Bluetooth™ Antenna Design and Testing

1. INTRODUCTION

This white paper discusses guidelines for Bluetooth antenna design and testing. The areas of interest are antennae built into Bluetooth modules, PC accessories such as PCMCIA cards, USB dongle attachments, and Bluetooth units built into laptop PCs. Each configuration has different requirements and critical parameters that will be discussed in this paper.

2. ANTENNA DESIGN

2.1. General Design Considerations

The antenna should be placed high and away from metal or conductive objects. In addition, its position against the ground plane is important depending on how the antenna is fed from the RF circuits.

2.2. Range

The free-space path loss is expressed as follows, where *S* is the distance between the transmit and receive antennas, and λ is wavelength:

$$PathLoss = \left(\frac{4\pi S}{\lambda} \right)^2$$

The following table shows the loss at 2.5 GHz at various distances:

Distance (m)	Path Loss (dB)
1	40
10	60
100	80

Table 1: Distance and Path Loss

2.3. Noise Considerations

PCs are normally a source of various digital noises. Since processor speeds now exceed 300 MHz, even low-order harmonics could fall into the Bluetooth frequency band. In addition, address and data busses carry random high-speed digital signals, which generate many frequencies in the form of harmonics and subharmonics. This is a serious issue since radiation specification limits in FCC Part 15 for non-intentional radiators (such as PCs) are much greater than the minimum signal levels which degrade sensitivity and other performance aspects of the Bluetooth receiver. Care must be taken for both antenna location and EMI shielding of the PC to minimize unwanted noise.

2.4. Module Configurations

The Bluetooth module may or may not include an antenna. For certain applications, it is preferred to have the antenna physically separated from the module. In this case, a mechanism such as an RF connector needs to be provided to attach the antenna cables. Only when the module is placed in the final product can an integrated antenna be considered to ensure proper function. Such antennas include the following:

2.4.1. Chip Antenna

The antenna element is enclosed in a surface mount package in a form similar to an inductor or spiral or meander line.

2.4.2. Patch Antenna

The antenna may also be in a surface mount package that uses a patch element enclosed with an associated ground plane underneath.

2.4.3. Stamped Metal Antenna

This could be packaged in the form of an “inverted-F” antenna, which is widely used for high-frequency pagers, or any other form of radiation element made from stamped metal sheet soldered onto the module PC board.

2.4.4. PC Board Trace Antenna

The radiation element can be formed by properly tracing the length directly on the module PC board. The ground plane and other signal traces should be eliminated from the area where the antenna is located. The antenna part of the module must be exposed to, if not protruding from, the surface of the final product.

2.5. PC Accessory and USB Dongle Configurations

The PC Card is normally inserted from the side into the keyboard base of the laptop PC. It is expected to have the antenna element located on the opposite end from the PCMCIA connector in order for it to be exposed to the outside of the laptop PC. The PC Card could be made slightly longer to have the antenna stick out from the laptop PC or it can have a retractable mechanism for the Bluetooth user to pull out the antenna. Another option may be to have an RF connector for a separate antenna unit that may be clipped on the edge of the LCD screen, or placed elsewhere away from the laptop. This is especially necessary when the PC Card slot is located on the front of the laptop because this area is likely to be covered by the user’s hands, which could act as an RF shield.

The USB port is located either on the side or on the back of the keyboard base of the laptop PC. The USB dongle Bluetooth unit could be a single-piece design with an integrated USB connector or a unit with a short USB cable with the connector. In either case, the antenna element can be integrated into the unit. Because the LCD screen could act as a reflector, which causes a strong directivity to the radiation pattern, the antenna should be located as far as possible from the PC to avoid performance degradation.

2.6. Laptop PC Antenna Configurations

There are several locations for the Bluetooth antenna on a laptop PC. The best location is either on the top edge of the LCD screen or the back surface of the LCD screen. Another excellent location is the side edge of the keyboard base. Many laptop PCs have PCMCIA slots on the side edge and this is a likely antenna location for PC cards with an integrated antenna.

2.7. Antenna on Top Edge of LCD Screen

The top edge of the LCD screen presents a challenge where space and form factor are very limited. Today's thin laptop designs require that the width of the antenna element be very small. Therefore, a separate antenna with a coaxial cable would be the best choice due to the limitation in space along the edge of the LCD panel. A small patch antenna or a PC board antenna would fit best in such a location. A coaxial cable can be soldered directly to the antenna element and routed to the main board location where the Bluetooth module is located (see Figure 1). The center of the screen edge is a preferred location since the antenna radiation pattern is less likely to be skewed by the LCD screen.

