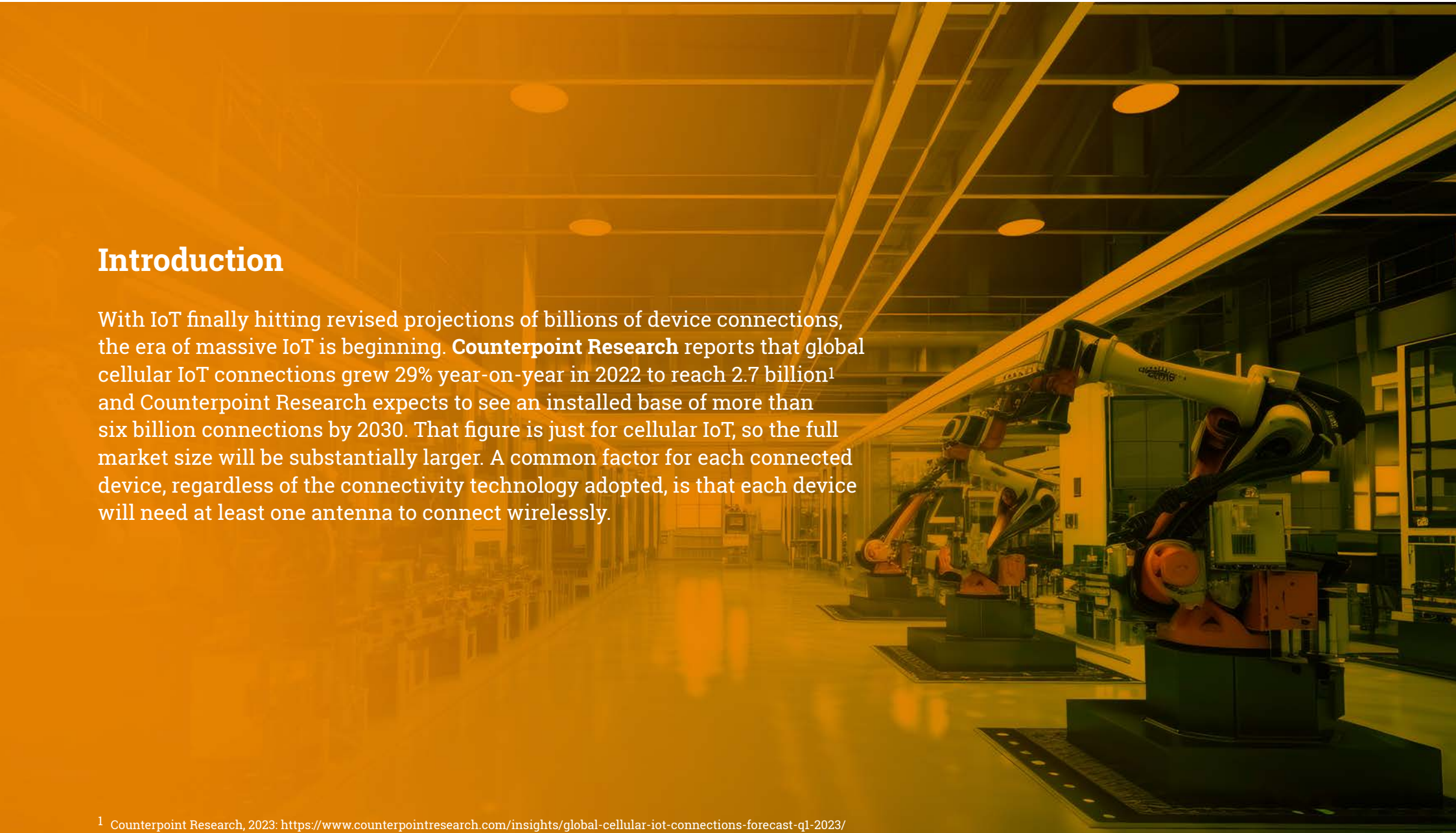
Why IoT must pay greater attention to antennas to ensure optimised device performance

Introduction

With IoT finally hitting revised projections of billions of device connections, the era of massive IoT is beginning. **Counterpoint Research** reports that global cellular IoT connections grew 29% year-on-year in 2022 to reach 2.7 billion[1] and Counterpoint Research expects to see an installed base of more than six billion connections by 2030. That figure is just for cellular IoT, so the full market size will be substantially larger. A common factor for each connected device, regardless of the connectivity technology adopted, is that each device will need at least one antenna to connect wirelessly.



