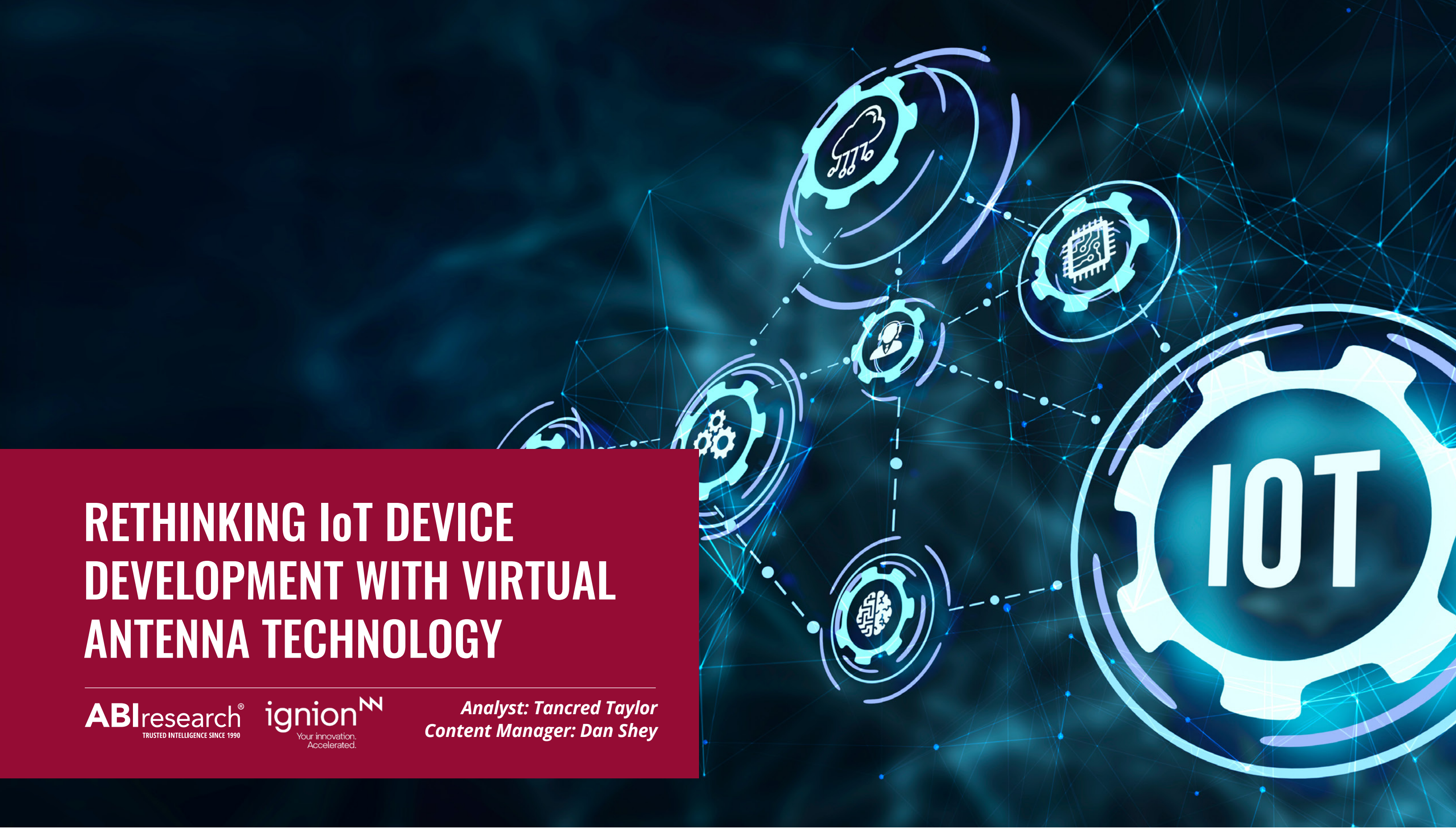

RETHINKING IoT DEVICE DEVELOPMENT WITH VIRTUAL ANTENNA TECHNOLOGY

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INTRODUCTION

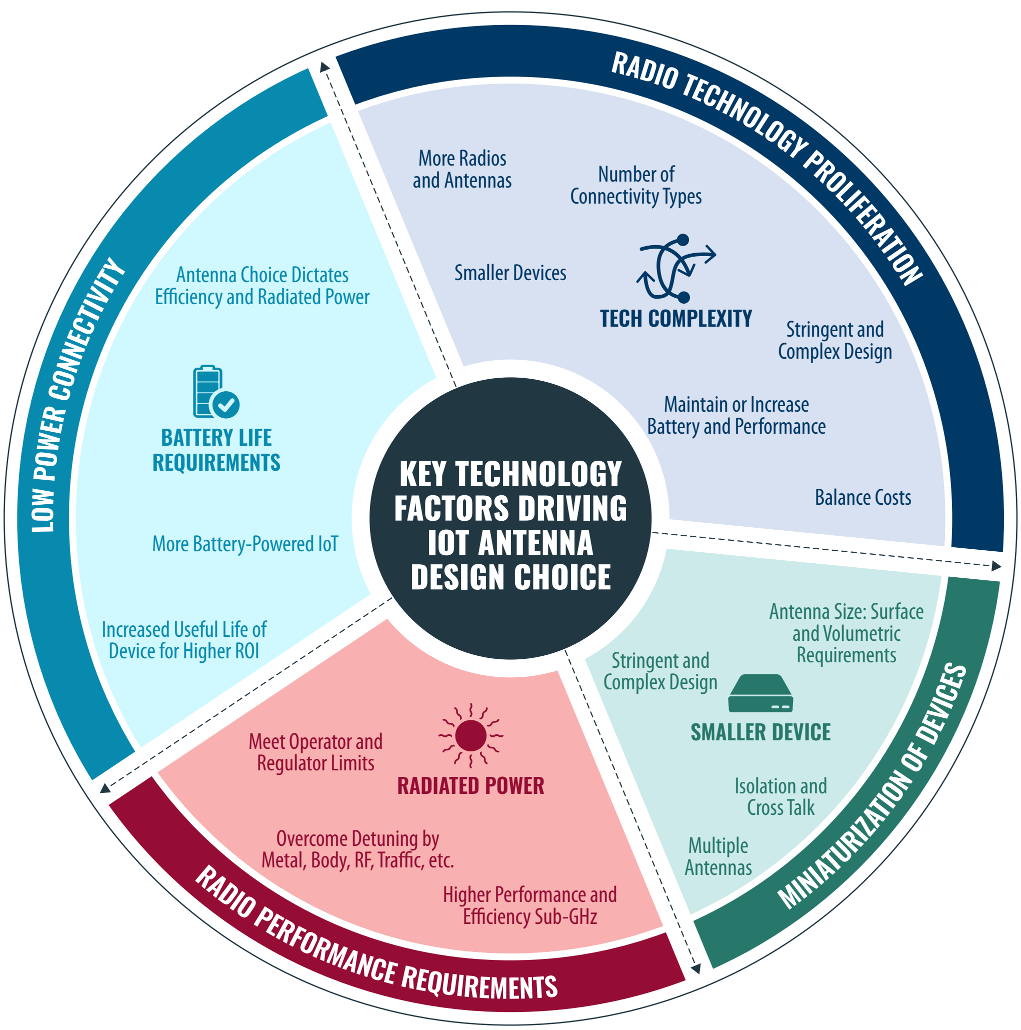
The Internet of Things (IoT) consists of billions of connected devices. By 2025, it is estimated that global IoT connections will reach more than 42 billion devices, a 5-year Compound Annual Growth Rate (CAGR) of 24%. Enabling this massive growth in connectivity is an unassuming, yet critical device component that enables data to be sent up to the cloud: the antenna. Central to an IoT system, the antenna is also one of the most difficult components to get right to address not only IoT edge device performance, but also cost and physical design requirements. Failure to successfully integrate and optimize the performance of the antenna component results in IoT devices not meeting certification requirements, time-consuming and expensive re-designs, or, in the worst cases, project failure because of faulty hardware.

Numerous types of antennas are currently available on the market, spanning designs embedded within devices and antennas mounted externally. Choosing an antenna best suited for a particular project involves a raft of considerations, including device design, antenna size, cost, performance, efficiency, and radiation pattern, among others. Unlike the smartphone industry, where the vast majority of antennas have converged around fractal-based and metal frame internal antennas, the IoT market has a much more diverse range of considerations based on the intended physical setting and the application of the device, making antenna selection critical. To help simplify the process and lower the development cost for hardware engineers, antenna vendors are growing their Off-the-Shelf (OTS) antenna portfolios, using more simulation software, and expanding partnerships with Original Equipment Manufacturers (OEMs) and module makers. While these developments are all positive, antenna selection and integration remain among the major stumbling blocks of any IoT project.

This whitepaper introduces a new approach to antenna technology, called the Virtual Antenna™ technology, which aims to remove complexity for the hardware designer and help OEMs streamline their approach to building IoT solutions. It starts with a discussion of the technology and business factors affecting IoT antenna choice. It then outlines the key antenna design requirements and the challenges faced by OEMs to meet these requirements, including an analysis of existing antenna types. The paper concludes with an examination of the Virtual Antenna™ technology's benefits and limitations relative to current antenna technologies, including an assessment of the IoT antenna market opportunity.

IOT MARKET EVOLUTION—TECHNOLOGY FACTORS DRIVING ANTENNA CHOICE

As in any device market, every new generation of IoT devices needs to have improved performance for lower cost. However, over the next 5 years, achieving this objective also must address increased technology complexity, as well as more stringent design and performance requirements. The following are the key factors affecting antenna choice and design in future IoT devices.



