A new method of quick synthesis of 3dB coupler

Yusheng Zhang[1, a], Yalin Guan[2,b]

[1]Department of Information Engineering, Communication University of China, Beijing

[2]Department of Information Engineering, Communication University of China, Beijing

[a]zhangys10@126.com, [b]ylguan@cuc.edu.cn

Keywords: even-odd-mode theory, coupled strip transmission line, 3dB coupler

Abstract. An analysis of UHF 3dB coupler which is based on the even-odd-mode theory is presented, in which we present a brief description of the even-odd-mode theory and its application in coupled strip transmission line. In particular, as the rapid development of the stimulation technology, we introduce a simple stimulation method based on these theories to design a 3dB coupler in the assistance of simulation softwares, like Advanced Design System and HFSS.

Introduction

In recent years, with the rapid development in the field of Radio and Television and wireless communication, the application scope of couplers have been greatly expanded. 3dB couplers are common components in microwave circuits, which are widely used in Radio and Television industry, like the Power Divider, the Multiplexer and the balanced amplifier. In recent years, as Communication technology has made great developments, there is a huge demand for multiplexers which consist of 3dB couplers. Because, with the development of Radio and Television technology, local radio and television station have an increasingly demand to expand business by adding FM channel or TV channel. Thus, a technical problem comes out: the reserved space on the original tower is too small, which cannot bear an additional channel antenna.

Under the situation, the multiplexer technology has been introduced and developed rapidly, and it has not only solved the above problems, but also greatly reduced the investment in the build of antenna tower and in the reform of television station. Therefore, the multiplexer technology has great economic benefits.

The theory of multiplexers

The introduction of multiplexer technology has brought great benefits, but it also makes the technical requirements of each component more and more rigid, for a good bridge multiplexer need rather low insertion loss and rather high isolation degree among input ports, and these indexes are virtually related to the performance of couplers and filters.

Fig. 1 is a schematic diagram of a bridge duplexer who is composed of two band-pass filters and two 3dB couplers (coupler Ⅰ and coupler Ⅱ). Port 1, 2, 3, 4 present for the different ports of each coupler. Port 1 present for the input port, 2 for the straight port, and 3,4 for the coupling port and isolating port respectively. BP1 and BP2 are two band-pass filters working at frequency f_1, who can pass through the signal of frequency f_1, and prevent the signal of any other frequency. Tx1 and Tx2 present for two input signals of different frequencies. Port 4 of coupler Ⅱ present for the output port of the duplexer. The function of the duplexer is to combine two signals Tx1 and Tx2 together to form one signal, and keep high isolation between them. Thus, we can use one antenna to deliver two signals, which has greatly saved the construction cost of the television station.

In practical situations, the performance of the bridge duplexer depends on the quality of the indexes of couplers. In the process of the coupler design, an important part is using an appropriate structure to approach the even-odd-mode impedance, and we may use theoretical calculation and other general simulation methods. But in computer age, we need to seek a more efficient and precise method to achieve the high goals.

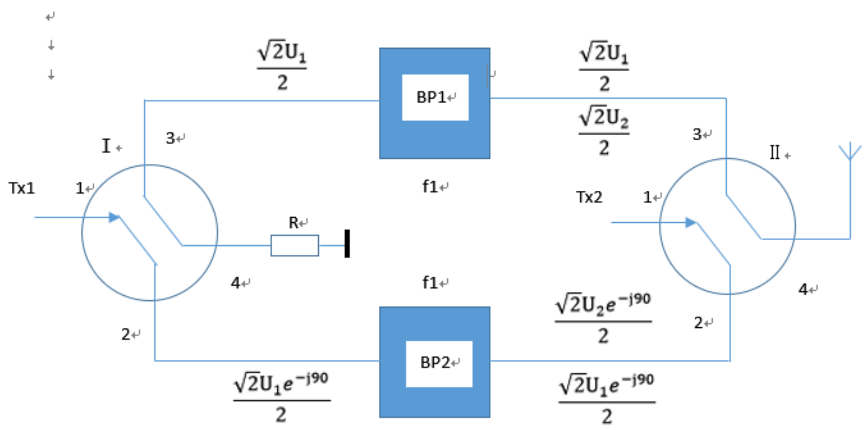


Fig.1. schematic diagram of the multiplexer

The even-odd-mode theory

Of course, couplers vary in structures. Parallel-coupled strip transmission line coupler has its own advantages in many working conditions, like High-power and strict isolation degree requirements, which is largely used in Radio and Television industry.

