mbps	4G LTE Cat 1 / Cat 1-bis ↓ 5G (e)RedCap
Low Cost & Complexity Low bandwidth: 10 – 500 Kbps	4G/5G LTE-M / NB-IoT

Table 1: The anticipated evolution from 4G LTE to 5G in the IoT space

Technology	Key Features
2G (GSM)	Ultra-low cost, legacy IoT
NB-IoT	Ultra-low power, long-range coverage
LTE-M (Cat-M1)	Low power, mobility
LTE Cat-1 / Cat-1bis	Moderate speed, low cost
4G LTE / 5G NR	High speed, high cost
5G RedCap / eRedCap	Mid-tier 5G
Asia Pacific	Band 28

Table 2: The anticipated evolution from 4G LTE to 5G in the IoT space

5G RedCap (Reduced Capability NR)

5G RedCap extends 5G into mid-tier IoT applications by reducing complexity compared to full 5G NR. Although it promises higher data rates and access to newer capabilities, it remains early in its lifecycle. It is designed to balance the cost and power requirements of various 5G uses such as wearables, security and surveillance equipment and industrial sensors. Specifically, it offers mid-tier IoT performance with the following benefits:

	Redcap	eRedcap
3GPP Release	3GPP Release 17	3GPP Release18
Speed	220 Mbps	10 Mbps
Channel Support	20 MHz	5 MHz

Table 3: A comparison between 5G RedCap and eRedCap

- Lower 5G device costs, by reducing complexity, such as a simpler antenna structure, narrower channel support and no carrier aggregation.
- Higher peak data rates compared to the LTE technologies outlined above.
- Lower latency than legacy 4G-based technologies.
- New spectrum – access to new 5G-specific spectrum bands.
- Benefits from 5G SA architecture such as power saving and coverage enhancement.

eRedCap is designed to further reduce the complexity and cost of 5G devices, thus encouraging further adoption and expansion. Compared to RedCap, eRedCap offers a compromise between cost and performance, such as reduced peak data rates, allowing for a greater expansion of the 5G device ecosystem within IoT.

Connectivity requirements for IoT applications

The cellular IoT technologies described above operate across licensed spectrum that varies by region, with many relying on low-band frequencies (<1 GHz) to deliver coverage and penetration. Supporting these requirements places specific demands on the RF front-end, particularly in terms of global band support, regulatory compliance and efficient operation within battery-constrained devices.

Key low-band cellular requirements for IoT include:

- Support for multiple 4G LTE and 5G NR low bands across different regions
- Operation with a single compact antenna in most cases
- High transmitter efficiency at moderate output power levels
- Robust receiver sensitivity under antenna mismatch conditions

In addition, compact IoT platforms face unique physical constraints:

- PCB area is limited by compact form factors
- Antenna performance varies significantly depending on product position/encasement
- Battery capacity places strong limits on power consumption

These requirements challenge traditional RF front-end solutions that rely on fixed duplexers and band-specific architectures.

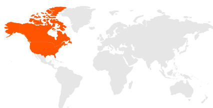
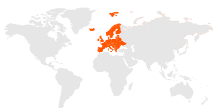
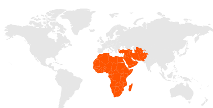
Region		Bands Supported
USA / Canada		Bands 12 / 13 / 17 / 26 / 29 / 71
Europe		Bands 8 / 20 / 28 / 31 / 73
China		Bands 5 / 8
Japan		Bands 8 / 18 / 19 / 26 / 28
Latin America		Bands 5 / 28
Middle East & Africa		Bands 8 / 20
Asia Pacific		Bands 5 / 8 / 28

Figure 3: Band support is highly fragmented across different global regions

Forefront RF reconfigurable front-end architecture

The Forefront RF FFM51010 is a low-band Tx-Rx L-PAMiD Front-End Module designed to address the specific challenges of global cellular connectivity and performance efficiency in a compact form factor. The module supports all major low-frequency cellular bands from 612 MHz to 960 MHz using a single hardware platform, eliminating the need for band-specific RF front-end variants. The block diagram of the module is shown in Figure 8.