[1] Counterpoint Research, 2023: https://www.counterpointresearch.com/insights/global-cellular-iot-connections-forecast-q1-2023/

Analysis by **ABI Research**[2] has explored how the antenna market is evolving to address challenges specific to IoT and finds that growing competition and technology complexity will drive 7.2 billion IoT antenna shipments in 2025. With billions of connected devices comes the need for potentially trillions of antennas as multiple antennas are required per device, but antennas are often overlooked in the design phase of IoT devices. This can lead to delayed time-to-market, re-engineering work, or suboptimal device performance. It's therefore important that antenna considerations are taken into account early on in the design process and properly integrated into the overall device concept.

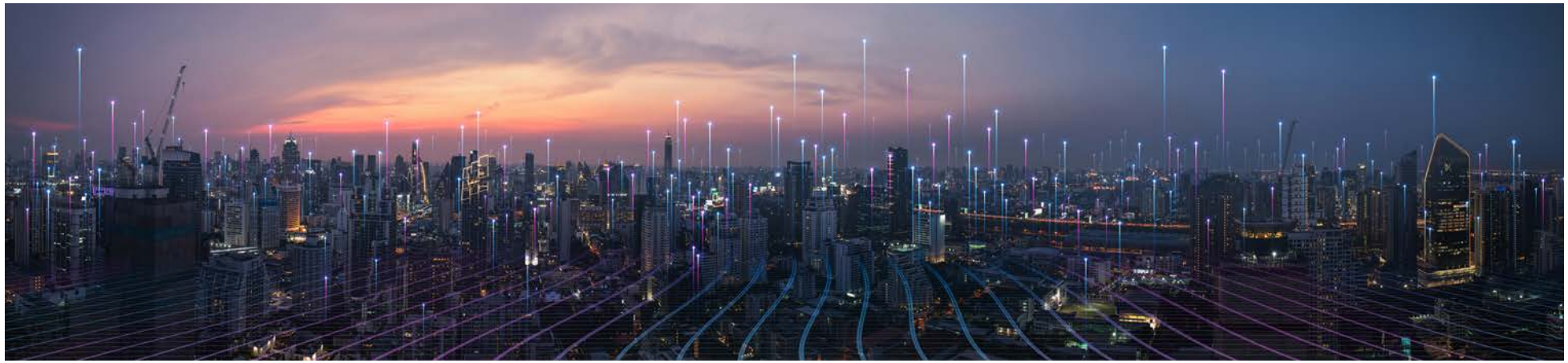
There are vast numbers of antennas on the market, starting at small board-mount chip antennas that have very small footprints and can be easily embedded into devices, and ranging to complex combination antennas that bring together multiple frequencies and technologies in a single externally mounted antenna. Although this results in a vendor landscape that is complex to navigate, it also ensures there is great choice and increases the likelihood that an appropriate antenna is available for every IoT use case. Even so, there remains a need for customisation to ensure antennas can be optimised for the often highly-specific requirements of an IoT device.

This paper sets out why antenna selection is so important as a critical consideration for IoT deployment success, how to avoid common antenna-related mistakes, and what to look for in an antenna supplier.

Why do antennas matter?

It's easy to imagine an antenna is just another off-the-shelf component that can readily be bought for a commoditised price and simply added to a device during manufacture. However, this over-simplifies the role of an antenna, which can be compared to the tyres on your car. Tyres that are the wrong size don't have enough grip, are excessively noisy or wear out quickly. Tyres that are not designed for the weather conditions you face will result in lower performance, greater fuel consumption, and increased potential for accidents. Similarly, incorrectly specified antennas can cause IoT devices to use more power, deliver lower throughput or even cause failures to communicate.

Therefore, developers and designers should take a step back and consider what they need from an antenna, specify and design-in accordingly.



[2] https://www.abiresearch.com/press/2025-over-7-billion-antennas-will-be-shipped-iot-devices-creating-challenges-oems-and-opportunities-antenna-vendors/

Key criteria

Broadly speaking, each development has baseline characteristics that immediately help organisations to zero-in the antenna suitable for their needs. A starting point should be to narrow your focus to antennas that enable the communication technologies your device will use. With 2G and 3G retiring in many markets, the focus on cellular solutions has shifted to narrowband-IoT (NB-IoT), LTE in various flavours and emerging 5G. In addition, various low power wide area (LPWA) technologies such as LoRaWAN and Sigfox are well established, Wi-Fi in various forms is utilised over short distances, and there is a new focus on low earth orbit (LEO) satellite and non-terrestrial networks (NTN).

