Designing Embedded Antennas for Bluetooth Protocol

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Abstract

In the near future, all kinds of portable devices ranging from laptops, PDAs, to cellular phones will be capable of communicating and inter-operate with each other using a new wireless technology networking protocol known as bluetooth. There are however, several hurdles that must be overcomed . One of these hurdles is to provide a communication link that mostly interference free. The design of an appropriate antenna is important in providing a good communication between devices. In this paper we present the outline of an embedded antenna using the method of moments. This work is also extended to address generally other design issues in bluetooth technology that can be address using computational electromagnetic.

Introduction.

One of the hottest technologies in the wireless world in bluetooth [1-2]. The bluetooth standard was created by the Swedish telecommunications equipment manufacturer Ericsson. Named after the Danish King Harald II, who received the nickname "bluetooth" when he unified Denmark and Norway in the 10^{th} century. The bluetooth standard is pose to be the standard for inter-device communications for short-range RF networking in the wireless medium. About 1800 companies are already members of the bluetooth consortium, with more to follow. Bluetooth is intended to provide an energy saving, safe (i.e no known adverse bioelectromagnetic effects), and low cost RF technology in order to eliminate wire connection over short distances. Bluetooth can be integrated in almost all kinds of electronic data-communications devices and can communicate among each other without a line-of-sight connection.

A bluetooth devices consists of a baseband controller and an RF section. The controller has an interface to the host system (e.g. laptop, PDA, cellular phone, desktop PC…). Bluetooth works in the industrial, scientific, and medical (ISM) frequency band between 2.402 and 2.480 GHz and uses a frequency hopping mechanism, where 1600 frequency changes occur every second. A single bluetooth connection uses 79 different frequencies with a channel separation of 1 MHz. The frequency hopping of bluetooth is necessary to provide a higher level of security against eavesdropping and to minimize interference. Interference is an issue because the bluetooth operating frequencies fall within that of microwave oven and other radio services close to the ISM band. Bluetooth also uses forward correction which limits the impact of random noise on long distance links. Whenever interference occur on a specific frequency, this frequency isn't assigned during frequency hopping, and hence a minimization of interference effects. In most cases for such situations, the antenna will be implemented by assigning a short segment of conducting track on a PC board.

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The maximum transmission for bluetooth is 1 mW which is enough to communicate up to a distance of 10 m. Most likely however, consumers envision communication at much larger distances. An output of power of about 100 mW is needed to communicate up to 100 m. In the receiving end, the bluetooth describes a sensitivity of –70 dBm working with an IF of 1 MHz. The bluetooth architecture can handle up to 8 devices and can communicate using what is called the "Piconet". Within 2 seconds, individual bluetooth controllers inside the Piconet identify themselves by using a unique 48-bit serial number. The first device that has been identified takes control of the master function. Several Piconets operating with individual hopping algorithms can communicate within a larger multiple Piconet environment known as a scatternet. Bluetooth works with shorter data packets. The full duplex data rate within a scatternet that has 10 fully loaded independent Piconets is more than 6 Mbits/s.

The baseband controller prepares the data for transmission and also controls the entire procedure. When voice data is transmitted, bluetooth works with a transmission rate of 64 kbits/s in a synchronous mode. Every single data packet is transmitted at another hopping frequency and a data packet is assigned to a single time slot. Data can be transmitted asynchronously at net data rates of 721 kbits/s upstream and 57.6 kbits/s downstream, or synchronously at 432.6 kbits/s in both directions. Bluetooth supports the transmission on one synchronous data channel and three synchronous voice channels. Furthermore, it can support one asynchronous data and one synchronous voice audio data within a single channel. Voice channels use the continuous variable slope delta modulation voice coding scheme which is highly robust.

<u>Bluetooth at Work.</u>

The entire connection is mastered by the link controller (see Figure 1) which is an integral part of the baseband IC. The controller takes cares of the protocol and link access routines. Every 1.28 seconds the Piconet "listen" for any signal. If a signal is detected, the bluetooth module will look for the communication partner on 32 individual assigned frequencies. The next step is assigning the master module by using a page message if the address of the communications partner is known. If the communications partners is not known, an address inquiry is followed by a page message that will be sent out. At the beginning of the paging mode, the master sends out 16 identical page telegrams on 16 different hopping frequencies. If no answer is received, then the master resends its page telegrams. The telegrams will sent 16 different hopping frequencies. The maximum time delay a master needs in order to finally contact is about 2.56 sec.

