A Novel Integrated GSM Balun Design and Simulation

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Abstract. Base on the LTCC technology, the high integrated circuit, the excellent performance high frequency characteristic and good reliability can be achieved. This paper depicted theoretical analysis of Balun, and simulated a integrated and small Balun by using HFSS, its center frequency is 900 MHz, band width is 120 MHz, unbalance and balance impedance are 50 Ω, the degree of phase balance is 180 ± 6°. The real Balun is manufactured by using microwave ceramics material which its dielectric constant is 8 and loss tangent is 0.0005, By comparing the results of HFSS simulation analysis with the results of experiment, it shows clearly that experimental data is consistent with simulated data. It is discussed that some should be keep watch out in the experiment and simulation, and some technique is presented to control error between experimental data with simulated data.

Keywords: Balun · LTCC · Integrated · HFSS · Simulation and analysis

1 Introduction

With the development of communication technology, the role of radio frequency (RF) device is becoming more and more important. Balun is a research hot spot as one of RF devices. Balun is a three port device, consisted of an unbalanced port and two balanced ports. The signals of the two balanced ports have the same amplitude, but there is a phase shift of 180°. Many circuits need to balance input and output, which is used to reduce the noise and the high harmonics of the circuit, and to improve the dynamic range of the circuit. Balun is widely used in balanced mixer, push-pull amplifier and antenna circuit [1–4].

There is a variety of the form of Balun, generally can be divided into active and passive Balun. Due to the active use of the transistor or other active devices, so it will inevitably produce noise and power consumption. The passive Balun can be divided into three categories, which are the lumped component type, the form of the spiral transformer, and the distribution parameters. The advantages of the lumped element form are small size and light-weight, but not easy to reach 180° of the phase shift and equal output amplitude; The spiral transformer type is only suitable for low frequency and ultra high frequency (UHF), and there is a certain loss; The Balun of distributed parameters is divided into the form of 180° mixed ring and Marchand Balun [5]. In the microwave

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band, the 180° mixing loop has a fairly good frequency response, but limit is a large size. It is applied to the radio frequency band from 200 MHz to a few GHz. Due to a better output amplitude and 180° of phase shift, and the bandwidth is wider, so Marchand Balun is used by many designers [6, 7]. However, the Marchand Balun is composed of 1/4 wavelength coupled line, which will occupy a large area, especially in the lower frequency band [8]. In this paper, we design an integrated, compact, light-weight, high reliability, multi-functional and low cost Marchand Balun with the method of multi-layer structure to reduce the bulk.

2 Balun Theory

Figure 1 is a schematic diagram of the Marchand Balun, the electrical length of each transmission line is $\lambda/4$, the signal is inputted/outputted from the unbalanced port and outputted/inputted from the balanced port, the two balanced port phase difference is 180°. The characteristic impedance of the four stage microstrip line and the coupling degree of the coupling section are designed suitably, then, the function of the Balun conversion and impedance transformation can be realized at the same time. Figure 2 depicted schematic diagrams of broadside coupled line Balun section, the coupling section A and B in cross section is completely symmetrical structure, ε_r is the dielectric constant of the dielectric.

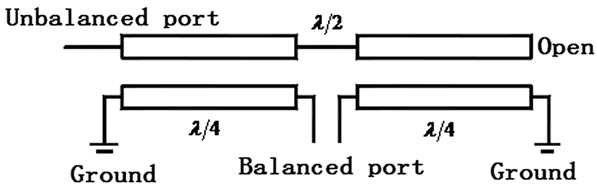

Fig. 1. Marchand microstrip Balun with edge coupling structure

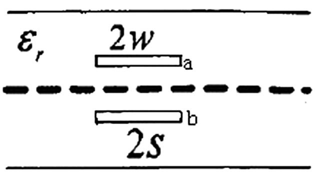

Fig. 2. Marchand microstrip Balun section with edge coupling structure

Marchand Balun equivalent circuit diagram is depicted in Fig. 3. Respectively, k_a, Z_{ac}, k_b, Z_{bc} were the coupling coefficient and characteristic impedance of broadside coupled belt line a and b segment. Z is the output impedance, R is the load. It can be further simplified equivalent circuit, as shown in Fig. 4, supposed $k = k_a = k_b$, Eqs. (1)–(5) can be derived:

