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Session:

BLUETOOTH SMART© SOLUTIONS FOR TINY METAL OBJECTS TECHNICAL TRADE OFF AND SOLUTIONS

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Abstract

The rapid expansion of phone usage has opened numerous new applications in which the phone is now the central hub for communications with other objects that are part of our daily life. Bluetooth and its low energy extension Bluetooth Smart are the prevalent standards that achieve wireless communication with a range exceeding 30m. However there are some applications, with high environmental constraints, where it is extremely difficult to achieve even short range wireless connections.

This paper will focus on two Bluetooth Smart examples in which the wireless signal is strongly affected by the object's environment. The first example concerns a metal case watch; whereas the second concerns a hearing aid device. For each example we indicate potential tradeoffs that can be made to optimize the antenna in terms of size and performance within a constricted environment. The paper indicates potential link budgets that can be achieved with selected solution sets for both examples.

Introduction

Bluetooth Smart is the dominant standard for short range communication between Smart Phones and small low power objects that require relatively low average data rates. The low power consumption achieved by Bluetooth Smart is essentially due to two factors:

- Minimisation of the power dissipation of the electronic circuits used in the slave object.
- Use of a real time clock controlled sleep/wake sequence that ensures that the slave object only consumes significant power during data exchange.

A Smart Bluetooth communication requires that both the Master (usually a Smart Phone) and the Slave have both transmit/receive circuits a real time clock, a microprocessor and an antenna. In this paper we consider slave objects that have severe environmental constraints, both in terms of size and electromagnetic environment.

The first case concerns the Smart Bluetooth wireless connection for a metal case watch. The main challenge is to design an antenna that allows a reasonable degree of overall transmission efficiency.

The second case concerns the wireless connection to an in ear hearing aid device. This application poses two major difficulties, the environment around the hearing aid consisting largely of soft tissue with high permittivity and loss tangent and the small space available for the antenna.

Metal Case Connected Watch

Recently a number of Smart Bluetooth connected watches have been put on the market. Products from both the traditional watch segment (Casio G-Shock) and the electronic sector (Samsung Gear, Sony SmartWatch, and more) have been launched.

Most of the above devices use a plastic case or a case with significant portions of plastic, which allow for relatively easy communication using a standard 2.4 GHz Bluetooth antenna structure. The antenna is placed in a zone that is sufficiently far from metal parts of the casing to ensure that its performance is not significantly degraded.

Traditional watch makers and even new comers that intend to create a connected watch that uses the usual mechanical metal casing need to find a solution for the antenna that will work within such constraints.

This paper examines the design methodology and tradeoffs that can be used to design such an antenna for a standard metal case watch.

Metal Case Description

A stylised metal watch case is shown in Figure 1. The case can be represented by a hollow cylindrical tube with a metal bottom. The internal diameter for a men's watch is typically between 28 and 35 mm and the internal height is around10mm.

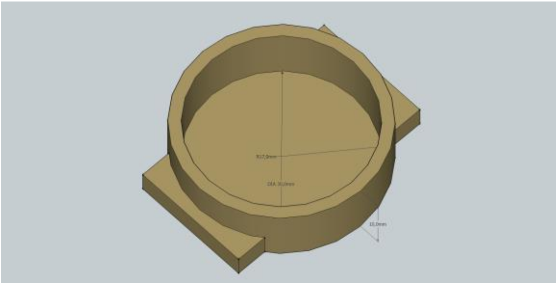

Figure 1 Stylised Metal Watch Case

In such a typical watch the mechanical movement or digital display is placed close to the top of the tube, whereas the electronic portion is usually placed under the movement/display near the bottom of the tube close to the back plate.

This arrangement makes for a particularly difficult scenario for the antenna design since as the antenna has to be connected to the electronics it is close to both the side walls of the watch and the back plate. In order to design an antenna for such a critical environment it is essential to take into account all the mechanical and material constraints throughout the design process. It is also important to consider the overall link budget that is required for the particular application.

Design Process

The design process consists of the following steps:

- Obtain all mechanical dimensions and material properties for key components
- Create a simplified 3D mechanical model of the watch
- Determine allowed space for 2.45 GHz antenna
- Evaluate antenna topologies using 3D Finite Element Electromagnetic Simulation of complete structure
- Choose best compromise solution
- Build and test prototypes of selected solutions
- Iterate if necessary
- Establish potential link budget
- Validate solution

Design Example

The design process described below has been used to successfully create an antenna for a metal case watch. In this case the area reserved for the antenna is extremely small and placed close to the bottom of the watch case within 2mm of the case back. Two different antenna topologies were evaluated both by simulation and measurement.

The most promising structure, given the constraints provided by the watch manufacturer is a form of miniaturized PIFA realized using the main PCB and an upper metal layer on an additional piece of FR4 material. An example is shown in Figure 2.