Central to the FFM51010 is Forefront RF's patented Foretune™ technology which combines an Electrical Balance n-plexer with Adaptive Passive Cancellation to create a digitally controlled duplexer. Unlike traditional fixed SAW-based duplexers, which are optimized for narrow frequency ranges, the Foretune™ can be dynamically configured across all low band frequency ranges and bandwidths.

The Electrical Balance n-plexer provides intrinsic isolation between the transmit and receive paths by balancing impedance networks rather than relying on high-Q acoustic filtering. This is particularly advantageous in low-band operation, where duplex spacing can be relatively small and where SAW duplexers tend to be physically large and insertion-loss heavy.

Adaptive Passive Cancellation further enhances Tx-to-Rx isolation by compensating for residual leakage paths that vary with frequency, antenna impedance, and operating conditions. In IoT applications, antenna characteristics can change during use or upon deployment and this adaptive behaviour provides a significant robustness and efficiency advantage.

The FFM51010 integrates the following key RF functions into a single module:

- A tunable duplexer covering the full 612–960 MHz range
- A multi-mode power amplifier supporting both 4G LTE and 5G NR waveforms
- A low-noise amplifier optimized for low-band receiver sensitivity
- An integrated bi-directional RF coupler located at the antenna port
- A single MIPI RFFE v3.0 digital control interface

By combining these functions, the FFM51010 replaces multiple discrete RF components, including fixed duplexers, external couplers, and associated matching networks. This high level of integration reduces PCB and simplifies RF system design and verification.

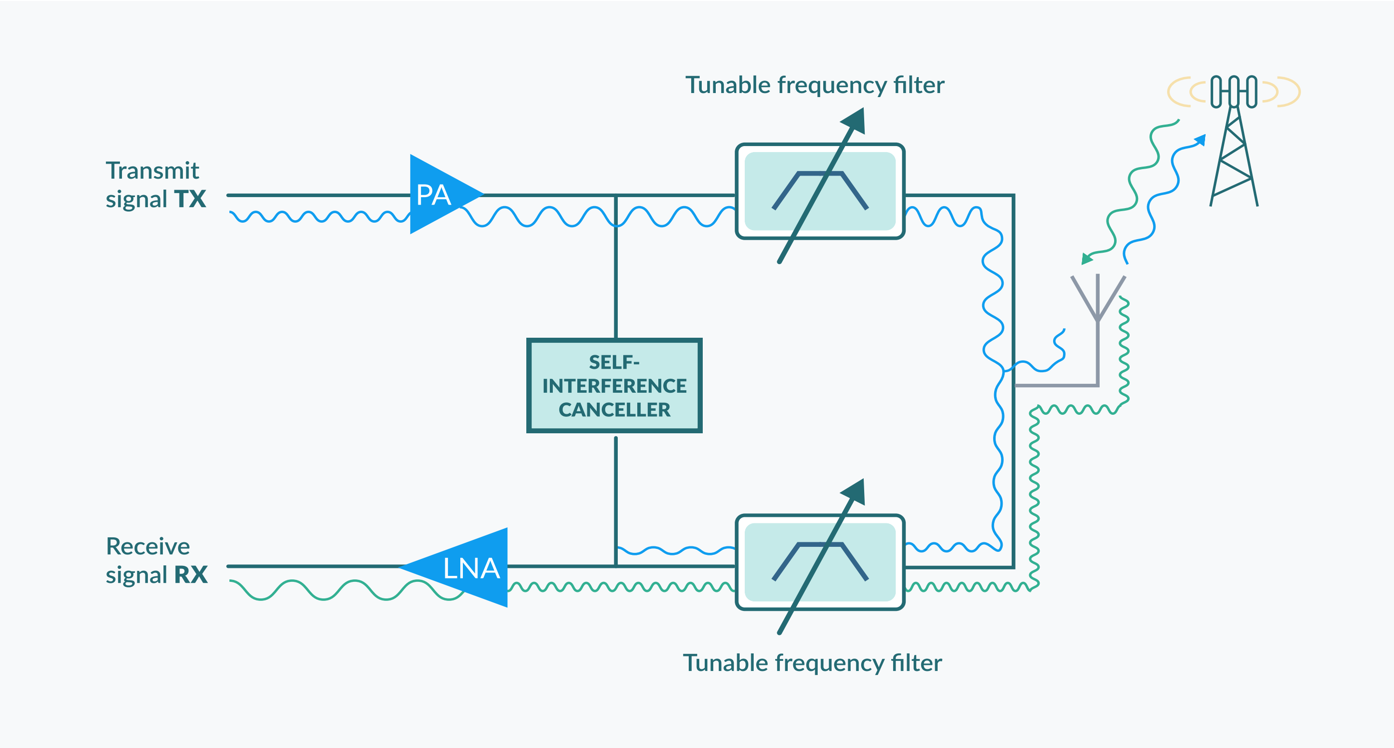


Figure 4: FFM51010 is a dynamic tunable duplexer, based on tunable filters together with self interference cancellation technology