$$Z_1' = Z_{ac}\sqrt{1-k^2} \tag{1}$$

$$Z_2' = Z_{bc}\sqrt{1-k^2} \tag{2}$$

$$Z_3' = (Z_{ac}+Z_{bc})\frac{k^2}{\sqrt{1-k^2}} \tag{3}$$

$$Z_4' = Zk^2 \tag{4}$$

$$R_5' = Rk^2 \tag{5}$$

from (1)–(5),

$$k = \frac{Z_3'}{\sqrt{Z_1'+Z_2'+Z_3'}} \tag{6}$$

$$Z_{ac} = \frac{Z_1'}{\sqrt{1-k^{2'}}} \tag{7}$$

$$Z_{bc} = \frac{Z_2'}{\sqrt{1-k^{2'}}} \tag{8}$$

$$Z = \frac{Z_4'}{k^2} \tag{9}$$

$$R = \frac{R_5'}{k^2} \tag{10}$$

And

$$Z_{in} = \frac{Z_1'^2}{-jZ_2'\cot\theta_2' + \frac{jZ_lZ_3'\tan\theta_3'}{Z_l + jZ_3'\tan\theta_3'}} \tag{11}$$

Respectively,

$$Z_l = \frac{Z_4'^2}{R_5'} \tag{12}$$

Obviously, Z_1', Z_2', Z_3', Z_4', R_5' were chose appropriately, it can be get the ideal characteristics of broadside coupled microstrip Balun.

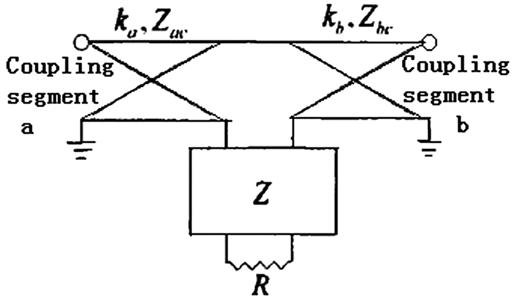

Fig. 3. Balun equivalent circuits 1

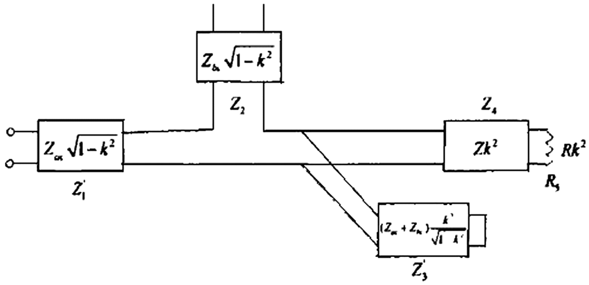

Fig. 4. Balun equivalent circuits 2

3 Analysis of HFSS Simulation

In the actual design process, the calculation process is more complex, so the electromagnetic field simulation software is used for many times to achieve the design goal. HFSS is one of the mainstream FEM 3D high frequency electromagnetic field simulation software. It adopts the advanced technology which is ALPS(Adaptive Lanczos Pade Sweep) and Mode-node conversion, and so on. The FEM method is applied to simulate the electromagnetic field for the passive 3D structure of arbitrary shape. It is applied to the adaptive mesh refinement technique.

Using the HFSS software to simulate, the 3D model structure of Balun is shown with a total of 15 layers in Fig. 5. The first and the second and the third are the ground layer, others is the signal layer.

Application of HFSS parameter optimization of scanning tools, the simulation results of the return loss and two output ports insertion loss are shown in Fig. 6, and the results of phase difference of balance ports are shown in Fig. 7. In 860–960 MHz range, the return loss is more than 13.7 dB, and two port insertion loss is less than 3.9 dB, amplitude imbalance is less than 0.3 dB, the phase difference of balance port is ±4°.