- **Radio Technology Proliferation**: IoT increasingly requires more than one connectivity protocol to be supported in a single device, also known as Multiple Radio Access Technology (multi-RAT). As an example, asset trackers are increasingly adding Wi-Fi and Bluetooth radios, in addition to an existing Wide Area Network (WAN) radio and Global Navigation Satellite System (GNSS). The addition of Wi-Fi and BLE can ease provisioning through a smartphone or from a central control unit, enable connectivity to other low-cost tags, or enable indoor tracking capabilities.

  In most cases, a separate radio module is required for each protocol, and radio modules typically require at least one antenna to ensure optimal connectivity performance. The number of connectivity types required in a single device adds considerable additional design complexity, device space, cost, and performance constraints.

  Multiple Input, Multiple Output (MIMO) system requirements are also adding to antenna complexity. Applying primarily to cellular and high-throughput Wi-Fi applications, additional "diversity" antennas are required to improve the link budget on the system, allowing network operators to maintain a suitable Quality of Service (QoS) for all devices on the network. On the cellular front, a 2x2 antenna system is sometimes required for the Long Term Evolution (LTE) Cat-1 standard, with the number of required antennas increasing with higher data-throughput LTE categories. With 5G and Wi-Fi 6 standards, this challenge increases to 4x4, 8x8, and higher antenna counts to meet MIMO systems benefits.

- **Low-Power Connectivity**: Many connected devices are battery-powered. Therefore, low-power consumption is important to prolong the useful life of the device and achieve an acceptable Return on Investment (ROI). Low-power connectivity using BLE or Low-Power Wide-Area Network (LPWAN) technologies, efficient components (*e.g*., microcontrollers or sensors), and effective device management are crucial to extending battery life. Antenna choice and position have also proven to be critical in finding the optimal balance between radiated power and battery life requirements and, in many cases, this is the primary factor affecting device power consumption..

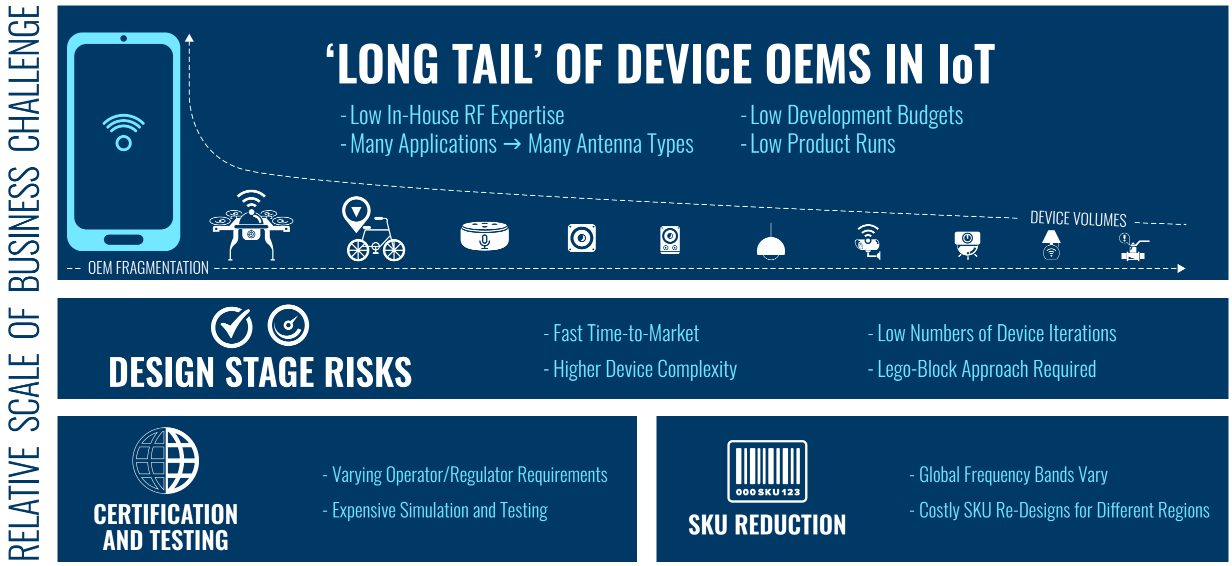
- **Radio Performance Requirements**: Devices are required to operate in a number of challenging Radio Frequency (RF) environments. Antennas can be detuned by any number of interference types, such as proximity to the human body, installation close to or within metal or another surface, obstruction by vehicular traffic, or radio congestion in a smart home setting. An IoT device must be designed and optimized with these environmental conditions in mind. Intelligent system-level design and extensive testing are the primary ways of overcoming these challenges.

  In addition, more and more devices are using non-cellular LPWAN (*e.g*., LoRa 868/915 MHz) and cellular (*e.g*., 700 to 960 MHz in the low bands) protocols because of the higher range and penetration possible at these frequencies. But lower frequencies require larger antennas, which then limits device miniaturization or performance in the low bands.

- **Miniaturization of Devices**: One of the most significant trends in the IoT is device miniaturization. Two device components that can consume most of the device's volume are the battery and the antenna(s). When multiple antennas are required, more focus on antenna design and integration is necessary to ensure isolation between the antennas and other conductive components.