The inquiry telegram is used in order to identify bluetooth devices which are nearby and with known addresses. The inquiry message is very similar to a page message. However, it can demand an additional routine whenever answers from several devices need to be collected. If no data is transmitted, a Piconet master can assign its slaves to operate in the "hold" mode to conserve energy. In this mode an internal timer circuits keeps on working. The master can assign all slaves to operate in the hold mode when it wants to set up a scatternet with an adjacent Piconet. On the side, slaves can request the master to allow them to change to the hold mode. When any kind of data communications is needed the master wakes up the relevant slave.

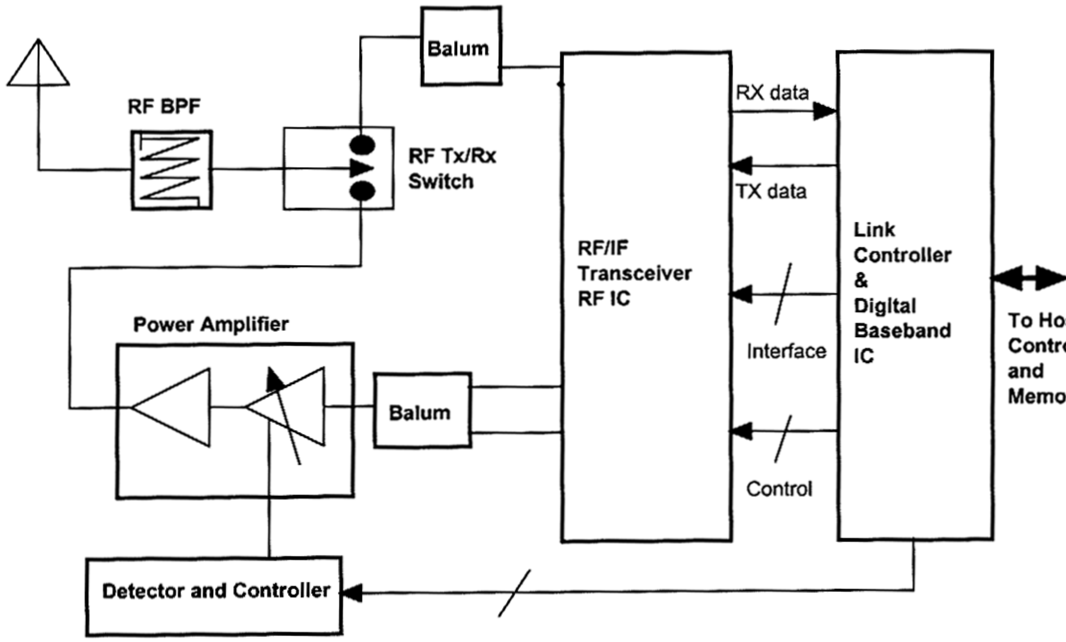


Figure 1. The Bluetooth Sample Architecture.

In Figure 2 the design is more advanced since we have integrated the power amp and baseband processing within a single RF IC and the link controller is implemented using digital signal processing (DSP).

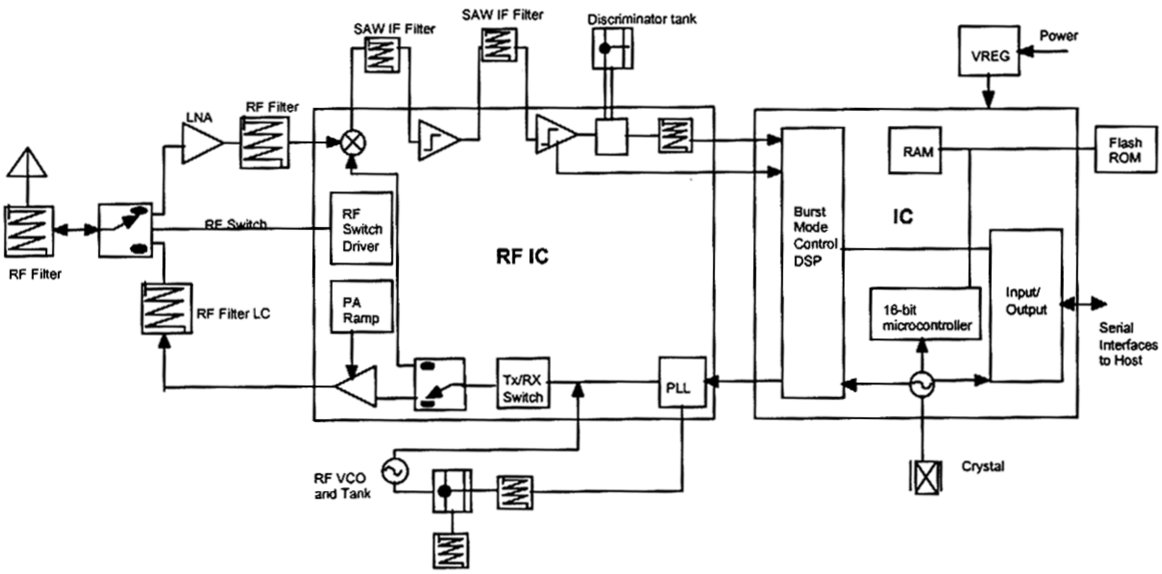


Figure 2. Advance Bluetooth Architecture

Antenna Design for Bluetooth Technology.