The parallel-coupled strip lines has been researched by a number of investigators for many years, which has been used to construct filters, directional couplers and many other microwave components [1] [2]. Papers of the pioneers have presented many deduction and analysis methods of the coupled transmission lines, and approximate formulas of the coupled transmission line models have been listed in their achievements, which can be used to calculate the coarse dimensions of the coupler[3]. But as the rapid development of computer science and stimulation technology, in this paper, we present a simple method for couplers' quick design in the assistance of stimulation software.

The even-odd-mode theory is the main theory in the analysis of symmetry networks. But the prerequisite of utilizing even-odd-mode theory is that the superposition theorem must be applicable, which need the network to be linear and loss-free. Fig. 2 shows a parallel strip lines system, which is a kind of four-port network meeting all the requirements above.

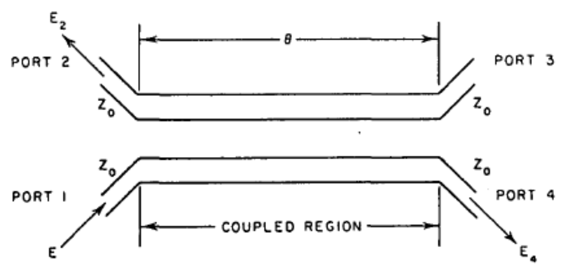
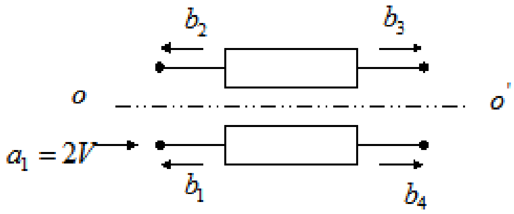


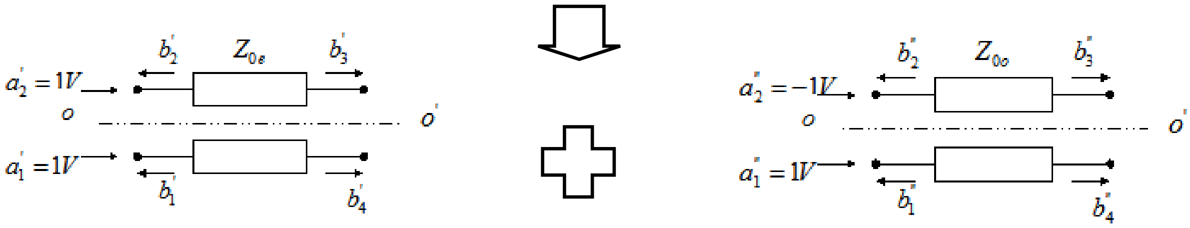
Fig. 2. Parallel coupled strip lines

Then we use the superposition theorem to analyze the strip lines system. Fig. 3 shows that to a linear and loss-free system, its original excitation can be transformed to the superposition of two kind of mode excitation- the even mode and the odd mode. In Fig.3, the parameter 'a' represent to the forward-traveling wave while the 'b' to reflected wave. Here we assume that the impedance of each port is well matched to the outer transmission line, so there is no reflected wave in each port. In even mode, there are two driving sources whose amplitude and phase are both the same, but in odd mode, the phases of the two driving sources are contrast.

The coupled parallel strip lines are in symmetrical placement, so under the two modes, the two kind of electric field distribution are different but both symmetrical, as is shown in Fig. 4 [3]. Under the even mode, there seems like a Magnetic wall in the right middle of the structure, while under the odd mode there seems to be an Electric wall. This is an important character which informs us that we can take the symmetrical structure apart just by placing a Magnetic wall or an Electric wall in the

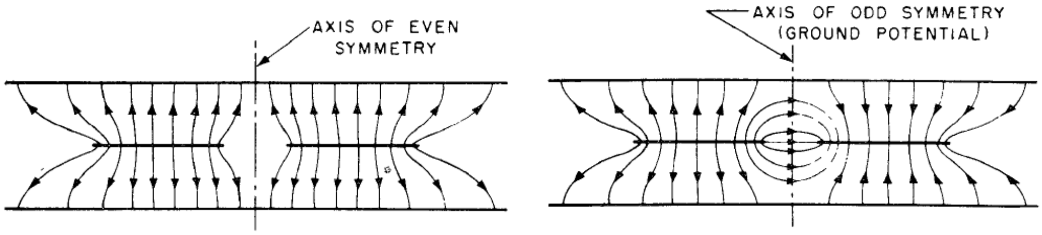


(a) The original excitation



(b) Even-mode excitation (c) Odd- mode excitation

Fig. 3. The superposition theorem



(a) Even-mode electric filed distribution (b) Odd-mode electric filed distribution