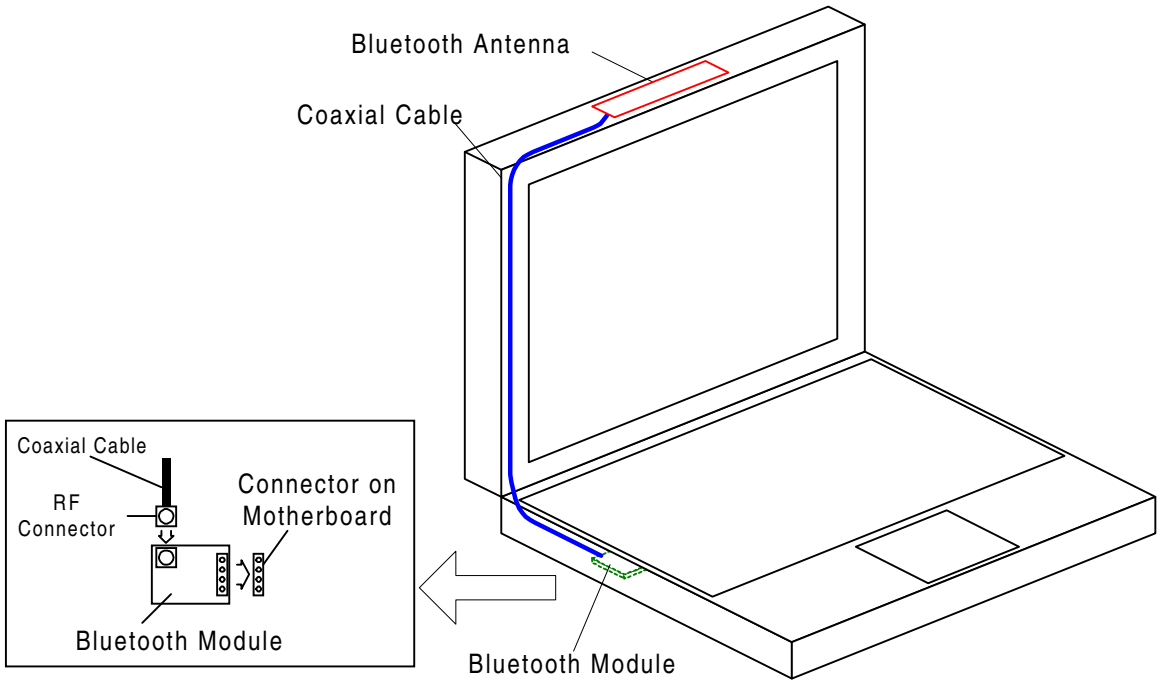

Figure 1: Bluetooth Antenna Option for Laptop PC

2.8. Antenna on Back Surface of LCD Screen

The back surface of the LCD screen may provide more space with respect to width and length. In this case, either a separate antenna or an entire Bluetooth module may be placed. The serial data could be either a UART or USB interface, both of which are normally supported by the PC motherboard. It may be convenient to provide a small compartment with an appropriate connector on the back of the LCD screen for add-on Bluetooth module. The entire back surface of the LCD screen should be metalized and used as an RF ground plane. A good RF ground connection should be provided between the Bluetooth module and the ground plane. The module antenna or antenna matching circuit may have to be tuned since the impedance will change due to the ground plane. One drawback of this antenna location is that it will create an antenna radiation pattern skewed in the direction to the back of the laptop PC.