An important component in the bluetooth technology is the design of the antenna. Bluetooth is intended for many kinds of devices such as portable devices (PDA, cellular/PCS phones, laptops) and desk top devices (PC, printers, ..etc) which means that antennas must come in different shapes and sizes to accommodate the type of technology. For example, in a cellular phone the bluetooth antenna must be small (smaller than the whip antenna used in most cellular phones) and inserted within the electronics of the phone in order to minimize the complexity of dealing with dual antennas and dual electronics for the phone. In larger devices, such as in a PC, a bluetooth antenna can be easily inserted externally at many possible locations.

Another important characteristic on bluetooth antennas is that an effort must be made to provide an omnidirectional azimuth pattern, since a communication link must often been establish among devices that are not on a direct line of sight (e.g one device can be in the kitchen and the other can be in the living room of a home). In residential homes, doppler and delay spread of the signals are minimal and can be considered as a slowly varying Rician flat-fading channel where all effective multipaths arrive within the information signal [3].

In this paper we address an embedded bluetooth antenna for small portable devices. We have extended the design to include not only an antenna for bluetooth electronics but also for a PCS (1.85 –1.99 GHz) mobile device electronics. The design in shown in Figure 3. The antennas are microstrip dipoles embedded in a dielectric substrate. The dipoles are $\lambda/4$ antennas. The dielectric is of low loss with ε_r =2.42 and a very low loss-tangent. The embedded antennas within the dielectric frame form a "chip" that can be "plugged-in" into a metal ground plane as shown in the figure. The ground plane should also be around $\lambda/4$ as a minimum. If it is too large, the radiation pattern becomes somewhat multi-lobe, but that is not necessarily a bad thing for an omnidirectional antenna. If the ground plane is much smaller than $\lambda/4$, then the tuning becomes more difficult and the overall performance of the antenna decreases. For example, that is indeed the case with pager antennas. Pager antennas are very much inefficient since the size of pagers are significantly smaller than their operational wavelength. Pager companies make up for this inefficiency by increasing the base station power.

It was decided to make the ground plane somewhat higher than the $\lambda/4$. The bluetooth electronics with its own antenna and ground plane can then be "fitted" within another wireless device such as a PCS device as illustrated in Figure 3. The ground plane of the PCS wireless device (not necessarily a phone) can either be separate or connected to the bluetooth ground plane. In some cases it may be OK to use one large ground plane for both the PCS and bluetooth electronics and antennas.

The analysis and design for both, the PCS and Bluetooth antennas was done using the method of moments in the code NEC. The microstrip design of the dipoles was converted into equivalent round wires with the same surface areas using well known analytical expressions. The modeling rules of NEC for properly using the method of moments in wire antenna design were faithfully abided by.