Often, one connectivity technology will be enough to support the communication needs of a device but, particularly for global deployments or those that demand high levels of network availability, it is desirable to have combo antennas that combine multiple technologies in a single unit. This is particularly attractive for organisations that want to ship a single product to markets that have different requirements or characteristics. In addition, having multiple antenna options in the device could help to future-proof and extend the device's lifespan.

However, a note of caution is that careful consideration should be given to selecting more technologies than you need. Some technologies will interfere with each other or require more costly antennas to eliminate interference. The characteristics of a cellular antenna mean it has different power, location and performance criteria than a Wi-Fi or Bluetooth antenna, so choosing to accommodate all of these technologies could ultimately turn out to be counter-productive if they are not all required.

Once you have selected the communication technology, or carefully-targeted technologies, that you want your device to be able to use, the next step is to consider the power resources of your deployment. If a device is, for example, connected to vehicle systems, power will be less of a consideration than in small battery-powered devices. Nevertheless, it is important to understand the power requirements of the antenna and the trade-off between lower power and lower antenna performance.

Further to the baseline power consumption of the antenna, thought also needs to be given to its operational performance. Incorrectly specified, located or configured antennas can result in significant, unnecessary power consumption as the device fights to find a good connection. Issues such as interference contribute significantly to power consumption and can be minimized by good design. You should therefore identify the best location for the antenna. To allow strong signal propagation it should not be obscured by thick metals, for example.

It is also important to understand that the efficiency of an antenna has an impact on power, particularly for battery powered devices. If an inefficient antenna has to ping 100 times compared to an efficient antenna pinging ten times in the same space of time, then you can see the effect this would have on power consumption.

Placement of the antenna has a significant impact and this should also be addressed early in the design phase. If you place your antenna between two pieces of lead and next to a battery, you may as well not bother adding the antenna at all. Therefore, careful consideration needs to be devoted to not only the location and area apportioned for the antenna but also the materials that surround it and sources of interference.

With the network technology, the location and placement of the antenna and its power characteristics decided, there follows a series of use case-specific considerations to take into account. These vary widely depending on the requirements of the application. The ruggedness of an antenna design could be a priority for an antenna located outside in a public area or in a location that experiences extreme weather. In another application, miniaturisation could be of greater importance, for example allowing for an internal antenna in an electric scooter.

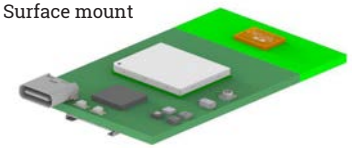
Other applications might prioritise improved data connectivity, extended operational lifetime or high availability with minimised numbers of faults. Still others will be looking to optimise cost or to accommodate the antenna as part of integrated solutions. It's therefore important to take into account all the different dimensions and variables that each application involves so you can arrive at the optimal antenna choice.

Only when you have identified the basic attributes for your deployment and targeted antenna characteristics to your specific application needs can you turn your attention to which type of antenna to select.

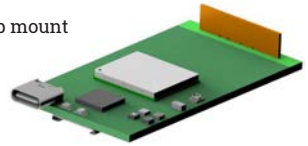
There are six popular types of antennas to choose from:

1. **Internal – Board Mount Antennas** include three main types: surface mount, tab mount and surface mount on ground. Surface mount antennas have a small size and low profile and are ideal for devices with very low weight requirements. They have a relatively large printed circuit board (PCB) 'keep out' area (an area that needs to be kept clear around the antenna) of 10-20mm. Tab mount antennas have a higher profile of 10-20mm but a smaller PCB 'keep out' area of 5-10mm. These antennas can save PCB space while offering good antenna performance. Finally in this category, surface mount on ground antennas have a higher profile of 5-25mm and require no PCB 'keep out' area. These antennas can save PCB space and are ideal for single or dual high-band antennas.

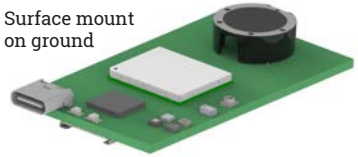
Surface mount



Tab mount



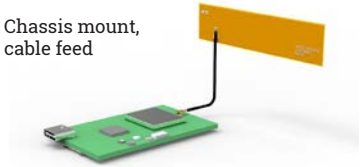
Surface mount on ground



2. **Internal – Direct and Cable Fed Antennas** include two main types: chassis mount, direct or cable feed. Direct feed antennas are compact and use the existing ground plane. The ground plane design and components or routing can have strong radio frequency impacts so they need to be carefully placed. These antennas are suitable for automatic and repeatable assembly. Cable feed antennas are larger and are often ground plane independent antennas. By removing the antenna from the PCB, the ground plane and other PCB components have little impact on RF. These antennas can offer greater performance than board mounted antennas and are available in flexible formats that include adhesive strips for easy and simple mounting even on curved device surfaces. However, manual assembly is often required.

