The Considerations of Antenna Design for IOT and Wearable Devices

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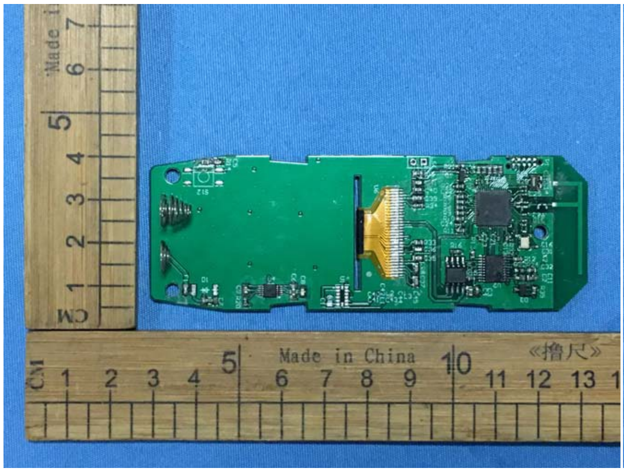
Part I: Project Background

Design the Antenna for IOT and Wearable Device could be challenge. The Industrial Design engineers usually want to define the product dimension as small as possible. However, the antennas usually need sufficient clearance from the rest of the circuit and plastic structure [1]. RF designers must make the trade-off between the Industrial Design and the Antenna requirements.

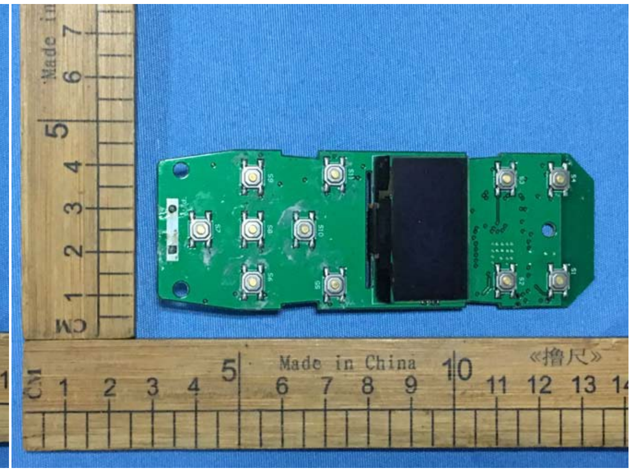
This paper is going to describe the strategies and considerations which were used to design our IEEE 802.15.4 based RF Remote Control Remoter [2].

Internal Photo 1

Internal Photo 2



Internal Photo 3



Internal Photo 4

Part II: Dielectric Constants of Materials

1. Enclosure

   Assume the antenna, balun, and matching circuit are all well designed. The RF performance meets the requirements without the plastic casing, but the performance may get worse when inserting the circuit into the plastic casing. The major reason for this situation is that the antenna does not have sufficient clearance from the plastic casing. The plastic structure near the antenna causes that the resonant frequency shifts to a lower frequency about 100Mhz to 200Mhz in general [1]. As the result, the antenna's Voltage Standing Wave Ratio (VSWR) may get worse especially when the antenna does not have enough bandwidth.

   I use two strategies to solve above problems. The first strategy is measuring the Dielectric Constants of Plastic, PCB, etc. The measured Dielectric Constants are used to model the product more accurately for the finite element method (FEM) and the method of moments (MoM) analysis. As the result, the more accurate resonant frequency can be calculated. The second strategy is designing a wideband antenna which has the bandwidth wider than 300Mhz. Wider bandwidth usually means that the antenna has more tolerance for Dielectric Constants varying, board by board and batch by batch.

2. Hands

   For handheld devices, the human hand is another factor which may affect the RF performance. As similar as the plastic casing, the human hand can also cause the resonant frequency shifts to a lower frequency, but the situation here is slightly different than the plastic. The plastic structure can be modeled accurately, but the human hands cannot. We even could not assume how the product be held by human hand. The only possible solution I have is designing a wideband antenna which has more higher frequency bandwidth. More details can be found in Part IV.

3. PCB

   Understanding the PCB's Dielectric Constant is the foundation stone for the successful high frequency design. However, the Dielectric Constant of PCB is a complex topic as you can easily find thousands research papers on this topic, but the Dielectric Constant control for the high frequency design especially the RF design is still considered as "black magic" of engineering in industry. I think this happens due to many factors affecting the PCB's Dielectric Constant.