IOT MARKET EVOLUTION—BUSINESS FACTORS AFFECTING ANTENNA CHOICE

Business pressures to decrease costs, accelerate time-to-market, and improve IoT solution ROI also affect IoT antenna choice. Some of the principal business considerations are highlighted below.



- **The "Long Tail" of Device IoT OEMs**: The smartphone industry has a small number of very high-volume manufacturers selling millions of devices. These companies frequently have extensive in-house manufacturing and RF expertise to oversee the end-to-end design and production of a device. The IoT market is different: the supplier landscape is a very large number of smaller firms, resulting in a wide variety of connected products, often sold in relatively low volumes.

  From a practical perspective, this means that the large number of smaller companies selling IoT products frequently do not have in-house design expertise or high product development budgets, leading them to require easy-to-use and low-cost components. On the antenna front, this will often mean that manufacturers use OTS products, rather than invest in a custom antenna design.

- **Design Stage Risks**: The high number of device makers in IoT also means that it is a competitive and fast-moving space. OEMs are under pressure to get a product to market rapidly and at the lowest possible cost. In the IoT domain, many device OEMs leave the antenna integration until last. But the risks of this approach for product profitability are increasing as technology complexity and use case requirements grow. Bringing the antenna integration process forward and considering it as part of the system design significantly reduces risks, such as performance issues, delays, and costs.

  One way in which OEMs are reducing design stage risks are by making more use of software to select, design, integrate, tune, and simulate antennas in devices. This is an important change for several reasons. Firstly, it reduces the need for RF know-how among device designers, opening the design and simulation process to a much broader audience. Secondly, it facilitates use of OTS antennas and, in particular, on-PCB antennas by accurately simulating surface and volumetric clearance requirements and interference from components. This, in turn, drives a "Lego block" approach to device design, as well as a system-level approach important for achieving the best performance. Finally, it shortens the design stage by simulating the expected performance early on, reducing the number of physical tests required.

- **Certification and Testing**: Devices using licensed RF spectrum require certification by the owners of that spectrum, the mobile operators. Even in the unlicensed spectrum, the need for harmonized device certification has led to programs implemented by standards bodies and executed by approved test houses. For IoT device OEMs, many of which are very small companies, device certification can be time consuming and expensive. Choosing the right antenna from the get-go and the ability to easily tune the antenna as the design evolves can greatly reduce network certification process time and fees.

- **Stock-Keeping Unit (SKU) Reduction**: For IoT devices connecting to WAN technologies, differences in spectrum allocation by region can require OEMs to produce multiple SKUs of the same device. This need will continue as 2G and 3G networks are turned off and devices transition to LTE, a technology with more than 40 spectrum bands. 5G technologies are only increasing the number of spectrum bands that OEMs need to consider for antenna design.

  Smartphone manufacturers can alleviate some of the need for multiple SKUs by using active antenna tuning. However, even these manufacturers require different product SKUs for different regions. IoT devices are less complex, so they rarely include active antenna tuning – although this is increasingly seeing uptake. As a result, for WAN connected IoT devices, OEMs need to make a choice between investing in antenna design for SKU reduction, but less global coverage, or offering more SKUs, but with different antenna designs in each.

IOT ANTENNA CONSIDERATIONS AND CHALLENGES

Considering the aforementioned technology and business challenges, antenna choice and design is a critical element in IoT device deployment success. Some of the principal considerations and challenges facing OEMs in antenna design and choice are set out below.

CONSIDERATIONS

Antenna selection in a device comes down to a balance of three principal considerations: size, performance, and cost. These three aspects are further elaborated below.

Size and Implementation: The size and form factor of the end device is frequently an inflexible condition. OEMs will typically start with the size of the PCB and the ground plane it carries, with on-PCB antenna implementations some of the most convenient. Antennas used in this category include PCB trace, Surface-Mount Technology (SMT) chip, or metal stamp antennas. In cases where the PCB is too small or tightly packed, an antenna needs to be taken off the PCB to avoid interference with other on-board components to meet the performance requirements. Antennas in this category include Flexible Printed Circuit (FPC), cabled PCB, shaped metal, or Laser Direct Structuring (LDS) antennas. When the highest performance is needed, when devices are constrained within metal, or when the application and form factor allow, OEMs may also opt for a more expensive external antenna.

Generally speaking, antenna performance decreases with size below a quarter of wavelength ($\lambda/4$). Dipole antennas are the highest performing, while monopole antennas perform less highly, but have the benefit of smaller size. While a small antenna may initially seem like the most attractive option, it may frequently not address the application's needs.

OEMs also need to consider how the antenna is integrated in the device for performance and ease-of-manufacture reasons. On-PCB antennas using pick-and-place machinery allow high-performance replicability, quality consistency, and speed of manufacturing.