Chassis mount, direct feed

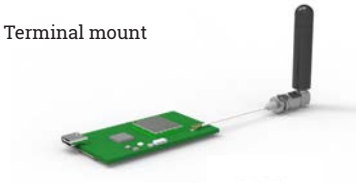
Chassis mount, cable feed



3. **External – Remote, Terminal and Low-Profile Antennas** are composed of three main antennas: remote, terminal mount and low-profile. Remote antennas are standalone with little or no dependency on the device ground plane. These are a preferred option for devices with metal cases and offer an option where the antenna placement can be outside the device but directly connected to the PCB inside the device. Terminal mount antennas offer similar functionality but the dependency on the device ground increases with lower frequency. An adapter cable from the PCB may be required, which can add cost, but these antennas also offer easy manipulation with minimal RF design effort. Low profile antennas can be positioned further from a device or board and offer higher gain options. These antennas are highly versatile and available in many formats with options available for all mounting positions, including outdoor placement.

Remote

Terminal mount



Low-profile

4. **Vehicle - Whip, Low-Profile, Multi-Port and Covert Antennas** come in a variety of shapes, sizes and formats and can vary from covering a single narrow band frequency to multiple frequencies such as cellular, Wi-Fi, GNSS, Bluetooth and more from a single antenna. The choice of antenna for a vehicle or mobile application is often governed by the frequencies that the user wants to communicate with and the radio, gateway or router in use. Radios, routers and gateways will have multiple channels dedicated to certain frequencies. This often dictates the antenna required. This includes the frequencies the antenna covers, the length of the cable required to run from an antenna mounted on the roof or exterior of a vehicle to the radio, and it will also govern the connectors on the cable that are required to connect to the radio.

Whip & Low-Profile

Multi-Port

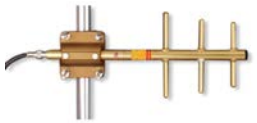
Covert

5. **Infrastructure - Fixed Position Antennas** are antennas that will be mounted in a fixed location and in most instances will not move from that location. They are usually available in two broad formats which is omnidirectional (360 degree coverage around the antenna) or directional (pointing to a more fixed location). These antennas are often much larger than anything used on an IoT device and they provide the overarching infrastructure that will allow IoT devices to operate in a given environment. A common example of these types of antennas might be seen on a cell tower or TV mast where multiple antennas will be fixed to that mast or tower. They can also be used in other environments such as factories or warehousing where Industrial IoT (IIoT) devices might operate.

6. **Molded 3D antennas**
Laser Direct Structuring (LDS) is a state-of-the-art technology used to create 3D antenna designs directly on a plastic surface and can save space within the application by integrating high performance, mechanical and electrical functionality into one component. LDS enables three-dimensional antenna performance by printing the antenna directly onto shaped plastic surfaces, versus the limitations of two-dimensional placement on a PCB or other substrate. This is achieved by utilising the existing 3D surfaces on the antenna carrier, which can't be used by traditional manufacturing methods, to provide wider bandwidth and higher efficiency.


Outdoor Omni Baton

Directional Panel


Directional Yagi


Ceiling Mount DAS


Fixed Wireless Access

Succeed with a fine balancing act

In order to arrive at a specification that delivers the perfect balance of performance, cost, power consumption, design simplicity and operational robustness, designers need to weigh various competing needs. A further step should be to decide how robust the antenna needs to be. What environments will it be deployed in, how can it be protected, and what level of protection is needed should be identified in the final specification. With those questions answered, the antenna choice can be made accordingly.

You should also investigate compliance issues in the markets that the device will be deployed in. Understand the safety, security, and regulatory landscape because this is important for device certification.

Balance all the above considerations from network and antenna technology to ease of design, robustness and ease of certification to determine the sweet spot of performance, power consumption and size. Finally, select a vendor that can support you with a wide portfolio of antennas and other, adjacent technologies so greater efficiencies can be driven by pre-integration and vendor consolidation.

How TE Connectivity (TE) helps

TE provides a range of components that power electric vehicles, aircraft, digital factories, smart homes and much much more. For more than 75 years, the company has engaged with customers to produce highly engineered connectivity and sensing products that make a connected world possible. TE's focus on reliability and durability and the huge range of its product portfolio enables companies large and small to turn ideas into technology that can transform how the world works and lives.