Fig. 4. Electric filed distribution of each mode

middle of the model. Then under each mode, the stimulation model can be separated from the axis of symmetry, and we can analyze just half of the model under each mode to get two very important parameters-Ze(the even-mode impedance) and Zo(the odd-mode impedance). Refer to previous papers, we can get the relation between the mode impedance and the coupling coefficient[5]. The relation is shown in formula (1). The formula (2) shows the relation between the coupling degree and the coupling coefficient.

$$k_0 = \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \tag{1}$$

$$C_0 = 20\lg k_0 = 20\lg \frac{Z_{0e} - Z_{0o}}{Z_{0e} + Z_{0o}} \tag{2}$$

And as is shown in formula (3), there is an inherent relation between the characteristic impedance and the mode impedance.

$$Z_0^2 = Z_{0e} Z_{0o} \tag{3}$$

The stimulation process

We can use the theories mentioned above to design a 3dB parallel-coupled strip lines coupler, and we require that the reflexivity and the isolation degree under -30dB, the coupling degree -3.01dB±0.3dB, characteristic impedance of each port 50Ω, and the power capacity 1kW.

The approximate formulas of calculating the coarse dimensions of the coupled -parallel strips can be found in many papers [3] [4], and the formulas are rather accurate under major common conditions. Moreover, the software we are ready to use below have taken full advantages of the formulas mentioned above. So we rather want to introduce the application of the software than to go deep into the theory.

As is shown in Fig. 5, the LineCalc tool of Advanced Designer System can be used to calculate the accurate dimensions of the parallel-coupled strip lines. The component type -SBCLIN represent for the broadside coupling structure. E_r is the relative dielectric constant. Mur is the magnetic conductivity. B is the distance of the two planes (act as ground). Among the physical parameters, W is the width of the strip line, S is the spacing between the two parallel strips, and L is the length of the strip line which relates to the center frequency of the components. Among the Electrical parameters, ZE represent for even-mode impedance of the parallel-coupled strips, while the ZO for odd-mode impedance. Z_0 is the characteristic impedance of the system. C_DB is the coupling requiring degree whose unit is dB. This tool can help calculate the initial dimensions by synthesizing.

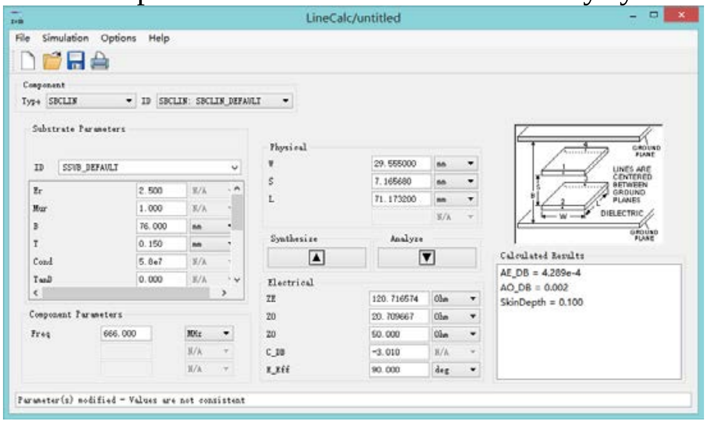


Fig. 5. The interface of the LineCalc tool

Then we can use the coarse data from the ADS to build HFSS models, which are shown in Fig. 6 (a) is the even-mode model and (b) is odd-mode model. The shadow face in Fig. 6(a) is set as a perfect Magnetic wall and that in Fig. 6(b) is a perfect Electric wall. These models are built to calculate the accurate mode impedance in realistic structure. The main mechanical parameters are strip width, strip thickness and strips spacing, so we can optimize the results by adjusting these parameters until the mode impedance closing to the theoretical value.

