A Small Printed Antenna for Bluetooth Wireless Communication

Liu Hui[1], **Bingjie Wang**[1], **Cheng Liu**[1], **Zhibin He**[1], **and Sailing He**[1,2]

[1]Centre for Optical and Electromagnetic Research, Academy of Advanced Optoelectronics
South China Normal University, Guangzhou, China
[2]Department of Electromagnetic Engineering, Royal Institute of Technology, Stockholm S-100 44, Sweden

Abstract— A small printed inverted-F antenna, operating at 2.44 GHz, for Bluetooth system is designed in this paper. The RF system diagram and PCB layout are drawn by Cadence Allegro. The small printed antenna, integrated in the PCB, is modeled by HFSS and both the simulation and experimental results verify of its suitability for the Bluetooth wireless communication.

1. INTRODUCTION

With the develop of semiconductor technology and wireless networking, many short range wireless communication technologies appeared one after another, of particular interest is Bluetooth wireless communication. A Bluetooth antenna is an importance component of the Bluetooth communication system as the device of transmitting and receiving electromagnetic waves. Research on small antennas becomes a hot topic nowadays, and printed antennas have a compact design suitable for portable equipment owing to its small size, light weight and low profile. It can be anticipated that more and more new small printed antennas for Bluetooth wireless communication will be applied widely in the near future.

2. HARDWARE CIRCUIT DESIGN FOR BLUETOOTH SYSTEM

The main chip which users select should be a cost-effective, low-power, true system-on-chip (SoC) for Bluetooth low energy power applications such as CC2540 of Texas instrument. Figure 1 shows the block diagram of the system hardware. Both the electronic schematic circuit diagram and PCB are designed by Cadence products. The electronic schematic circuit diagram is design by Allegro Design Entry CIS and the print circuit board is designed by Allegro PCB Design Entry. The print circuit board layout should be a manual work rather than an auto routing in order to improve the electromagnetic compatibility.

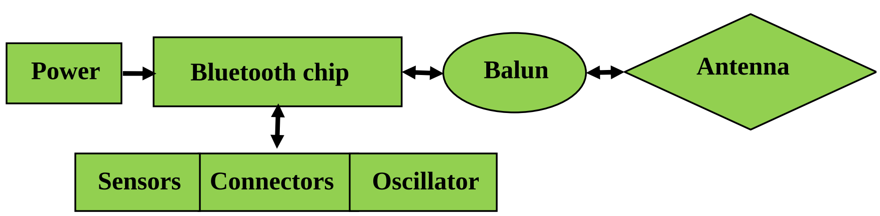
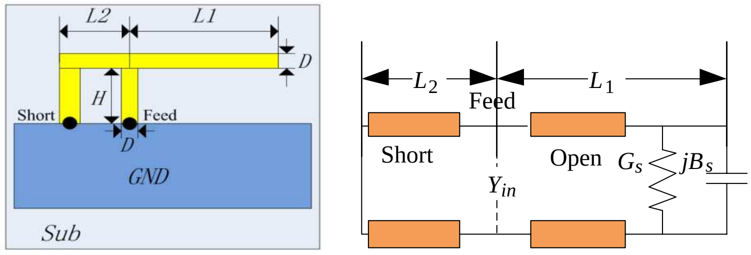


Figure 1: The block diagram of the system hardware.

3. ANALYSIS OF ANTENNA

3.1. Antenna Selection

Through analyzing the advantages and disadvantages of many antennas, in this paper we choose an inverted F antenna (IFA), this structure have the advantages of low cost, high performance, compact and simple feeding network [1, 2, 3, 9, 10]. Figure 2 shows the configuration of the invert F antenna which is designed by Allegro PCB Design Entry. It contains one radiation arm, one flat arm and one short-circuit line. The short-circuit line can make the RF model less sensitive to the ground plane and thus it ensures the reliability of the System on chip (SoC). According to the data and materials available today, the invert F antenna is good at reducing antenna size and improving its frequency characteristics. By correctly sizing the antenna size, the resonance frequency of the antenna can be reduced and so the dimension of this antenna can be reduced significantly.