   The factors may affect PCB's Dielectric Constant:

   a. The Dielectric Constant can be dependent on the substrate thickness, the testing frequency, the operation temperature, the type of copper used and the microwave structure.
   b. Two different microwave circuits using the exact same material will experience two different Dielectric Constant due to how the

electromagnetic fields are using the different planes of the material.

c. Dielectric Constant was determined by a very specific test method which may or may not correlate to the microwave application of interest. The Dielectric Constant which is reported for a material can be dramatically different by the test methods.
d. The permittivity behavior is mainly attributed to dipolar moments and relaxation. Different dielectric materials will have different properties related to the dipole relaxation time.
e. The low-end material such as FR-4 may have worse dielectric tolerance, moisture absorption, passive intermodulation (PIM), Dk/Df over Frequency and Temperature etc.
f. In the manufacturing process control, the most of manufacturers in mainland China still used and only used legacy TDR equipment such as Polar CITS500s Controlled Impedance Test System. They may do not have capability to use the proper test method for the microwave application of interest.
g. In the manufacturing process control, the manufacturers usually do not follow the material's datasheet. The impedance is controlled by achieving the different pressout thickness. They use copper thickness, copper area, resin, estimated dielectric constant etc. to estimate the desired thickness. The Prepreg's thickness may very under the different cure temperature and pressure. The Core's thickness will not be changed during the laminating process.

According to the manufacturers' capability, my strategy for controlling the PCB's Dielectric Constant is:

a. Specify the Part Numbers of the Core and Prepreg. Specify the PCB layer stackup and the total PCB pressout thickness.
b. Implement the PCB calibration kit with the transmission line

c. Use the proper test method to measure the Dielectric Constant of the PCB calibration kit
d. Measure the transmission line's impedance using the TDR
e. Using the Dielectric Constant measured in the step c to implement the microwave application with the same Core and Prepreg of the PCB calibration kit. The same transmission line of the PCB calibration kit also needs to be placed on the microwave application's PCB.
f. Require the manufacturer using the TDR to control the transmission line impedance as the same value which is measured in the step d.

4. Surface mount components

   Many RF designers did not notice PCB material, solder paste, soldering method and reflow soldering temperature curve may also affect the high frequency performance of the surface mount components.

   My suggestion is that measure the component's high frequency parameters in the same production condition by using the same reflow soldering profile of the mass production process.

Part III: The problems of IC suppliers' support

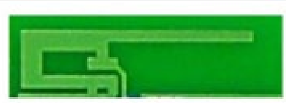
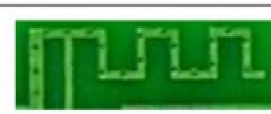
As far as I know, TEXAS INSTRUMENTS(TI) provided the best antenna design references. TI's DN007 and AN043 antennas were widely used, we even could find them with other companies SOCs, such as NXP JN5169, NXP JN5189, Silicon Labs EM35x, Nordic Semiconductor nRFx etc.

TI's DN007 and AN043 antennas were designed based on Isola DE104 low Tg laminate and prepreg. The PCB stackup:

PCB DESCRIPTION: 4 LAYER PCB 1.6 MM

Copper	1	35 um
Dielectric	1-2	0.175 mm (e.g. 1x Prepreg 7628 AT05 47% Resin)
Copper	2	18 um
Dielectric	2-3	1.14 mm (6x 7628M 43% Resin)
Copper	3	18 um
Dielectric	3-4	0.175 mm (e.g. 1x Prepreg 7628 AT05 47% Resin)
Copper	4	35 um

Above PCB stackup means we may get the similar RF performance as the reference design if and only if we use the Isola DE104 material and the same PCB stackup. In other words, we are going to get into trouble with the product which must use different PCB material and stackup. By the way, all TI's reference designs are designed without the enclosures, thus according to the section enclosure, Part II, we could not use the reference designs for the most of products without necessary modifications due to the resonant frequency shifting and the antenna's bandwidth being extremely narrow.

		
Design / Application Note	DN007 *1	AN043 *2
Frequency	2.4 GHz	2.4 GHz
Typical Efficiency	80%(EB) 94%(SA)	68%(EB)
Bandwidth@ VSWR 2:0	280 MHz	101 MHz
Dimensions (mm)	26 x 8	15 x 6