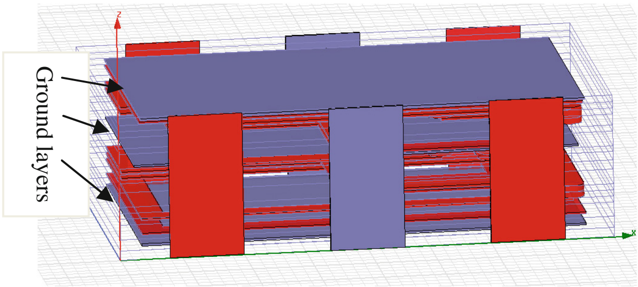

Fig. 5. Balun structure with 15 layers

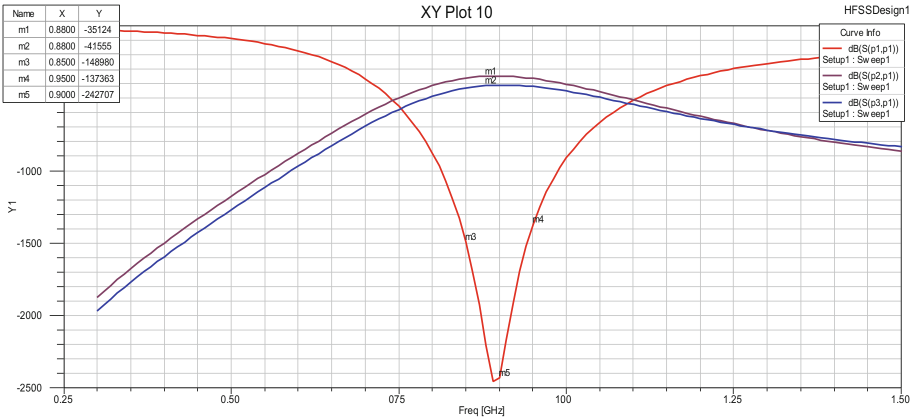

Fig. 6. Return loss and insertion loss of HFSS simulation

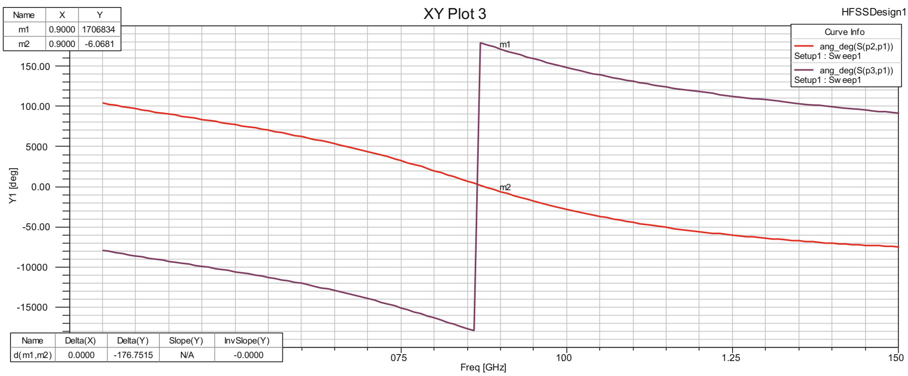

Fig. 7. Phase difference of HFSS simulation

4 Production of Balun Base on LTCC

4.1 Introduction of LTCC Technology

Low temperature co-fired ceramic (LTCC) technology is currently more popular three-dimensional microwave integrated circuit packaging technology [9, 10]. Due to the high number of wiring layers, wiring conductor square resistance, low dielectric constant, low sintering temperature, low thermal expansion coefficient, LTCC substrate has become an ideal multi-chip-components(MCM) substrate [11–13]. At the same time, the resistance, capacitance and inductance can be buried because of the special characteristics of LTCC. LTCC also has excellent high frequency characteristics. The MCM can reduce the size and weight because of use of LTCC substrate, but in many computer systems, high speed imaging systems (or components), the size and weight of the system (or components) is still required to occupy a large number of size and weight with multiple 2D-MCM. If the multiple 2D-MCM vertical stack up to form 3D-MCM and replace 2D-MCM, it can make the assembly area to decreased significantly, the system will greatly reduce the size, further reduce weight. At the same time, due to the shortening of the mutual connection, the parasitic effect is reduced, and the signal transmission is faster, the noise and the loss is also decreased. Additionally, LTCC technology has more advantages than the traditional PCB technology.