Performance: Antenna gain, efficiency, operating frequencies, impedance match, and radiation pattern are also crucial when selecting or designing an antenna system. These factors might condition whether a device will pass the certification processes, as well as determine the effectiveness of connectivity, optimal battery power consumption, and IoT solution performance. An important consideration for antenna performance is their exact placement on the PCB (surface clearance) or within the device (volumetric clearance) to ensure that antennas do not interfere with each other or with surrounding conducting components.

Another important aspect of antenna performance is replicability: in other words, whether an antenna can be manufactured identically in large batches and in different production batches with the same performance.

Cost: The cost of the antenna is a significant consideration for OEMs. The price of different types of antennas may vary from cents (*e.g.*, PCB trace or wire antennas) to tens of dollars (*e.g.*, high-end external antennas). This factor is important as device deployments reach high volumes, where small savings per antenna can translate to higher profitability. The cost of an antenna grows further in importance for low-cost IoT: after the PCB board, the main processor, the radio modules, and the battery, the antenna can be the most expensive component in the Bill of Materials (BOM).

An important antenna design consideration for OEMs is choosing between custom-designed and OTS antennas. While a custom antenna may sometimes perform better in the specific application when no PCB space is available, these antennas involve Non-Recurring Engineering (NRE) costs and additional investments in specific production molds that will not be reused in later product runs. OTS on-PCB antennas can deliver the same performance as a custom antenna, particularly when antenna integration is considered from the beginning of the project. The final decision comes down not only to the volume produced, but also to the required performance and cost of the end device, number of frequencies required, number of SKUs the antenna can work across, and number of re-design cycles necessary for each product.

CHALLENGES

Low In-House RF and Antenna Expertise: The long tail of the IoT means that in-house engineering teams often do not have the specific RF or antenna expertise to successfully integrate an antenna within a device. While antenna datasheets are available, antenna performance measurements are typically taken in free space and on specific evaluation board sizes, which does not accurately account for device and use case-specific factors. As a result, datasheets act more as design guidelines than design rules. Module vendors, antenna vendors, and device design houses play an increasingly important technical support role in new product designs to ease this challenge through reference designs and the use of tuning mechanisms required when the design matures.

Decreasing PCB Real Estate: While a PCB-mounted antenna, such as a trace or SMT chip, may be a commonly-used path, the surface area of the PCB becomes a more important consideration as OEMs integrate more features, radios, and components within this small space. PCB design and antenna layout often require the input of antenna vendors and design houses to manage the design challenge.

Sub-Gigahertz (GHz) Design: Many IoT devices operate at frequencies under 1 GHz because of the higher range and penetration of radiation in lower spectrum bands. However, they also require larger antennas compared to devices connecting on higher spectrum bands due to the inherent physics of antenna design, where radio wavelength is inversely proportional to frequency, such that a lower frequency requires a larger antenna size. In addition, if external antennas are not an option, embedding larger antennas is more complicated, making the integration and isolation of these antennas within a device more challenging as well.

Managing Trade-Offs: OEMs need to balance antenna performance with power consumption, particularly when it comes to battery-powered devices. A more efficient antenna will require less power to transmit the same data payload. Moreover, if an antenna is not sufficiently efficient, the connectivity to the IoT network becomes a service-level issue for service providers. But antenna efficiency is affected by its integration within a device, which affects device design and costs. Trade-offs are an inherent requirement in antenna choice.

Iterative Process: Testing is necessary to ensure proper antenna performance. In many cases, this involves building a prototype board and testing the antenna in different setups with any modification to the device very likely to affect the antenna performance. This process is further complicated when antenna integration is left until the end of the design phase as options to change will have become more limited.

COMMON ANTENNA TYPES

In response to the inherent challenges in choosing and designing antennas, a very large range of antenna types for IoT edge devices are available and in use today, quite the contrary to the more mature mobile phone industry.

The current antennas and their characteristics are briefly summarized in the table below. As mentioned above, antenna design and selection involve a compromise between physical size, performance, and cost. Antenna choice is highly dependent on the specifics of the IoT use case and device design.