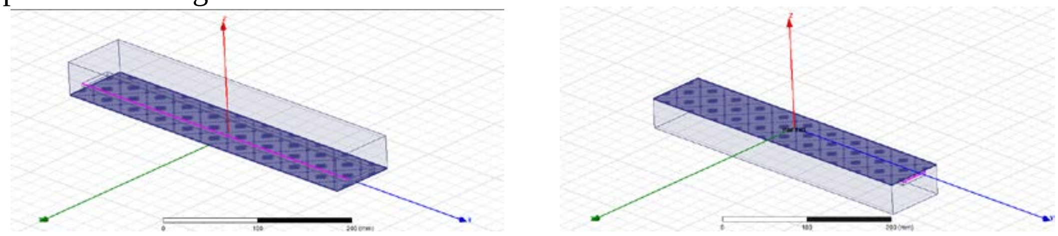

(a) even-mode HFSS model (b) odd-mode HFSS model

Fig. 6. HFSS model of each mode

Results

When we get the exact dimensions of the structure, we can use them to build the integrated coupler model. Fig. 7 shows the structure of the required 3dB coupler. It consists of a pair of parallel-coupled strips calculated above, a cavity acting as the ground-plane, and four ports for input and output signals. The cavity dimension is determined by the power capacity, which in this paper are designed to withstand 1kW. Every port's characteristic impedance is 50Ω. The uncontinuity of the connection between the strips and the ports inevitably produces reflection which deteriorates the reflexivity and the isolation degree [6] [7], so adjusting the structure of the connection to eliminate uncontinuity is another important work. The final stimulation result is shown in Fig. 8. It meets the requirement well. At this point, we have obtained a 3dB coupler with nice index.

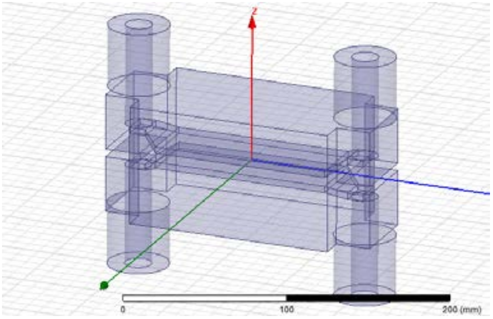


Fig. 7 The final model of the coupler

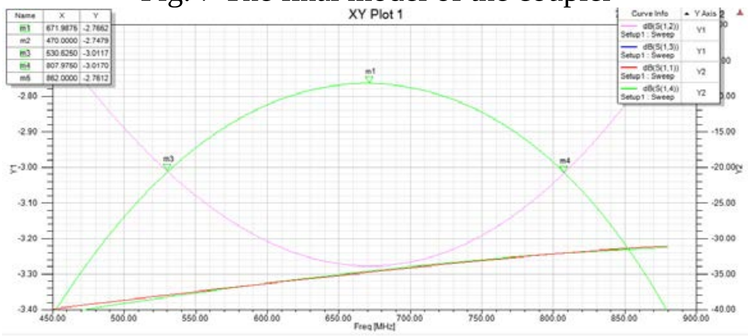


Fig. 8 The stimulation result of the coupler

Conclusions

In this paper, we have designed a 3dB coupler by a new brief method based on simulation software like ADS and HFSS. From the analysis above, we can see that the new method can help lead to greater efficiency and get a rather good result. And also the method is easy enough for a designer who do not fully understand the principle. In conclusion, the method proposed in this paper is useful in quick design of 3dB coupler.

References

[1] Seymour B. Cohn and Ralph Levy, History of Microwave Passive Components with Particular Attention to Directional Couplers [J], IEEE Transactions Microwave Theory and Techniques, 1984-9(32):1046-1049

[2] E. M. T. Jones, J. T. Bolljahn, Coupled strip-Transmission-Line Filters and Directional Couplers [J], Proc. IRE, 1956:75-76

[3] S.B. Cohn, Shielded Coupled Strip Transmission Line [J], Proc .IRE, 1955-10:29-31

[4] J. Paul shelton, JR., Impedances of offset parallel-coupled strip transmission lines [J], IEEE Transactions Microwave Theory and Techniques, 1966-1(14):8-11

[5] Leo Young, M.A., M.S., Dr.Eng., Member, The analytical equivalence of TEM-mode directional couplers and transmission-line stepped-impedance filters [J], Proceedings I.E.E., 1963-2(110):275-277

[6] Slawomir Gruszczynski, Krzysztof Wincza, Krzysztof Sachse, Design of Compensated Coupled-Stripline 3-dB Directional Couplers, Phase Shifters and Magic-T's—Part I: Single-Section Coupled-Line Circuits [J], IEEE Transactions Microwave Theory and Techniques, 2006-10(54):3986-3993

[7] Slawomir Gruszczynski, Krzysztof Wincza, Krzysztof Sachse, Design of Compensated Coupled-Stripline 3-dB Directional Couplers, Phase Shifters and Magic-T's—Part II: Broadband Coupled-Line Circuits [J], IEEE Transactions Microwave Theory and Techniques, 2006-10(54):3501-3507