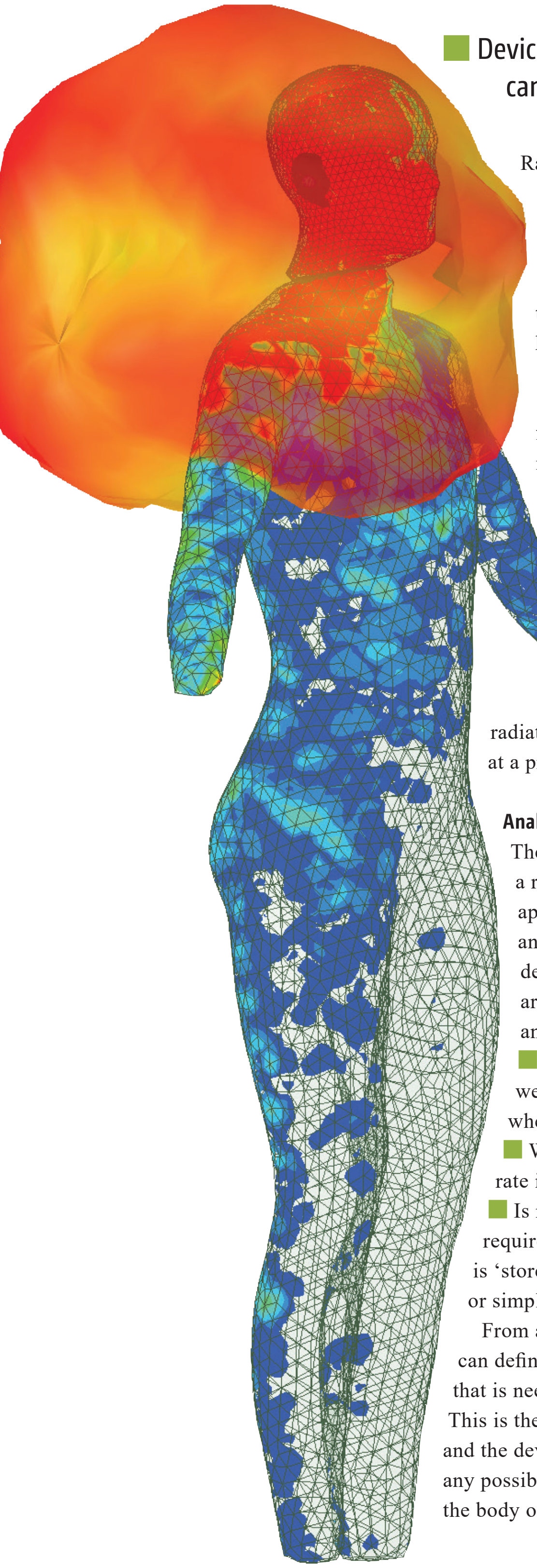
Keep body-worn wireless devices connected



Devices in the wearable sector range from medical, fitness and consumer devices, but they can throw up challenges for radio communications, warn **Nick Wood** and **Chris Barratt**

Radio solutions are designed for a typical scenario, an RF component on a PCB, mounted in a plastic box, with an air gap around the PCB and an optimised keep-out zone and ground plane.

While this is logical for an all-purpose design, it is far from the typical wearable case. In this case, the RF component will be in close proximity to the body, which is a strong absorber of microwave radiation. Additionally, space is at a premium.

Analyse use-case

The first step in designing a radio for a wearable application is to analyse and define the use-case and define the overall solution architecture. This means answering the questions:

- With what will the wearable communicate, and when?
- What throughput or data rate is required?
- Is near continuous connection required, or in case of interrupt, is 'store and forward' acceptable, or simple break in data continuity?

From analysing the use-case, one can define the worst-case scenario that is needed to be supported. This is the position of the wearable and the device it connects to – and any possible obstruction, including the body of the wearer and the data rate necessary to achieve the use-objective.

It is a different case if the connection is just used to configure a device. In this case, one can assume the two objects will be close to each other and largely unobstructed, as opposed to a wearable in continuous contact, where a device might have most of the body between it and a phone some distance away.

RF absorption

Most wearable devices use Bluetooth to communicate, although they could include a GPS receiver and/or long-range radios such as a cellular or LoRa connection.

Bluetooth supports a maximum data rate of 2Mbps in ideal conditions, excluding long range, meaning throughput is limited to around 1Mbps. It is important to understand how far the requirement is from this limit case, to assess the problem.

The 2.4GHz frequency of Bluetooth is easily absorbed by the human body. Studies show that a device held one side of the body will be attenuated by 60-80dB relative to a device on the other side.