(a) (b)

Figure 2: The representative model of the IFA and the equivalent circuit.

3.2. The Transmission Line Theory of Representative Printed IFA

As shown in Figure 2(a), the print IFA is different from a conventional monopole antenna with a short-circuit line, so the transmission line theory of the original model must be modified [4–8]. The IFA is similar to a shorted transmission line, which can be modeled by the equivalent circuit shown by Figure 2(b). L_2 is the length for the short circuit line of IFA and L_1 is the length for the radiation arm. According to this model, a formula for evaluating the equivalent admittance of the equivalent circuit is presented below (Y_1 and Y_2 are equivalent admittance of L_2 and L_1, respectively; Y_{in} is the equivalent shunt admittance of L_2 and L_1)

$$Y_1 = Y_0 \frac{Y_s + jY_0 \tan \beta L_1}{Y_0 + jY_s \tan \beta L_1}, \quad Y_2 = -jY_0 \cos \beta L_2, \quad Y_{in} = Y_1 + Y_2 \tag{1}$$

where $Y_0 = \frac{1}{z_0}$, $Y_s = G_s + jB_s$ are the characteristic admittance of the micro strip line and the radiation admittance, β is propagation constant, Z_0 is the characteristic impedance of transmission line, which can be expressed as

$$Z_0 = \frac{\xi_0}{\pi} \ln \left[\frac{H}{D} + \sqrt{\frac{H^2}{D^2} - 1} \right] \Delta 120 \ln \left[\frac{2H}{D} \right] \tag{2}$$

In this equation, $\xi_0 = 120\pi$ is air wave impedance.

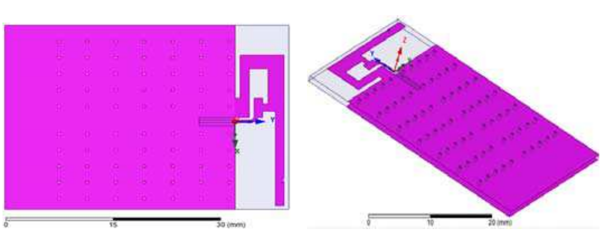
4. DESIGN OF PRINTED IFA AND BOTH RESULTS OF SIMULATE TO TEST

4.1. HFSS Model of Printed IFA

Figure 3 shows the HFSS model of the printed IFA after optimization [9, 10]. Figure 3(a) is the top view of the HFSS model, and Figure 3(b) is a perspective view of the HFSS model (the length and width of the PCB are 35 mm and 40 mm, respectively). In our model the top and bottom part of the ground plan material is copper. In this design, the board is made of FR-4 material with a relative dielectric constant of 4.4, and thickness $h = 0.8$ mm. The top ground plan of the IFA is connected to the bottom ground plane through conducting via. The printed antenna is designed by Cadence with the those dimensions.

4.2. The Optimized Parameters

Based on the structure of antenna dimentions shown in Figure 4, the optimal parameters of the model were simulated and produced by HFSS. The geometry and dimensions of the printed IFA



(a) (b)

Figure 3: The HFSS model of the printed IFA.

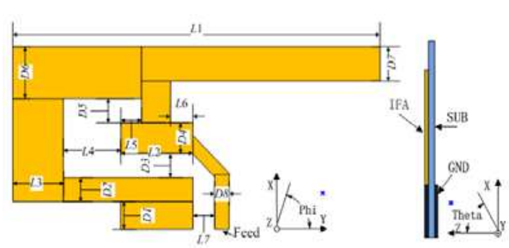


Figure 4: Dimensions of the print IFA.