LTCC technology applied in low frequency circuit and the digital circuit has decades of history, but in the field of RF and microwave applications abroad from the early 1990s, it is began to research and is widely used in the active phased array radar and communication fields, such as standard mobile phone, Bluetooth module, GPS, PDA, digital camera, WLAN, automotive electronics, drives and other. Among them, the amount of mobile phone is the main part about more than 80 %. Followed by Bluetooth module and WLAN. Due to the high reliability of LTCC products, the application in the automotive electronics is also increasing.

4.2 Production of Balun

Magnetic particle ingredients which dielectric constant is 8 and loss tangent is 0.0005 is selected to casting, screen printing and other processes, the final, actual products was fabricated by sinter and plate electrode, as shown in Fig. 8, size is $2 \times 1.25 \times 0.9$ mm, and is applicable to mobile phones and other devices of high integrated degree and miniaturization.

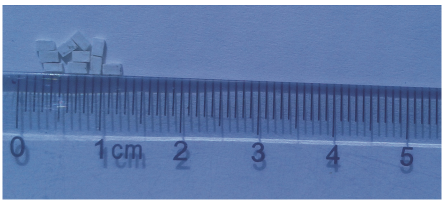

Fig. 8. Balun of implement

5 Results and Discussion

The actual products is tested by using Agilent e5071c network analyzer, and the test results and simulation results are compared and shown in Figs. 9 and 10, solid line is simulation results, and point line is test results, it can be seen that simulation results is consistent with test results from the below picture. In the 820–940 MHz range, the test results show the return loss is more than 12 dB and two port insertion loss are less than 4.1 dB, amplitude imbalance is less than 0.5 dB, and phase unbalance degree is ±6°.

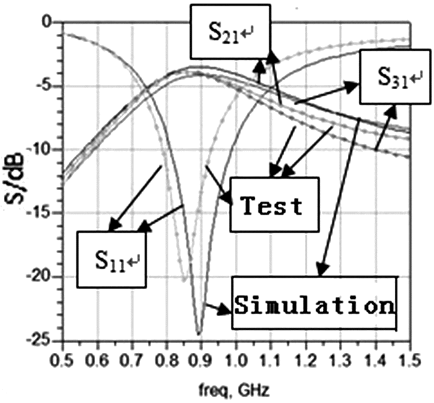

Fig. 9. S parameter comparison of simulation and measurement

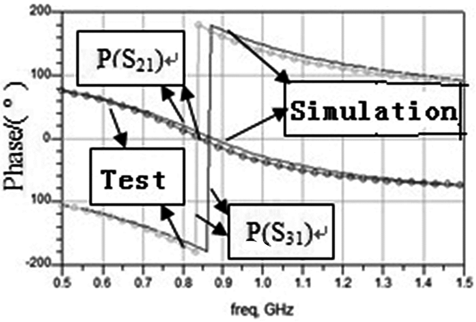

Fig. 10. Phase comparison of simulation and measurement

Obviously, this simulation and design are feasible. The difference between the simulation results and the actual product testing results mainly is the following several reasons: First, LTCC tape casting process of diaphragm have a little thickness error; Second, calibration also exist certain error before the test. Cast film thickness should be measured repeatedly in a real production, and as far as possible to control the film thickness in the admissible error of simulation.

6 Conclusion

This paper designs a kind of Balun with multi-layer structure, its principle is discussed. The results of simulation by using HFSS are compared with tests. The EM simulation and experimental results show a good agreement. The new Balun is small size, light-weight, good balance, low insertion loss, low cost, etc., and can be applied to China Mobile and China Telecom 900 MHz GSM band up-link communication and other systems.

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