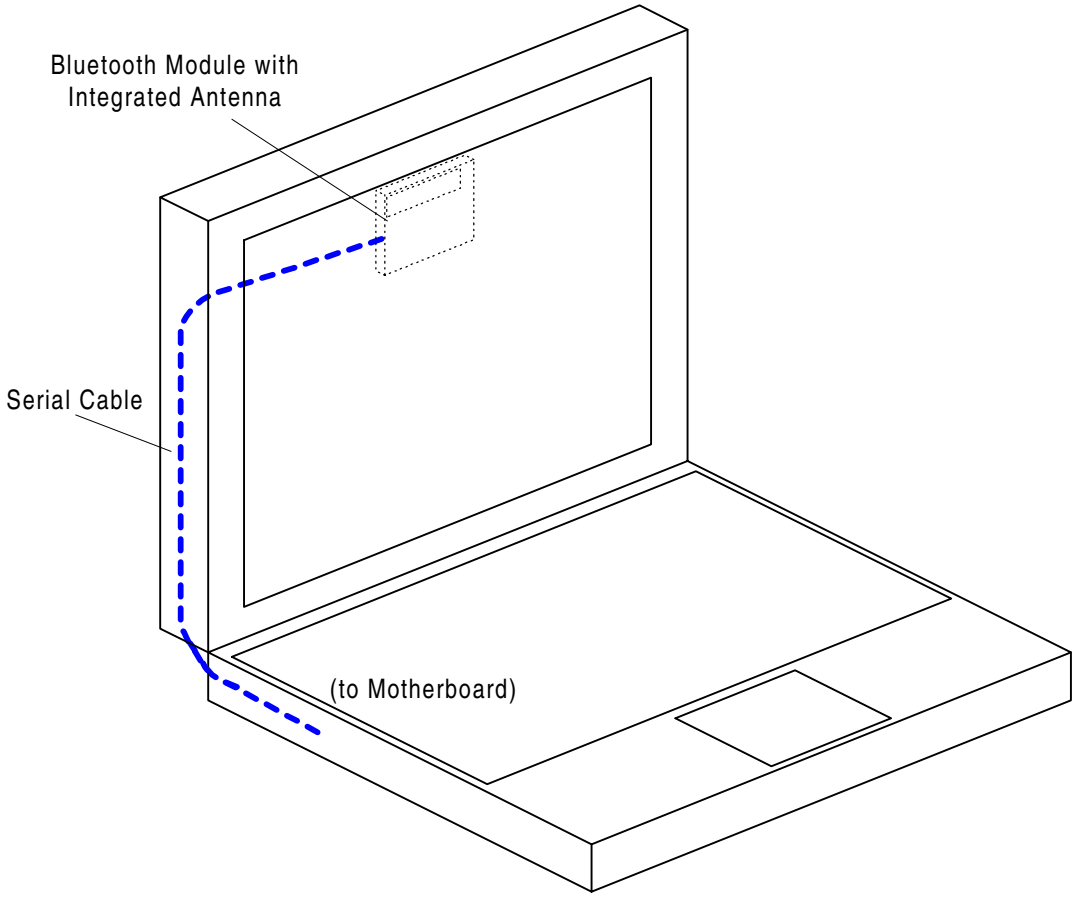

Figure 2: Bluetooth Antenna Option for Laptop PC

2.9. Antenna on Side Edge of Keyboard Base

This is a less desirable location for the antenna since its radiation pattern will be greatly affected by the LCD screen. In addition, since it is near human hands on the keyboard, they could degrade the performance of the antenna. Other objects such as AC adapter cables could run near the antenna, which could degrade the performance as well. A solution to this would be to place either a separate or an integrated antenna in this location (see Figure 3). The motherboard could be designed to have the Bluetooth module located near the edge of the board and the antenna portion of the module facing or extending through the edge of the keyboard base. Some mechanism to allow the antenna to be pulled out of the laptop PC may be advantageous in order to reduce the effect from the LCD screen or human hands (e.g. a retractable antenna).