TE's broad portfolio of antennas includes products designed for cellular, Wi-Fi, Bluetooth, WLAN, Zigbee, GNSS, RFID, IoT, DAS and LPWA technologies. The antennas are available in standard and custom designs and engineered for use in cars, heavy-transport vehicles including rail, and a wide variety of personal electronics, including mobile devices and wearable technology. TE manufactures antennas in multiple facilities worldwide, which include testing capabilities in near and far field patterns, scattering parameters, SAR, vibration, humidity, temperature shock, salt fog, throughput and acoustics. The company also manufactures antenna accessories including mounts, cables and connectors.

This broad exposure to the world of connectivity and the requirements of many IoT devices has generated decades worth of experience in providing options to aid the proper selection and placement of antennas and associated products.

TE recognises that while many deployments can use off-the-shelf antennas, the nature and complexity of some IoT deployments demands customisation. TE's experts can help address the wireless industry's demands for increased complexity and miniaturisation of antennas and the need to integrate a multi-radio environment into one component. TE therefore offers a range of customised antenna solutions to accommodate the mechanical constraints of your application so you can configure the placement and use of our antennas that address your stringent operating requirements.

TE is an expert in the field of moulded interconnect device (MID) technology, including laser direct structuring (LDS), which can help save valuable space in your application by integrating high performance, mechanical and electrical functionality into one 3D component.

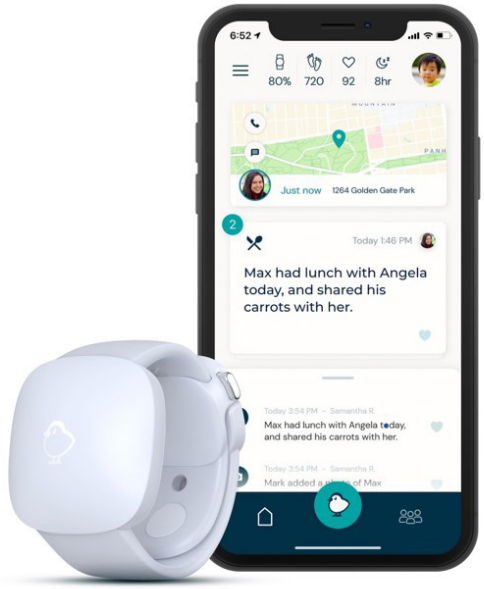
Customer example

Littlebird Connected Care (Littlebird; **www.littlebird.care**) is a pioneering digital health company that has created an innovative care connection SaaS AI platform and IoT wearable device. Littlebird's Bluetooth chain-of-custody approach to tethering aims to reduce the risk for parents and caregivers and improve long-term health outcomes. Littlebird enables caregivers to answer the three most important questions about those they care for: Where are they? Who are they with? How are they doing?

Given the need for low latency and seamless connectivity, the Littlebird device needed an antenna solution that could address cellular, GPS and Bluetooth connectivity, fit into an ultra-compact form factor, support a longer battery life, and withstand daily wear and tear. In addition, there were regulatory challenges that needed to be addressed.

"There is a critical need to stay connected with loved ones under care supervision, such as the very young, differently abled and elderly populations," explains Monica Plath, the CEO of Littlebird Connected Care. "TE immediately saw the US$45bn gap in digital healthcare connectivity and jumped. We are thankful for their support and contributions to our national awards and press in our first year."