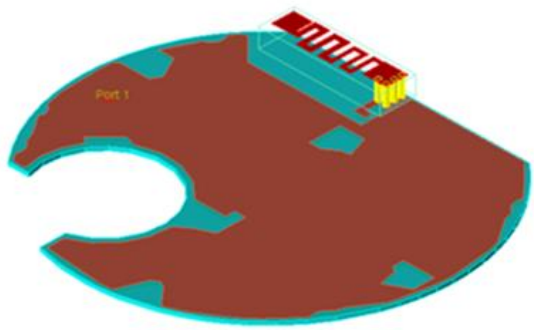

Figure 2 Typical PIFA type antenna on main PCB

A parametric analysis of this antenna structure, housed within the metal casing was carried out using FEM Electromagnetic simulation. Optimum simulated antenna performance in this case is limited to -9dBi with a 6dB match over the2.4 to 2.5 GHz band.

The above antenna was built and tested within the metal watch case. The performance is close to the simulation results as indicated by the curves in Figure 3. Note that the actual prototype is slightly down shifted in frequency due to material parameter inaccuracies during EM simulation.

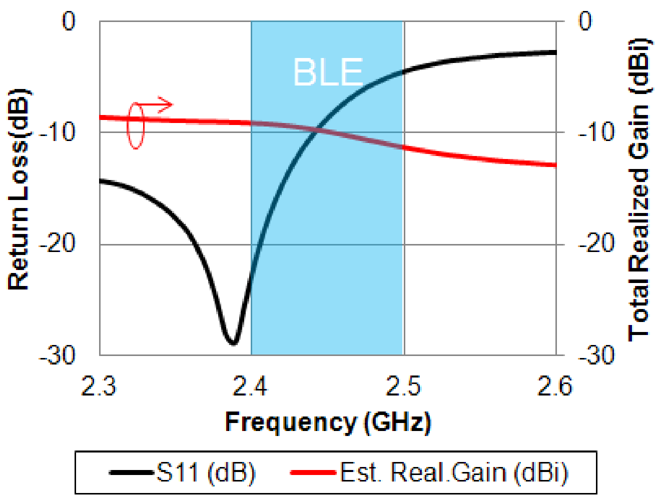

Figure 3 Measured Gain and return loss of prototype antenna in metal case

In this case assuming Friis link budget rule

$$\frac{Pr}{Pt} = GrGt(1-S11^2)(1-S22^2)\left(\frac{\lambda}{4\pi R}\right)^2$$

The total range for a typical Bluetooth Smart connection can be calculated assuming:

- Transmit Power Pt = 0 dBm (1 mW)
- Receive Power at sensitivity threshold Pr = -85 dBm (for state of the art solution)
- Master Antenna Gain (at Smart Phone) Gt = 0dBi
- Slave Antenna Gain (at watch) Gr=-9dBi
- S11 and S22 < -6dB

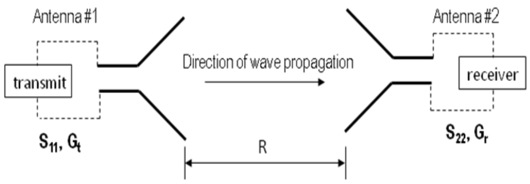

Figure 4 Link Budget

Calculation of the above formula shows that the threshold range in this case is around 60m. Taking into account random alignment of antennas assuming a 10 dB hit on link budget the communication range is still a highly acceptable 18m. Given that the use case is a cell phone and a watch this would seem to be amply sufficient to maintain a connection assuming the cell phone is carried by the watch wearer, somewhere on or near his body.

In-Ear Hearing Aid

Hearing aid devices have become smaller and smaller as electronic integration has progressed. Today in certain cases the whole hearing aid can be placed within the ear cavity so that it is practically invisible. In order to provide Smart Bluetooth connectivity to such a device it is necessary to add an antenna to a device that is already extremely small and contains, electronics, a battery a microphone and a loudspeaker.

The following design example shows the design methods and tradeoffs possible.

Design Example

The in-ear hearing aid has two major challenges:

- realizing a very small antenna
- ensuring that some of the radiation leaves the head since the soft tissue surrounding the ear is extremely low loss.

The design is based on using extensive 3D FEM simulation that takes into account the ear cavity and the soft tissue around it.

The model used in the design process is a simplified model of the head that is assumed to have the following dielectric characteristics:

Freq (MHz)	**ε'r**	**ε"r**	**σ (S/m)**	**εr**	**tg δ**
2450	52.7	14.3	1.9	54	0.27

Figure 5 shows the simplified model that uses a hexagonal extruded shape with a small air cavity to model the ear and head.

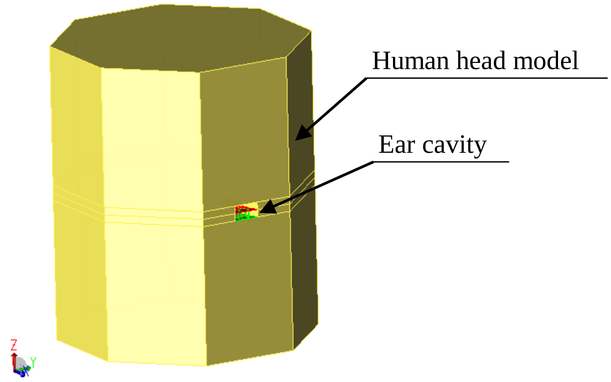

Figure 5 Simplified human head model

A number of antenna topologies were tested within this environment. The most promising antenna type places a modified monopole near the extremity of the ear cavity.