To ensure communication between a radio transmitter and receiver a minimum link budget is required. This defines the maximum acceptable loss between the two devices while continuing to receive good data. The loss is affected by the antenna gains, miss-match loss and path loss. The budget is the difference between the minimum required receive signal (receiver sensitivity) and the transmit power.

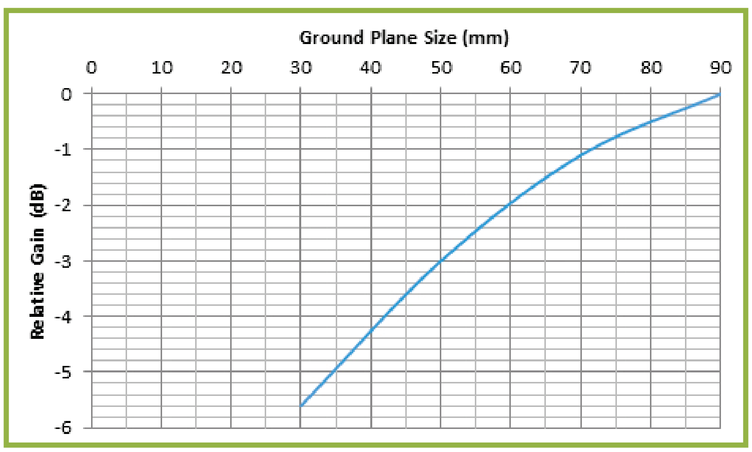
In a typical Bluetooth Low Energy case, the link budget is +4 (Tx power) +92 (Rx sensitivity) = 96dB.

Assuming antenna gains of 0dBi, miss-match loss at each end of 1dB the maximum allowed path loss would be 96-1-1+0+0dB = 94dB.

Path loss can be translated into free space distance by the Friis equation:

$$TRLoss(dB) = 10Log(\lambda/4\pi R)^2$$

For Bluetooth, this would equate to 500m, but this does not take into account fading due to proximity to the earth's surface. This leads to a typical range of 50-100m for a pair of



Antenna gain and link budget decrease as the ground plane dimension decreases

Bluetooth devices having a 94dB link budget.

The next step is to look at the physical design of the device. The key issues here from a radio perspective are materials used in the housing, placement of battery, radio component and PCB within the device and the antenna choice.

Physical design

Technical considerations may drive design in a different direction to aesthetic ones,

For materials, an RF transparent material, such as polymeric plastic, ABS or Perspex is recommended, whereas the advice would be not to use a conductive metal, although it is possible to use some metal with an RF window for radiation to escape, but performance will be degraded.

The battery is typically cased in metal. Ideally, it is positioned to the side of the PCB containing the RF component with the antenna separated as far as possible. Then the battery can form part of the ground plane for the RF solution. Underneath the RF component is a far less favourable position and it should be separated vertically by as much distance as possible.

The PCB placement is also critical as the body is a strong absorber of RF radiation, especially at 2.4GHz. Achieving the maximum distance between the body and the RF component (specifically the antenna) is crucial.

A separation of $\frac{1}{4}\lambda$ – which at 2.4GHz equates to 3x108/4x2.4x109=~30mm – would be optimum.

This might not be possible but extensive simulations showed that at 2mm spacing from the body, the antenna gain away from the body is close to -2dBi, increasing to 0dBi at 3-4mm.

Antenna choice

The final part of the puzzle is the antenna. Performance will be enhanced with a large antenna, yet wearables need to be small and convenient to wear.

There are three main options for the antenna. In increasing order of complexity, they are: to use a certified module with integrated antenna, connect an antenna part to the RF circuit, or design a custom antenna as part of the wearable device.

The first option is the easiest in terms of minimising design effort and risk. It also removes the requirement to engage in lengthy and expensive certification efforts such as CE, FCC and Bluetooth SiG.

Experienced RF designers can consider the other two options. An RF reference design may look relatively easy, but it is easy to get wrong.