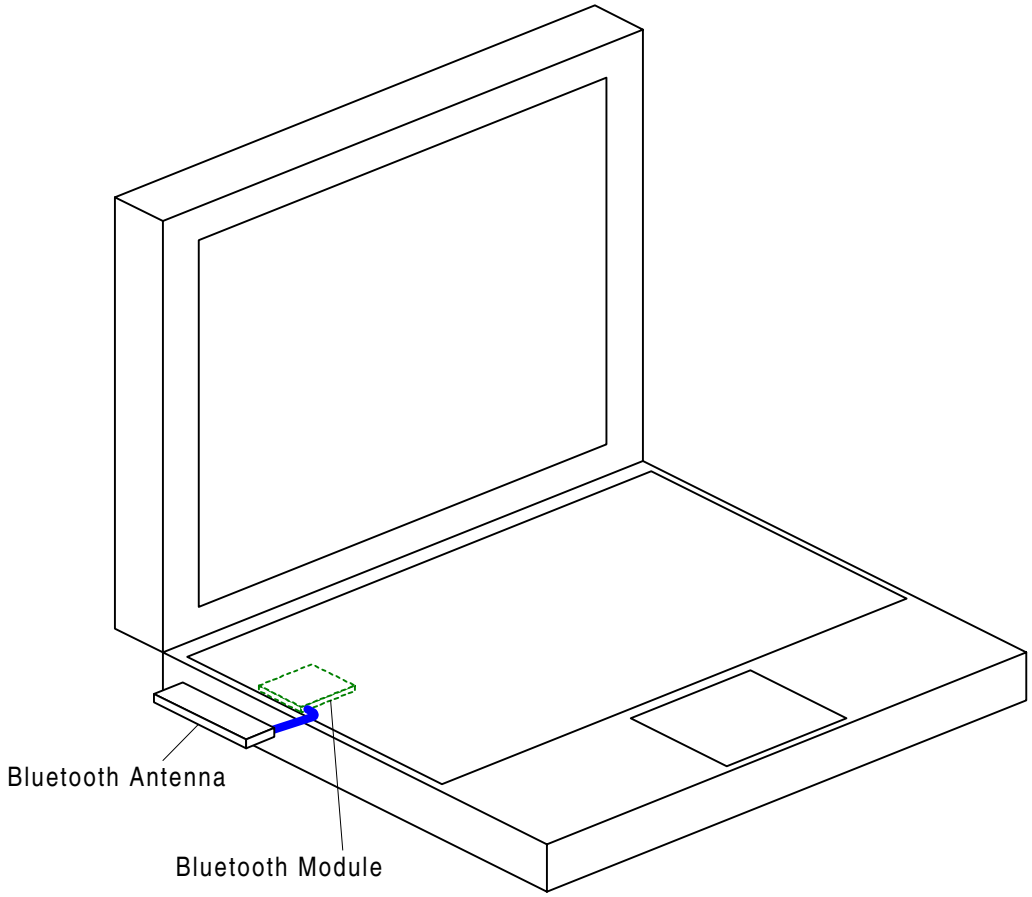

Figure 3: Bluetooth Antenna Option for Laptop PC

3. ANTENNA TESTING

Antenna testing normally consists of two phases: impedance matching and radiation pattern measurement.

3.1. Impedance Matching

Impedance matching is performed to ensure that RF energy is efficiently transferred to and from the antenna to the RF front-end circuit of the Bluetooth unit. The test configuration is shown in Figure 6.

Table 2 shows a list of recommended equipment. The antenna should be designed to achieve a voltage standing wave ratio (VSWR) of 2:1 or better over the Bluetooth frequency band.

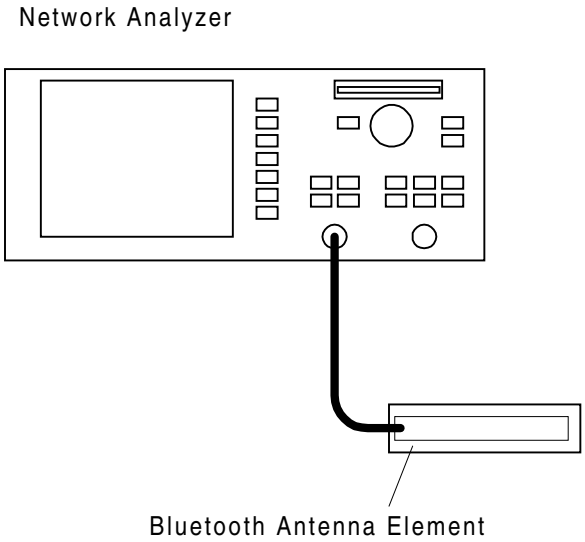

Figure 6: Antenna Impedance Matching Test Set Up

Equipment Name	Recommended Model No.	Manufacturer Name	Approximate Price
Network Analyzer	Agilent 8714ET	Agilent	$18,250

Table 2: List of Equipment for Impedance Matching Test

3.2. Antenna Radiation Pattern Measurement

The radiation pattern measurement is ideally performed inside the anechoic chamber. A free space such as a dedicated outside antenna range or even a large room can be used for slightly less accurate measurements. The measurement requires a turntable from which the turn angles can be read. The unit, which contains the antenna under test, could transmit an RF signal by itself, or the signal can be fed from an external signal source (i.e. RF signal generator) through a connected RF cable. Care must be taken to the feed cable because it also radiates an RF signal. This includes placing ferrite beads on the feed cable, and positioning the cable at the proper angle.