Which cellular IoT applications are supported by FFM51010

Due to the fragmentation of the IoT landscape, product developers are increasingly faced with a structural challenge - how to design devices that can operate across multiple standards without requiring repeated hardware redesign. In addition, it is not just about keeping pace with a single technology roadmap, but about designing for variability from the outset. As cellular IoT continues to expand across multiple standards and regions, the ability to build adaptable, future-ready hardware is becoming a critical differentiator. Those that embrace flexible design approaches will be better equipped to navigate uncertainty, reduce redesign cycles and scale globally. In contrast, fixed implementations risk being constrained by an ecosystem that is no longer moving in a single direction.

The table below summarizes some of the key features of the cellular IoT technologies that have been described in detail in this application note. Forefront RF's FFM51010 module supports all these standards aside from LTE Cat-1 owing to the 2 receive antenna configuration.

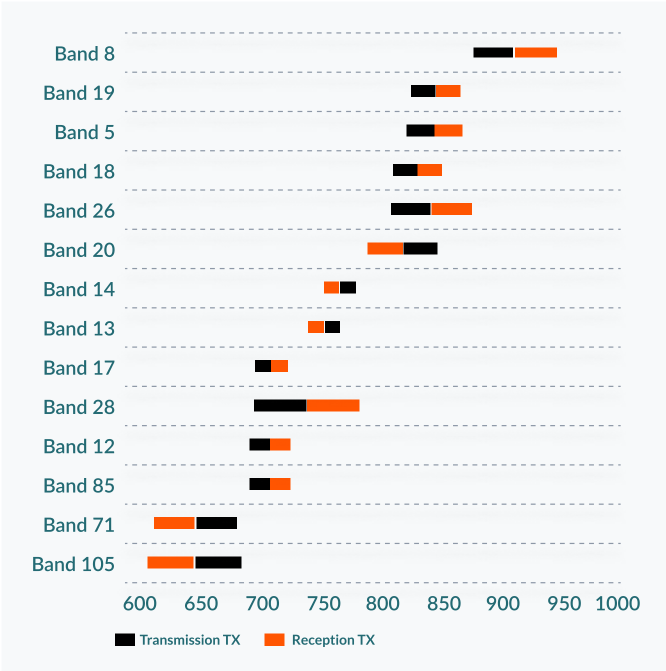


Figure 5: FFM51010 supports all the low-bands between 612 and 960 MHz

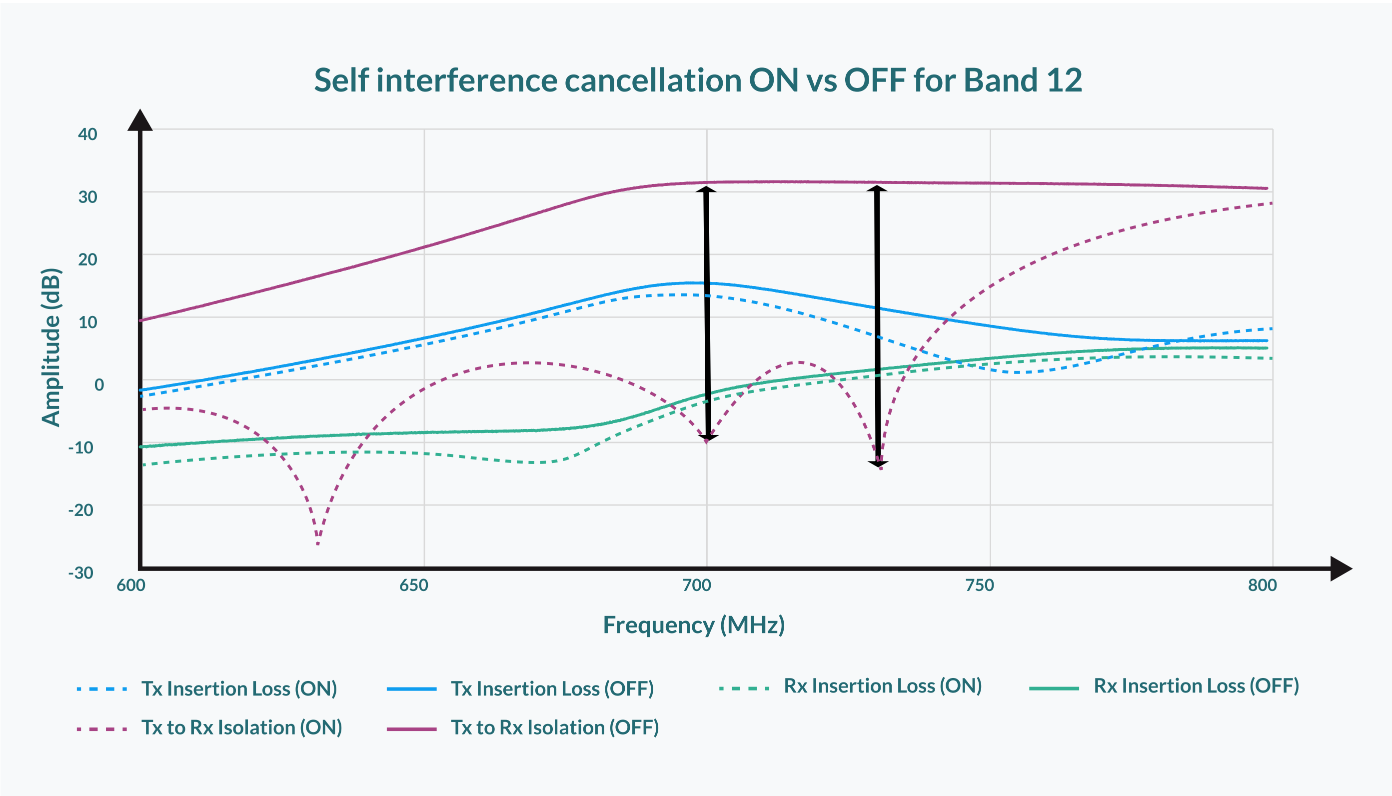


Figure 6: Demonstrating the impact on isolation of the self-interference cancellation technology

	LTE Cat-1	LTE Cat 1-bis	NB IoT	LTE-M1 (eMTC)	RedCap	eRedCap