ANTENNA TYPE	BENEFITS	LIMITATIONS
External	- Enhanced performance in some applications - Essential when device is encased in metal or when space inside the device is not sufficient - Lots of OTS models available	- Highest per-unit cost, though it can be as low as $2.00 - Biggest size and not suitable when a streamlined form factor is required - Subject to accidental breakage and vandalism - May still require specialist installation - Not flexible in addressing multiple bands and global SKUs
Trace	- Least expensive of all antenna types in high-volume markets - Acceptable performance across frequencies in single-band applications - Operating frequency related to size; high frequencies take up little board space - Already mounted on PCB	- Requires high levels of customization, tuning, and board design - Operating frequency related to size; low frequencies take up a lot of board space - Mostly suitable for simple devices with low number of radios and/or frequency bands - Possible inconsistency in production process leading to quality issues
Wire/Helix	- Very cheap; just a piece of wire, sometimes coiled - Acceptable performance in small form factor and for low bands	- Requires high customization based on end device - Low repeatability of mechanical manufacturing process - Manual assembly, with associated time and cost constraints - Mostly suitable for simple devices with single radio and/or frequency bands
Surface Mount Technology (SMT)	- Can cover multiple frequencies in a compact and embedded form factor - Good performance with large ground plane - Easy integration into the electronics design, and with pick-and-place machinery - Mostly OTS models accelerate implementation - Global and pervasive supply when using PCB manufacturing techniques - Can be miniature for high frequency, frequently less than 2.0 x 1.0 x 0.5 mm - Ceramic models are resistant to detuning	- At low frequencies, requires a significant ground plane to resonate - Require a clearance area, extending the space requirements - Requires optimization with matching network - Price can vary substantially based on size and required frequencies covered - Location of the PCB within the device is important
FPC	- Can be tethered via a cable to PCB when little PCB space is available - Flexible film can be placed on irregularly-shaped surfaces - OTS and customizable models available	- Cable becomes part of antenna; careful wiring required to avoid interference with other components - Manual installation may lead to performance irregularities and quality issues - Quite costly at volume, especially with cables/connectors
Shaped Metal	- Small size - Cheap in very high volumes - May require less clearance on the PCB - Multiband performance with proper custom design - Good performance	- Significant physical size when mounted planar to the PCB - Typically, a custom design; requires investment in manufacturing molds and tooling for each design - Not easy to assemble; often requires manual assembly - Usually for single-frequency applications - Less suitable for mobile devices, which undergo shocks and vibration and can loosen the antenna
3D Printed (MID, LDS)	- Best performance and option when no real estate is available on the PCB - Based on existing proven fractal technology - Optimized for performance in a particular setting - Can be directly printed onto the casing - Can support many frequencies in compact area	- Very high NRE costs; only suitable for very high volumes - Custom design requires investment in manufacturing molds and tooling for each design - Not easy to manufacture; often requires manual assembly
Patch	- Best antenna for GNSS due to narrow bandwidth and circular polarization - Does not require clearance area on PCB	- Too large and heavy for the smallest of devices - Highly directional; most suited to devices where antenna is always facing the sky - Costly at volume

VIRTUAL ANTENNA™

OVERVIEW

The Virtual Antenna™ is a new type of antenna technology offered by Ignion. The solution is made up of three principal components:

Booster: This is a small, wideband chip that comes in a relatively limited variety of form factors. The chip is mounted directly to the board using pick-and-place machinery and usually requires a clearance area around it. Unlike standard SMT chips, the booster's role is not to resonate at a specific frequency, but to maximize how much signal is passed on from the radio to the ground plane, and *vice versa*. Boosters support a frequency range from 698 MHz to 10.5 GHz.

Matching Network: The matching network is a series of very low-cost standard capacitors and inductors placed between the radio and the antenna. In a traditional resonant antenna, a matching network is used to retune the impedance of the radio with the antenna when shifted from its natural resonance due to suboptimal design or environmental factors. In the Virtual Antenna™, however, the purpose of the matching network is to select the required frequencies of operation and maximize the transfer of RF energy from the radio to the ground plane. For any Virtual Antenna™, the matching network is the only component that needs to be modified to operate at desired frequencies.

Ground Plane: The Virtual Antenna™ is "antenna-less" in that the booster does not resonate like a traditional antenna. Instead, the required resonance that transmits radio waves for communications is achieved through use of the ground plane. All existing monopole ($\lambda/4$) antennas use the ground plane to reduce the required length of an antenna to provide the best performance ($\lambda/4+ \lambda/4= \lambda/2$). In contrast, the Virtual Antenna™ resonates purely through the ground plane and is often the smallest antenna option available on the market.

The Virtual Antenna™ does not require a larger ground plane than existing monopole antennas to achieve alike or better performance; in fact, the ground plane may be smaller than that required in a resonant antenna, with the matching network determining the frequency ranges and the booster optimizing the use of the ground plane. However, as with all antennas, a larger ground plane always means higher performance and efficiency.

In its implementation, a Virtual Antenna™ is an SMT-type antenna:

- Both SMT antennas and Virtual Antenna™ require a chip, usually a clearance area around the chip, a matching network, and a ground plane to function.
- Both SMT antennas and Virtual Antenna™ are SMT-mounted using standard pick-and-place machinery.
- As with SMT antennas, larger boosters perform better and have better bandwidth coverage.

In its operation, however, a Virtual Antenna™ differs from a traditional SMT antenna in four main ways:

- **The booster does not resonate**. Instead, this component covers a very wide bandwidth and transfers the signal efficiently to the ground plane. While SMT requires tuning to ensure it resonates at the stated frequency, booster users select the desired frequencies of operation. In addition, SMT components need to feature a certain size to resonate, while boosters do not.
- **Frequency selection is done through the matching network**. This is the only part of the entire antenna setup that needs customization or modification. The matching network has a similar implementation as the SMT, but a different role from that used in resonant antennas. One booster can support multiband requirements, simultaneously if needed.
- Because a Virtual Antenna™ can be tuned to anything in its stated frequency range, **it can accommodate many protocols** from cellular, non-cellular LPWAN, Bluetooth and Wi-Fi, GNSS, and others.
- **SKU reduction**. Because boosters cover a wide frequency range and any number of protocols, booster users avoid the need to shop around for different antenna types. Furthermore, the same booster can be used across different product SKUs, with modifications purely on the matching network side.