The measurement also requires a reference antenna to receive the radiated signal, and a signal strength meter to measure the received signal strength. A spectrum analyzer is usually used for this purpose. The measurement system has to be calibrated for cable losses and other factors that affect the measurement results. A typical measurement set up is illustrated in Figure 7.

Table 3 shows a list of recommended equipment for radiation pattern measurement.

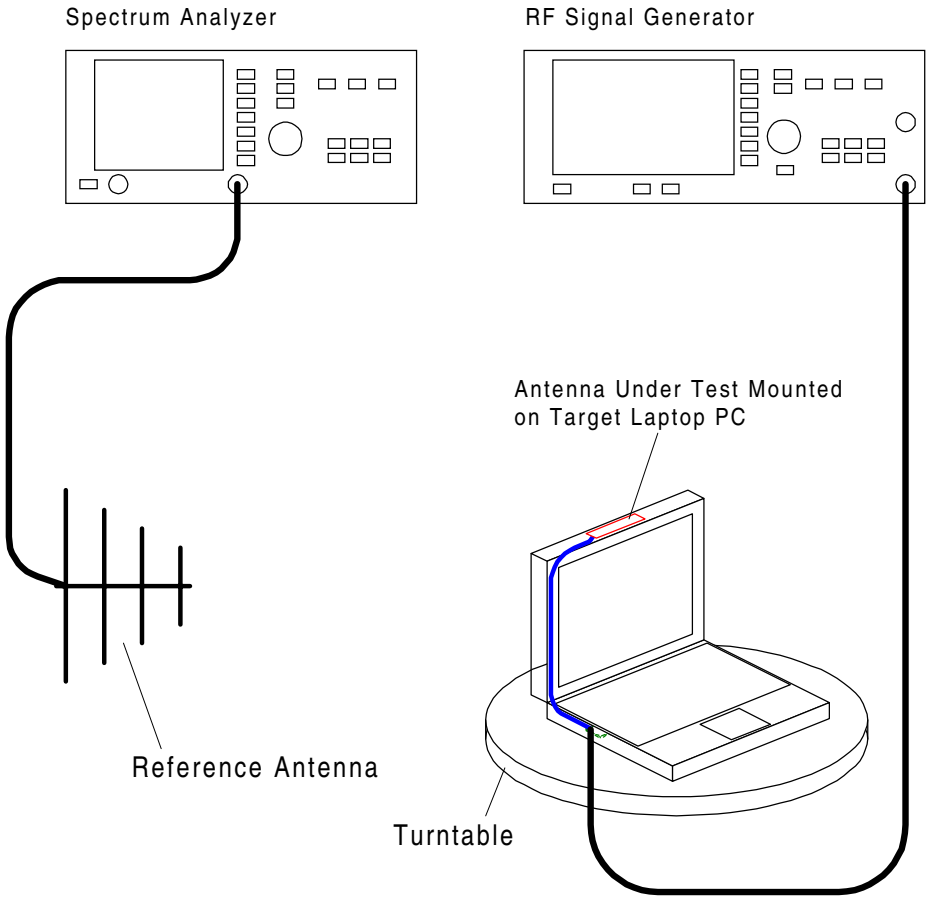

Figure 7: Antenna Radiation Pattern Measurement Set Up

Equipment Name	**Recommended Model No.**	**Manufacturer Name**	**Approximate Price**
RF Signal Generator	Agilent E4421B, Agilent 8648C	Agilent	$10,100/$8,960
Spectrum Analyzer	Agilent 8594E	Agilent	$14,535
Reference Antenna	Agilent 11966N	Agilent	$4,190
Turn Table			
Anechoic Chamber			

Table 3: List of Recommended Equipment for Radiation Pattern Measurement

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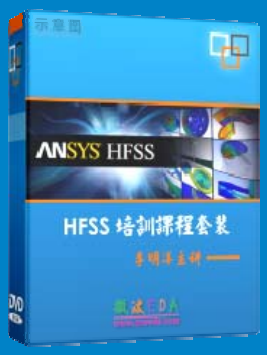

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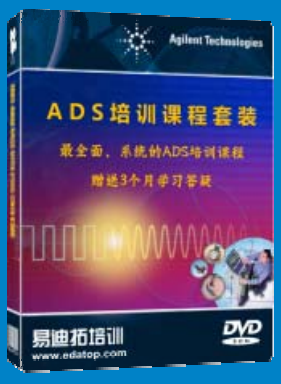

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