3GPP Release	Rel-8	Rel-13	Rel-14	Rel-13	Red-17	Rel-18
Bandwidth	<20 MHz	<20 MHz	180 KHz	1.4 MHz	<20 MHz	<5 MHz
DL peak data rate	10 Mbps	10 Mbps	127 Kbps	300 Kbps	220 Mbps	10 Mbps
UL peak data rate	5 Mbps	5 Mbps	159 Kbps	375 Kbps	120 Mbps	10 Mbps
Max Tx/Rx chain	1T/2R	1T/1R	1T/1R	1T/1R	1T/2R	
1T/1R	1T/1R	+3.4	+4.6	V		
Voice calls	Supported	Supported	Not Support-ed	Supported	Supported	TBD
Coverage Scope	Global	Global	Country specific	Country specific	Country specific	TBD
FFM51010 compatibility	✗	✓	✓	✓	✓	✓

Furthermore, many IoT applications, such as asset trackers, in smart meters, smart city infrastructure or sensors, have varying deployment conditions. The IoT module mounting will have a significant impact on performance if the antenna impedance is not tuned correctly – this can add resource, cost and time to module deployment, especially in high volume and rural projects. FFM51010 is capable of in-situ adaptation to differing antenna (and therefore impedance) conditions, reducing deployment time – the benefits of an adaptive front-end technology.

This robustness reduces sensitivity to antenna detuning, thus helping to maintain both transmit efficiency and receive sensitivity in real-world usage conditions. Figure 6 highlights an example where SAW filter performance drops off at 3:1 VSWR, whereas the tunable solutions to able to adapt, without performance loss as a result.