In this case the performance is as shown in Figures 6 and 7

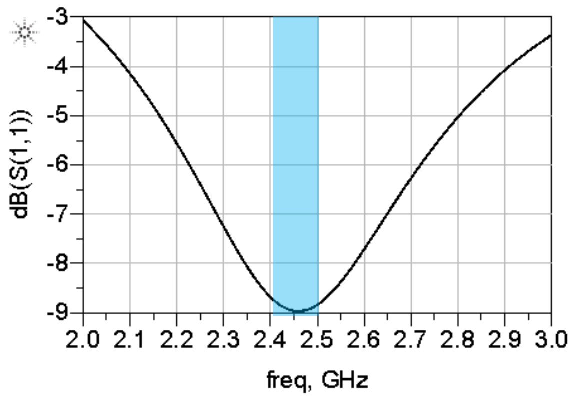

Figure 6 Return Loss

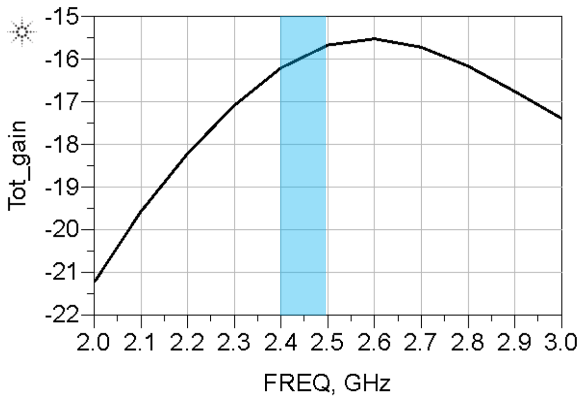

Figure 7 Total Gain of in-ear antenna

The 3D radiation patterns are shown in Figure 8.

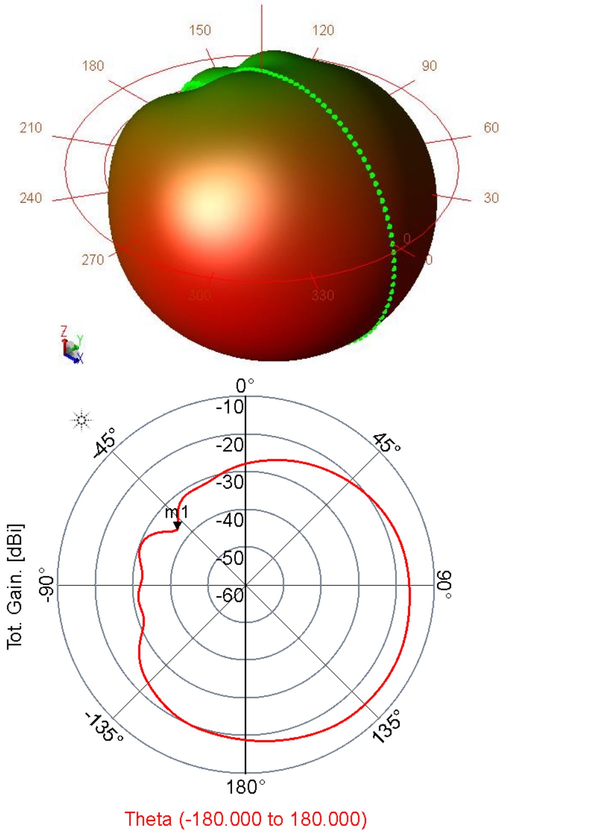

Figure 8 Radiation pattern of in-ear antenna

Using the same formula as earlier for the connected watch example the following range can be calculated for this antenna

Max. gain (dBi)	Max. free space range R_{max} (m)	Multipath error correction $\alpha = 0.6\ R_{max}$ (m)
-16	25	15

Note that this estimation does not include the potential effect of power variations on the far side of the head which can be as much as 20 dB lower than the maximum signal strength. Even with such an assumption the minimum range is still greater than 1.5m. Thus connectivity with a Smart Phone will be maintained provided that it is close to the user.

Conclusions

The paper has examined two design examples for integrated antennas that are designed to provide Smart Bluetooth connections to objects that are extremely small.

The rigorous design methodology allows for accurate prediction of performance for such objects.

In both use cases it has been shown that, although the antenna is extremely small and constrained by the operating environment, a workable solution can be found. The solutions maintain a reasonable link budget margin for the envisaged operating conditions.

About the Author

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38 years experience in RF and Microwave design with specialization in filters and active circuits in thin film, thick film, laminate and LTCC.

Prior to Insight SiP he was instrumental in setting up National Semiconductor’s Design Centre in Sophia Antipolis.

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