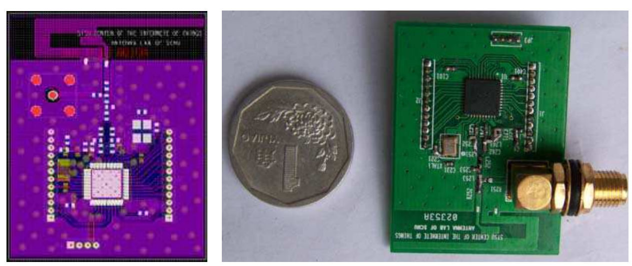
are shown in Figure 4 and Table 1 (unit mm). L_8-L_9 and D_8-D_9 are reserved parameters. GND_X is width of the PCB and GND_Y is length of the PCB.

Table 1: (mm).

L_1	L_2	L_3	L_4	L_5	L_6	L_7
26.2	3.2	2.2	4.8	1	1	0.5
L_8	L_9	D_1	D_2	D_3	D_4	D_5
x	x	0.75	1.3	0.65	1.21	0.8
D_6	D_7	D_8	D_9	D_{10}	GND_X	GND_Y
2.2	1.2	0.5	x	x	35	40

Before the design of the Bluetooth system by Cadence, several steps should be done in order to get the PCB (printed curcuit board) layout.

Firstly, the schematic circuit diagram of the Bluetooth system is designed by Allegro Design Entry CIS based on the block diagram of system hardware. Secondly, import the netlist to Allegro PCB Design Entry and Design PCB. Lastly, generate Gerber files. The PCB layout design by Cadence is shown in Figure 5(a) and the photo of this Bluetooth system.



(a) (b)

Figure 5: The PCB layout and photo of the Bluetooth system.

The measured and simulated results are shown in Figure 6. The Smith Chart, shown in Figure 6(a), marked by three points from the bandwidth of 2400 MHz to 2484 MHz. Point 1 (2400 MHz) is the lowest frequency, point 2 (2441 MHz) and point 3 (2484 MHz) are the middle and highest frequencies. Those markers are the operating frequencies of Bluetooth main chip and all near the match point of 50 ohm. Both of 3D far field and 2D far field radiations (2441.8 MHz) are shown in Figure 6(b) and Figure 6(c). The antenna gain is 2.59 dBi, the main lobe magnitude is 2.5 dBi at -166 deg in XY-plan (Theta $= 90°$) and 2.4 dBi at 120 deg in XZ-plan (Phi $= 0°$). The radiation parameters are shown in Table 2. The simulated and measured S_{11} (dB) are shown in Figure 6(d). In this figure, the redline is the simulated result from 0 GHz to 4.0 GHz, the blueline is the measured result from 1 GHz to 3.5 GHz. The measured bandwith of S_{11} (dB) below -10 dB is wider than the simulated one, i.e., the measured results have a better performance than the simulated results. Thus, the measured bandwih of the samll invert-F antenna is well matched for the bandwith of Bluetooth main chip (2.44 GHz). The measured S_{11} (dB) shown in Figure 6(d) (marked with blue colour) shifts a bit when the required ICs are mounted on the PCB shown in the photos of Figures 5(b) and (c). We found the return loss and radiation effects by mounting ICs onto the PCB and the error in profile machining are difficult to improve.

Table 2: Far field radiation patterns.

Plan	Frequency	Gain	Main Lobe Direction
XY-plan (Theta $= 90°$)	2.44 GHz	2.45 dBi	-166 deg
XZ-plan (Phi $= 0°$)	2.44 GHz	2.3 dBi	120 deg