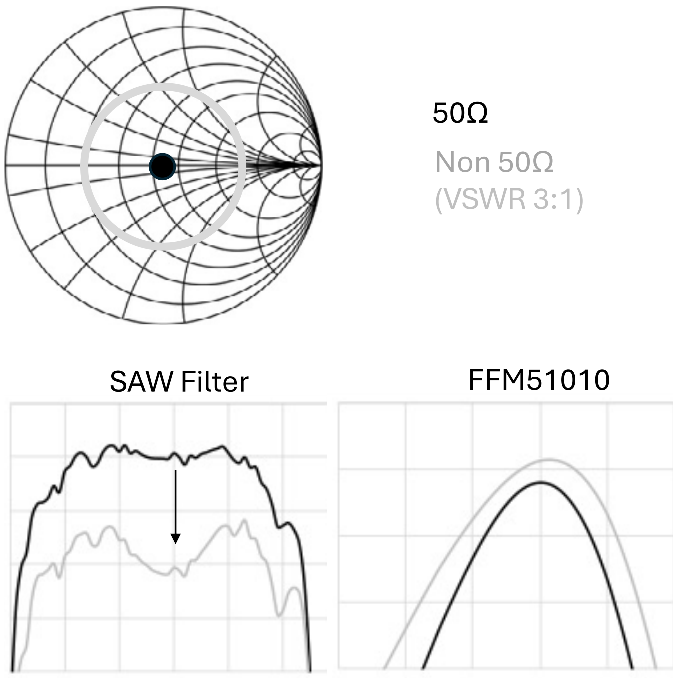


Figure 7: FFM51010 is designed for adaptability, supporting product tuning for optimal performance benefits.

Why select Forefront RF's reconfigurable RF front-end module?

For FDD supporting modules, to achieve global connectivity means introducing a large number of SAW or BAW filters alongside the necessary switches. This complicates design, adds to the BOM and cost, increases footprint and adds losses. Multiply this design effort by the number of IoT standards that need to be covered. Forefront RF's FFM51010 module provides global connectivity at all low-band frequencies between 612 to 960 MHz, ensuring connectivity in both rural and dense cityscapes alike, across LTE Cat1-bis, NB-IoT, LTE-M and 5G (e)RedCap.

Forefront RF's tunable filter technology allows for software control over bandwidth, meaning the same product can be integrated for both 20 MHz and smaller bandwidth applications. FFM51010 provides low band coverage in any region of the world, limited only by the global coverage of some of the IoT standards.

Traditional RF front-end architectures assume relatively stable antenna impedance conditions and rely on fixed matching and filtering networks. In IoT devices, especially those that are mobile and mounted to a solid object, this assumption often breaks down, leading to degraded efficiency and reduced sensitivity.

The reconfigurable nature of the Foretune™ duplexer allows the RF front-end to adapt across a wide frequency range, helping to mitigate the impact of antenna detuning. The integrated bi-directional RF coupler at the antenna port enables monitoring of forward and reflected power. This capability can be leveraged by system software to implement antenna diagnostics, detect abnormal operating conditions, or support adaptive tuning strategies at the platform level.

This features provides a more resilient RF system that is better suited to the variable operating environment of some IoT applications. In addition, the FFM51010 is housed in a compact LGA module measuring approximately 6.0 × 4.5 × 0.75 mm, making it well suited for space-constrained products.