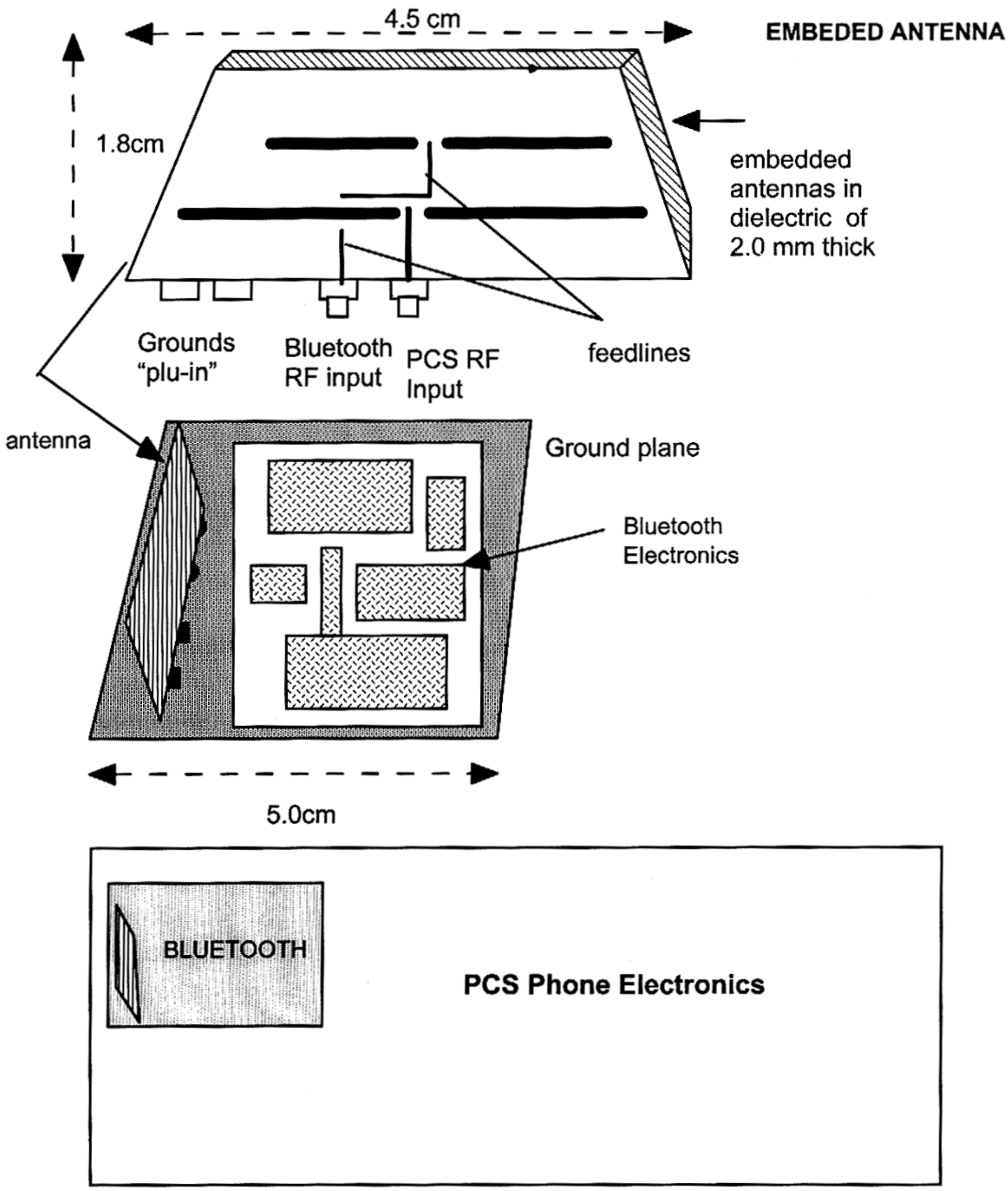


Figure 3. Design of bluetooth and PCS embedded antennas for personal wireless devices

The dielectric material was not ignored, even though it was a low-loss dielectric. The dielectric material was accounted for by putting a "sleeve" of the dielectric around the round wire. The thickness of the sleeve of dielectric was obtained by known equivalence transformations of a dielectric slab into a cylinder. The ground plane was also modeled in NEC using perfectly conducting patch surfaces.

The calculation of the electric fields were performed in an azimuth manner and normalized at 1 meter so as to calculate the antenna patterns. The results of these calculations are shown in Figure 4. Figure 4 also shows some measured results using an antenna chamber.