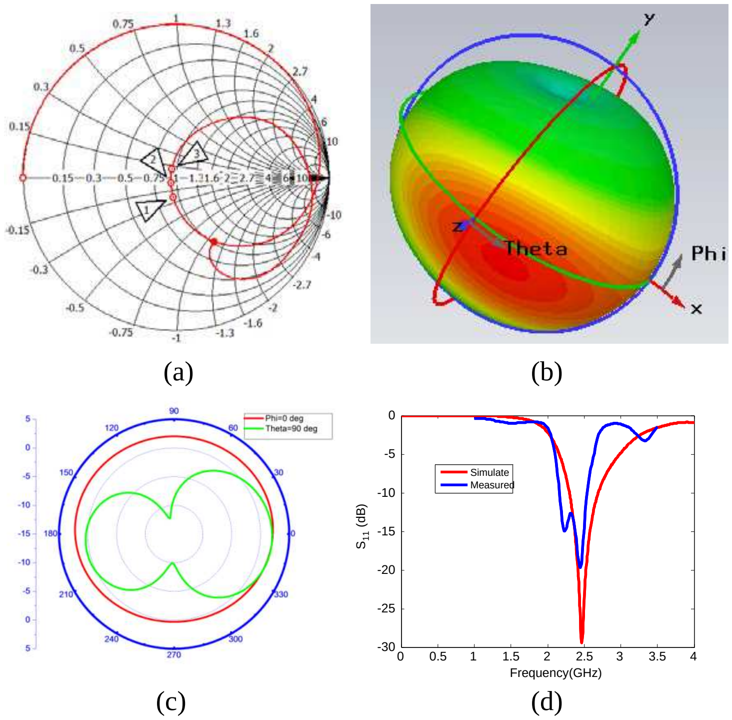


Figure 6: Results. (a) S-parameter Smith chart. (b) 3D far field at 2441 MHz. (c) Far field at 2441 MHz (dBi). (d) S_{11} (dB).

5. CONCLUSION

The small printed inverted-F antenna (IFA) for Bluetooth wireless system with the bandwidth between 2400 MHz and 2484 MHz, has been studied in this paper. The small printed inverted-F antenna is more convenient to integrate because of the compact size and low profile. The small antenna can be used in other 2.4 GHz ISM (Industry, Science and Medical) frequency band short range wireless communication system such as ZigBee. It is very convenient and quick to design this kind of antenna. Furthermore, this kind of antenna is also suitable for mass production with low cost.

ACKNOWLEDGMENT

This work was partially supported by Guangdong Innovative Research Team Program (201001D010-4799318) and the National High Technology Research and Development Program (863 Program) of China (No. 2012AA030402).

REFERENCES

1. Gao, H. and J. Liu, "Design and improvement of printed IFA for Bluetooth system," *International Conference of Soft Computing and Pattern Recognition, (SoCPaR), Pro.*, 212–216, Oct. 2011.
2. Kan, Y.-C. and C.-K. Chen, "Analysis of the inverted-F antennas integrated on the displacement detector for wireless sensor network applications," *Microwave Conference, (AMPC), Pro.*, 1849–1851, Dec. 2009.
3. Liu, T., H. Fan, and L. Shen, "Analysis and design of printed IFA for WHAN," *Journal of Southeast University*, Vol. 36, No. 2, 184–187, Mar. 2006.
4. Zhu, Q., K. Fu, and Y. Li, "The analysis of planar inverted-F antennas with equivalent models," *Journal of University of Science and Technology of China*, Vol. 35, No. 2, 144–147, Apr. 2005.
5. Gallo, M., O. Losito, V. Dimiccoli, D. Barletta, and M. Bozzetti, "Design of an inverted F antenna by using a transmission line model," *Proceedings of the 5th European Conference on Antennas and Propagation, (EUCAP), Proc.*, 635–637, Apr. 2011.
6. Jung, J., H. Lee, and Y. Lim, "Modified meander line monopole antenna for broadband operation," *Electronics Letters*, Vol. 43, No. 22, 508–510, 2007.

7. Misman, D., I. A. Salamat, M. F. Abdul, et al., "The effect of conductor line to meander line antenna design," *Antennas and Propagation Conference, (LAPC), Proc.*, 17–18, Mar. 2008.
8. Khaleghi, A., "Dual band meander line antenna for wireless LAN communication," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 3, 1004–1009, 2007.
9. TI. Antenna Selection Guide [EB/OL], Feb. 12, 2013, [2013-02-12], http://www.ti.com.cn.
10. TI. 2.4 GHz Bluetooth low energy System-on-Chip [EB/OL], Nov. 20, 2012, [2013-01-01], http://www.ti.com.cn/product/cn/cc2540.