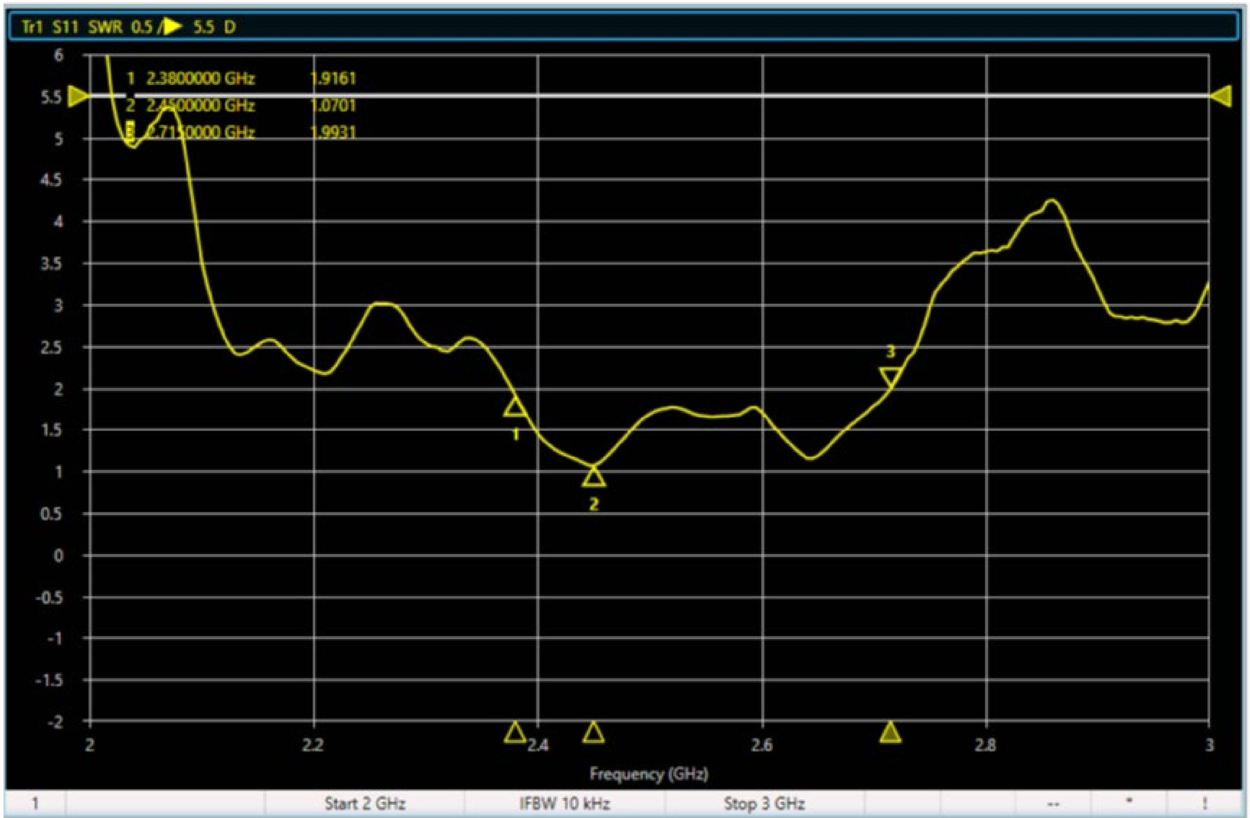
Technical Data of DN007 and AN043 Antennas

I knew some engineers tuned the antenna in the enclosure by cutting the antenna which could shift the resonant frequency toward the higher frequency. This method works for simple antenna design such as Inverted-F antenna (IFA), although cutting the antenna usually causes the bandwidth and the VSWR get worse. For the more complex design, such as patch antenna and antenna array, we almost have no chance to tune the antenna by cutting them.

Part IV: The Solution for Antenna Design

Before starting the antenna design, the dielectric constants of the materials need to be studied. The proper dielectric constant test method and the dielectric constant control method should be already kept in mind. After we totally understanding the dielectric constants, we may start to design the antenna using the measured dielectric constants. For the better performance, the design process may totally count on the finite element method (FEM) and the method of moments (MoM) analysis without the real-world tuning.

For the RF Remote Control Remoter, I designed the IFA antenna shown in the Internal Photo 3. When the antenna was installed in the enclosure, this antenna still had 330Mhz bandwidth @VSWR<=2 and the VSWR = 1.0701 @2.45Ghz. Compared to TI DN007, the bandwidth had been improved by 18%. This antenna also had more higher frequency bandwidth for against the affecting of human hand.



SWR diagram of the IFA Antenna for the RF Remote Control Remoter

Part V: Conclusion

This paper described the necessary considerations of antenna design and manufacturing for IOT and wearable device. As the real-world design example, the strategies for designing the antenna of the RF Remote Control Remoter were explained and the antenna testing results met the project requirements.

Part VI: References

[1] AN91445 Antenna Design and RF Layout Guidelines. Retrieved Nov 20, 2019, from https://www.cypress.com/file/136236/download

[2] FCC Reports of Libre Home Inc Wireless Smart Remote RMT. Retrieved Nov 20, 2019, from https://fccid.io/2AQXA-RMT

[3] 2.4-GHz Inverted F Antenna. Retrieved Nov 20, 2019, from https://www.ti.com/lit/an/swru120d/swru120d.pdf

[4] Small Size 2.4 GHz PCB antenna. Retrieved Nov 20, 2019, from http://www.ti.com/lit/an/swra117d/swra117d.pdf