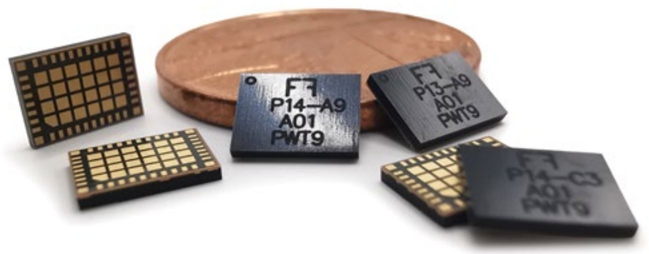


Figure 9: FFM51010 modules are 4 x 6.5 mm in dimension

Functional Block Diagram

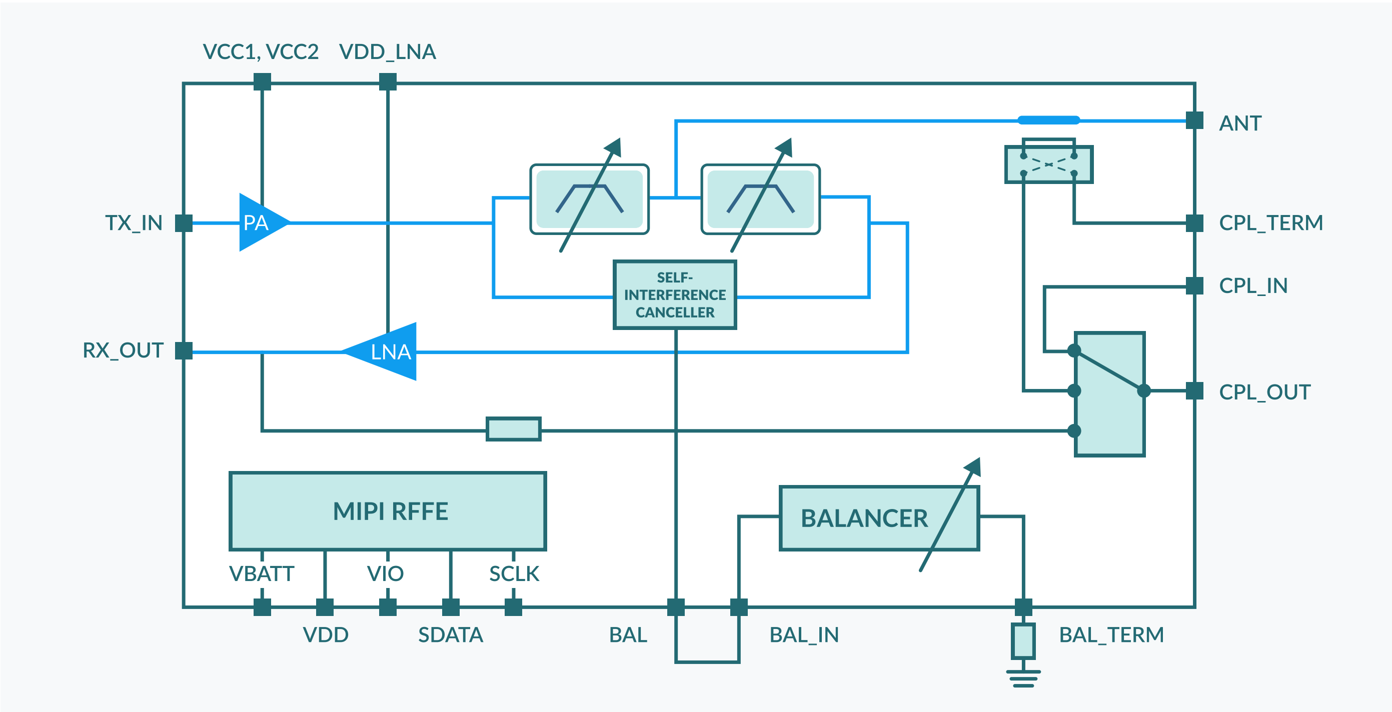


Figure 8: Block diagram of FFM51010

Conclusion

Cellular IoT remains the dominant solution for wide-area connectivity across a broad range of applications. LPWAN technologies address ultra-low-power, niche use cases, while short-range standards such as Wi-Fi and Bluetooth are widely used in consumer and domestic environments. Satellite connectivity is also maturing, with increasing adoption in remote and infrastructure-limited applications.

However, the IoT market is hugely fragmented and this Application note has shown the wide array of cellular technologies are now in use – all but LTE Cat-1 are compatible with Forefront RF's FFM51010 module which provides tunable FDD coverage for all low-band frequencies.

FFM51010 reduces RF front-end complexity, enables global coverage from a single module and supports single SKU consolidation across multiple IoT platforms. This is particularly valuable in applications where PCB footprint, BOM cost and design complexity are tightly constrained. Forefront RF's software-defined RF approach aligns well with the evolving requirements of the fragmented IoT market, offering scalability, efficiency, and flexibility as connectivity standards continue to evolve in line with future network developments.

Figure 10: IoT is driving rapid growth in wireless connectivity across industrial, enterprise, and consumer applications such as asset and people/animal tracking, smart metering and remote cameras.

Contact Information

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