BENEFITS

Single SKU: The booster can remain the same for different protocols within a single device, as well as between several device generations. With a single booster, it is possible to connect to cellular, Industrial, Scientific, and Medical (ISM), Wireless Local Area Network (WLAN), Bluetooth, and GNSS frequency bands. The booster itself is a miniature pick-and-place mounted component, making integration and device design simpler. One of the principal benefits of the Virtual Antenna™ is to help streamline product stocks and integration complexity.

Electronic-As-Usual Engineering, No Customization: The only component of the Virtual Antenna™ that requires customization is the matching network. All required bands can be selected and optimized through standard matching network design software and passive components, as used for standard matching network design. However, proper board size and placement are foundational requirements for high performance, so it is recommended to include the booster in the full system design from the start of the project.

Software Driven: Antenna design usually requires significant RF Front End (RFFE) design expertise. One of the benefits of the Virtual Antenna™ system is access to standard software and existing design libraries to aid in board design and antenna placement. This is a key benefit of the technology, enabling completion of an initial design of the PCB dimensions, antenna layout, and matching network within hours. RF engineering becomes accessible to general hardware designers, and the design process is straightforward and predictable.

Multi-Band Efficacy in Small, Consistent Size: Because the frequencies that can be covered are not tied to the size of the booster component, the Virtual Antenna™ is able to maintain a consistent size regardless of the application or connectivity type. In practical terms, this means that the same component can be used for low-band cellular, sub-GHz ISM, as well as higher-band protocols without having to change the component and without requiring the antenna to become larger to function in the lower frequencies. In addition, the boosters offer the highest number of bands covered of all antennas of a similar size, without sacrificing on performance. While a whole range of traditional chip or FPC antennas cover a wide number of bands, these are considerably larger than the Virtual Antenna™ boosters.

Connect to Multiple Radios: Multiple antennas can be replaced by a single Virtual Antenna™ component embedding multiple boosters into a single chip, such as the DUO mXTEND or TRIO mXTEND components. These are single components with multiple boosters and multiple Inputs/Outputs (I/Os), offering a separate connector and feed line to separate radio modules (or to a single multi-radio module). These products help limit the number of antennas and the associated PCB design constraints associated with needing to integrate and isolate multiple antennas.

Low Total Cost of Development: Because there are fewer antenna SKUs for a range of devices, and because of their ease-of-implementation, Virtual Antenna™ boosters do not materially impact the cost of development. Rather than selecting or designing a different antenna for each protocol in a device, the same antenna type can be used with different radios—both within a single device and across an OEM's product range. With regard to direct cost, boosters are available from US$0.20 based on volumes and the selected product. The other direct cost, applicable across antenna types, comes from the matching network inductors and capacitors. The Total Cost of Ownership (TCO) of the solution is low due to omitting antenna NRE costs, speeding up and facilitating on-PCB design and implementation, as well as reducing testing/certification time and related costs.

Wide Frequency Range: The Virtual Antenna™ is very wideband. Most Virtual Antenna™ products cover the gamut of frequencies from 698 MHz to 8000 MHz, and can be made to operate at any frequency within this range. Two products extend frequency coverage to 10,600 MHz at the highest limit with a sacrifice at the lower frequencies. Based on the matching network design, the Virtual Antenna™ can support any number of bands with a single booster, while maintaining a stable performance across each frequency band. The larger the booster, the higher the total number of bands that can be covered with optimal performance. In addition, the boosters are compatible with active switching and tuning systems, providing great flexibility for devices as this technology makes its way from smartphones to the IoT.

While there are many existing antenna types that offer wideband coverage, the Virtual Antenna™ brings additional advantages, namely ease of use, small component size, on-PCB mounting, and a streamlined product range.

LIMITATIONS

Performance *versus* Band Coverage: While Virtual Antenna™ have a wide bandwidth and perform well in frequencies above 1 GHz, performance in the low frequencies (698 to 960 MHz) in currently available boosters is somewhat less than in comparable and competing SMT antennas. For instance, when operating in the 698 to 960 MHz bands, the biggest and highest-performing booster has an average efficiency at 55% and a Voltage Standing Wave Ratio (VSWR) of <3:1, compared to high-performing SMT antennas with 65% efficiency and a VSWR of <2.5:1. However, it is worth noting that the marginally lower performance of the antenna booster comes with a significantly reduced antenna component size relative to the SMT antenna, as well as the ability to cover multiple protocols within the same antenna component (*e.g.*, LTE, GNSS, and Wi-Fi).