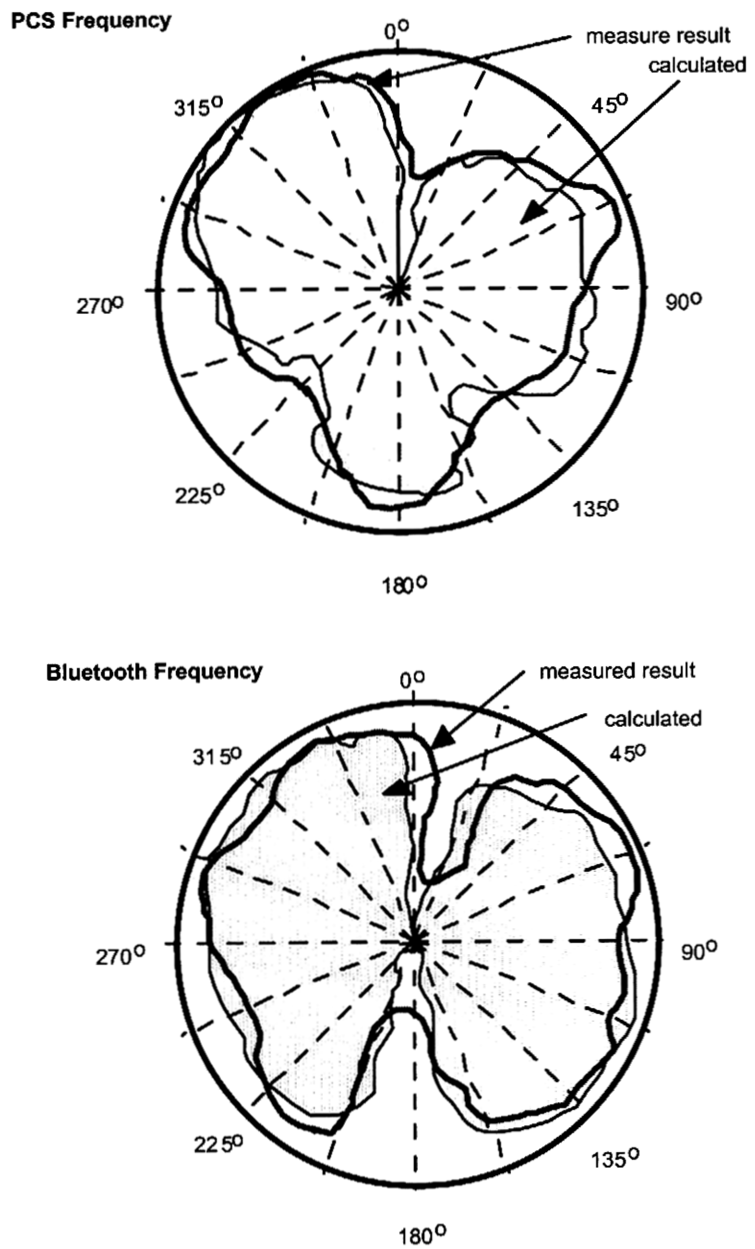
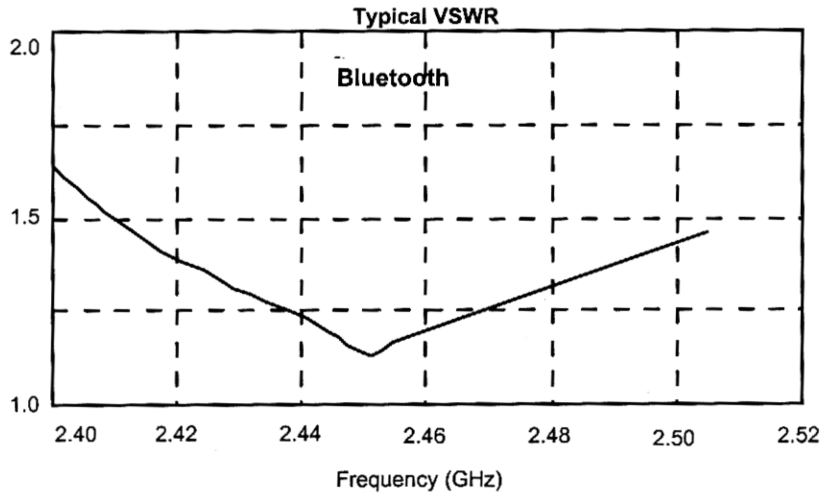
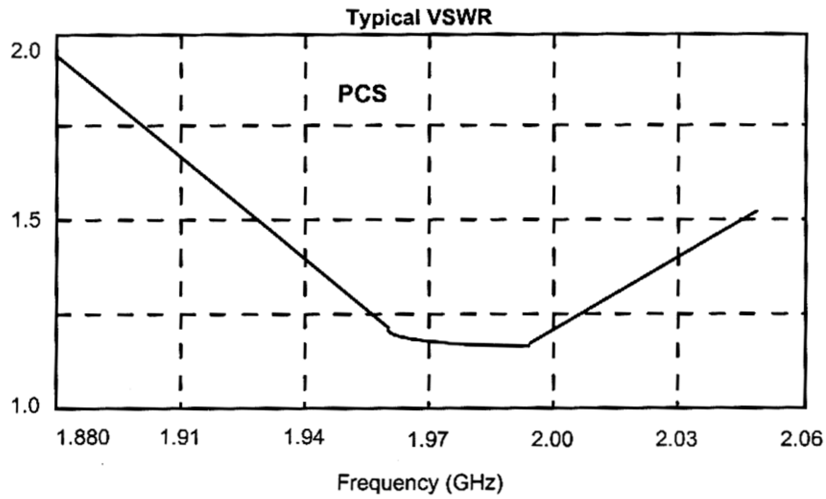


Figure 4. Antenna pattern for PCS and bluetooth antennas, both measured and calculated

Some measured VSWR is shown in Figure 5.





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[3] W.Roberts Nichols II, Moeness G. Amin,"Modeling systems based on bluetooth wireless connectivity," Microwaves and RF, August 2000.