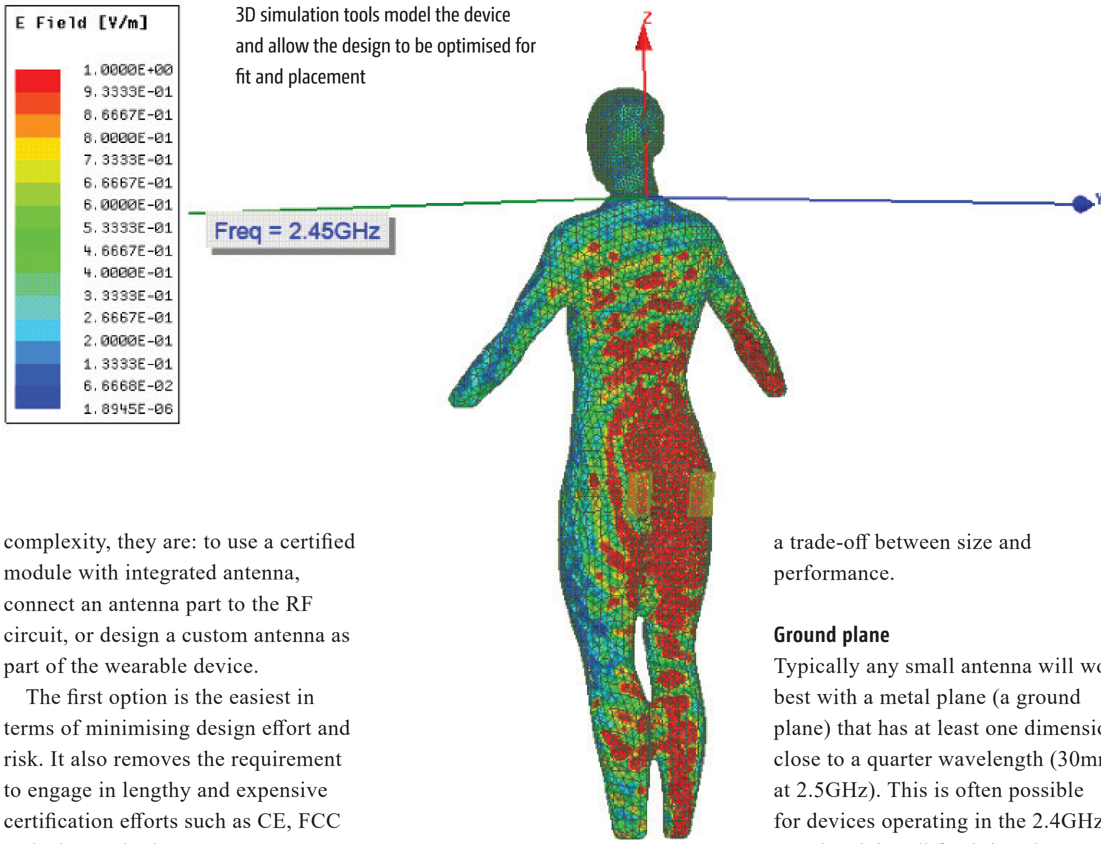
Wearable devices are already a difficult environment and a reference design may result in a poorly functioning device or multiple development cycles, as well as problems with certification.

The possible upside of a custom antenna design is that it could be optimised with respect to the overall design of the device. This is not a process for which straightforward rules can be provided.

For this option, 3D simulation tools can build a computer model of the device. This includes the RF components/antenna, and a model of the human body so the device can be correctly placed (*above*). The elements can then be configured to optimise the design.

Even with these tools and significant experience, such simulation work is a time-consuming process.

To do so via a prototyping and a trial-and-error approach could result in a lengthy project.



3D simulation tools model the device and allow the design to be optimised for fit and placement

Directionality

Another issue is what sort of antenna directivity and/or polarisation is optimal.

Most small wearable devices require an omni-directional antenna with a gain as close to 0dBi as possible. The polarisation is typically linear, despite the fact the device may suffer from reduced link budget when transmitter and receiver have cross-polarised antennae. This effect is usually mitigated by reflections and/or frequency hopping.

If the module option is chosen, there are miniature solutions available which are small enough to work in most wearable devices. In many cases, a lot of work has gone into optimising the miniature antenna performance and it would be difficult to improve on the design.

Placement of the RF component also needs consideration. Typically, the module manufacturer will recommend a ‘keep out’ zone around the antenna portion. However, this might be hard to achieve in a space constrained device, requiring a trade-off between size and performance.

Ground plane

Typically any small antenna will work best with a metal plane (a ground plane) that has at least one dimension close to a quarter wavelength (30mm at 2.5GHz). This is often possible for devices operating in the 2.4GHz ISM band, but difficult in sub- GHz communications.

For the 868MHz ISM band (Zigbee, LoRa or Sigfox) this translates to a minimum size of 90mm, which is large for a wearable product. Figure 2 shows the antenna gain and link budget decrease as the ground plane dimension decreases.

The key issues in designing a wearable device have to take into account the challenge of designing a small device worn close to the body. Tools can aid design but, conversely, doing everything from the ground up should only be tackled by the highly experienced designer.

Following some simple design principles from the start can vastly reduce the risk and enhance the chance of bringing the device to market on time. ❑

About the author

Nick Wood is technical market director and **Chris Barratt** is chief technology officer, Insight SiP