Performance Linked to Design Constraints: As with all traditional embedded antennas, performance of the Virtual Antenna™ is tied to the size of the ground plane and the size of the booster – although it should be noted that even the largest boosters are small in comparison to any other multiband embedded antennas. The matching network can address the challenge of ground-plane size for boosters to an extent by optimizing the tuning, but performance remains tied to the PCB size of the device, to the location of the booster in the PCB, and to the location of the PCB within the device.

SUMMARY OF BENEFITS/LIMITATIONS.

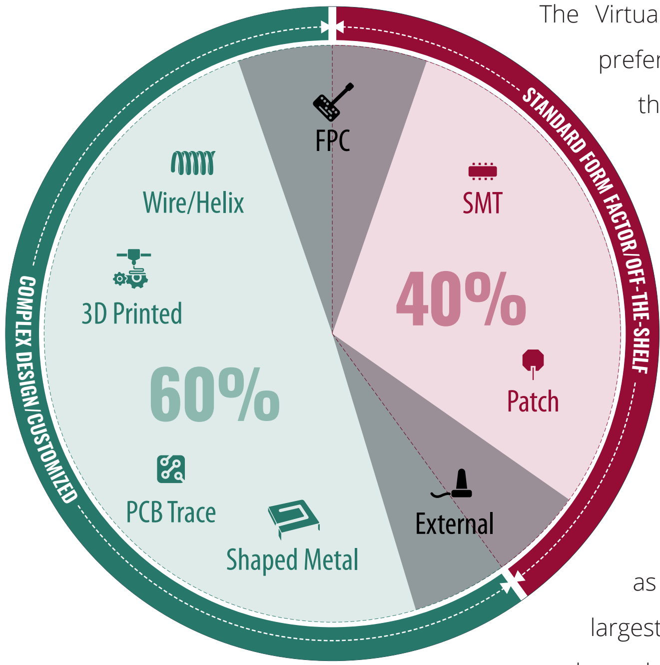
	BENEFITS	LIMITATIONS
Business Leaders	- Single SKU across all devices and protocols: component streamlining - Very low TCO: no NRE costs and low component cost - Easy, fast, and predictable to implement - Future proof: flexibility in design to new frequency bands and wireless protocols	- Single sourcing to date
Hardware Engineers	- Easy to design in; software-driven - Easy modification and tuning to any frequency - On-PCB design - Small size for highest number of bands supported - Systematic and predictable design process - Full performance of standard SMT chip antennas	- Lower performance sub-GHz, and different products required below 600 MHz - Requires a ground plane to function - Some degree of general RF know-how is desirable

MARKET OPPORTUNITY

Regardless of the antenna technology, the IoT market represents a significant opportunity for antenna OEMs. As shown in table below, annual IoT antenna shipments are expected to grow from 2.6 billion in 2020 to more than 6.2 billion in 2025. While the vast number of "things" that can be sensorized, digitized, and connected is large, the top markets fueling antenna shipment growth will be wearables, smart home, and tracking/logistics. These three markets will make up nearly 73% of antenna shipments from 2020 to 2025.

IOT ANTENNAS	2019	2020	2021	2022	2023	2024	2025
Shipments (MM)	2,404	2,593	3,133	3,762	4,411	5,241	6,228

The Virtual Antenna™ will play an important role in growing the deployment of wireless IoT devices across all application segments and vertical markets. Simplicity in device antenna design, particularly for multi-radio applications, will not only reduce device OEM development costs, but also limit the total number of device SKUs needed to serve IoT applications across the world.



The Virtual Antenna™ will provide the most benefit in IoT markets that prefer OTS components. OTS antennas are critical to device growth in the IoT because, as noted above, the IoT market is served by a long tail of device OEMs serving a broad range of use cases. Over the next 5 years, OTS antenna shipments will account for 40% of all antenna shipments. Depending on pricing levels, however, the Virtual Antenna™ also has the opportunity to target markets using complex custom antennas because of its ease of use and the ability to support complex frequency requirements.

ABI Research expects that OEMs that have traditionally used SMT antennas will initially be the most likely to benefit from access to the Virtual Antenna™. The top SMT antenna markets are the same as the top selling IoT markets. Wearables and tracking/logistics are the largest markets followed by smart home. Shipments of SMT antennas will reach nearly 1.8 billion devices by 2025.

SUMMARY

Antenna vendors are increasingly building out their OTS product lines to help the long tail of device OEMs get to market faster and for less development cost. Increasingly, device OEMs serving the IoT market are seeking to use flexible and miniature antenna components within their products. These demands are in response to an increasingly complex and competitive IoT market, driven by more radio complexity and band coverage, faster product SKU refresh cycles, and higher performance in battery-operated devices.

The Virtual Antenna™ technology addresses several of these challenges: it can simplify and enhance the capabilities of on-PCB antenna design; help drive OEMs toward greater awareness of system-level design; and simplify the antenna selection process for designers and business leaders. While product breadth in the IoT antenna market will remain, Virtual Antenna™ technology has the potential to transform the IoT device market through its single design providing both technology and business advantages.

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