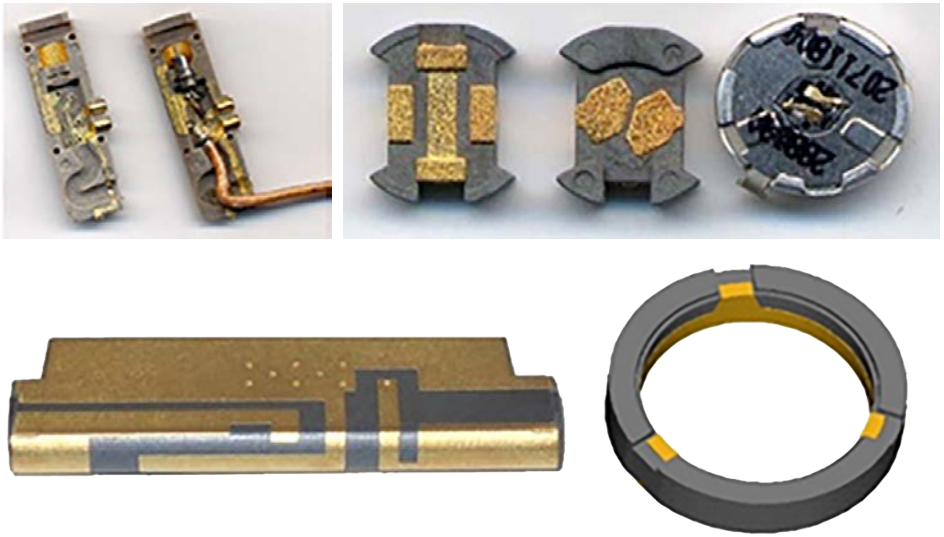
Given the ultra-compact form factor of Littlebird's CareTracker device, TE's robust portfolio of standard off-the-shelf Bluetooth, LTE cellular and GPS antenna solutions would not meet the device's design requirements. The design called for an out-of-the-box custom RF/antenna architecture in order to comply with challenging carrier requirements. Those constraints led to TE offering a customized solution that met Littlebird's needs.

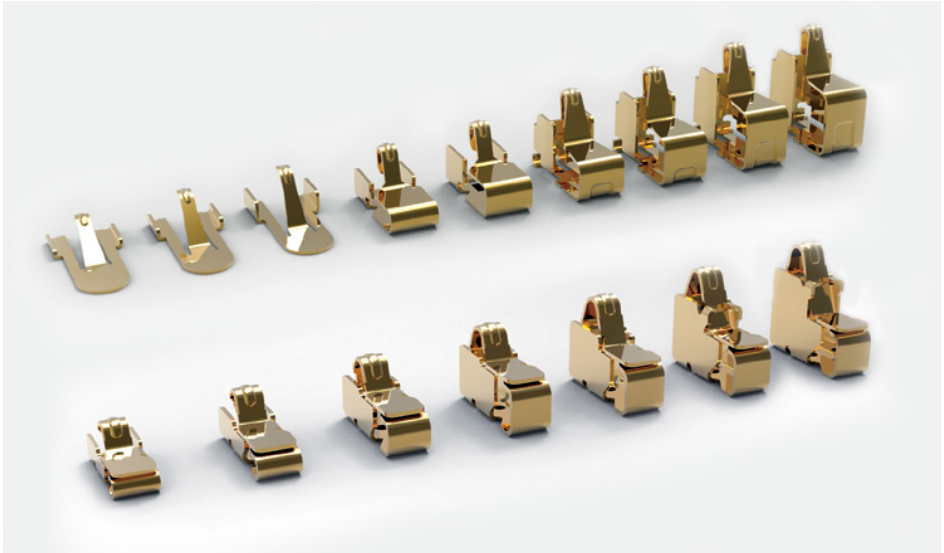


The FCC approved Littlebird Toddler CareTracker wearable device shown with the Connected Care mobile app.

Numerous factors can affect overall antenna performance, including ground plane dimensions, distance to nearby metallic components, antenna position, RF feed placement, PCB layout and component selection. Over the course of six months, TE's global development team closely collaborated with Littlebird, their design house, contract manufacturer, and others to creatively design, optimise and test an antenna architecture solution to meet the system level requirements and achieve FCC approval.

The final design utilises custom LDS antennas with LTE, Bluetooth and GPS functionalities combined in a single antenna. The housing of the CareTracker's LDS antenna also features a ring for ultrasonic welding, which helps seal the assembled device for waterproof, IP67-rated performance.





Examples of laser direct structuring on various devices (left). Spring finger contacts for grounding, antenna feeding and EMI shielding.

Conclusion

Antennas haven't been given sufficient attention as part of the bill of materials (BOM) of IoT devices, but it is becoming increasingly recognised that accurate antenna specification leads to improved device performance while reducing the BOM cost and positively impacting the overall performance of the device. Additional benefits in the form of accelerated time-to-market and simplified design and production are harder to quantify but are becoming more clearly defined as IoT matures.

This is further highlighted as IoT devices scale up into the mass market. Higher volumes mean that errors, as well as successes, are magnified. So take the time to assess your antenna options carefully and ensure you choose an optimal solution from the thousands of antennas on the market. Alternatively, keep it simple and get guidance from an expert antenna provider that really knows what your device may need and is able to achieve customisation quickly and effectively alongside pre-integration with a variety of adjacent products and components.

Learn more about TE's antenna solutions at **www.te.com/antennas**