A Novel 3dB Electric Bridge in Navigation Band: Design and Simulation by HFSS software

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Abstract

3dB bridges are commonly used passive components in communication systems, especially in radio frequency and microwave circuits and systems. Based on a certain engineering application background and corresponding design principles, a novel 3dB electric bridge for navigation frequency band was designed. A comprehensive physical modeling and simulation of this 3dB bridge was carried out using HFSS software. The simulation results showed that this type of 3dB bridge can achieve the equal division of the two output signals and the phase difference of 90º. At the same time, by restricting the length of the microstrip line, a fixed output position is formed in the HFSS software. The S13 and S14 of the S parameters are within -3dB~-3.1dB and the phase difference is between 85º and 95º. The dielectric plate and the microstrip line are irrational materials. Considering that the dielectric plate and microstrip line in the simulation diagram are irrational materials, the 0.1dB loss generated the error of sum ±5º belongs to a reasonable interval and meets engineering design requirements.

Keywords

3dB bridge; Navigation band; HFSS; Simulation.

1. Introduction

With the in-depth application of wireless communication systems in production and life, compared with active devices, the emergence of passive devices greatly reduces the pollution to the ecological environment, reduces the power loss ratio of devices, and has strong azimuth directivity. It has a profound impact on the gradual progress of miniaturization, integration and high packaging of microwave radio frequency devices in wireless communication systems. Among them, the 3 dB electric bridge is a commonly used passive component in the microwave radio frequency device under the wireless communication system, especially in the radio frequency, microwave circuit. Besides, the 3 dB electric bridge is alsoused in system, such as the power signal splitting and synthesis, the adder and subtractor, as well as other components to form a reflective phase shifter.

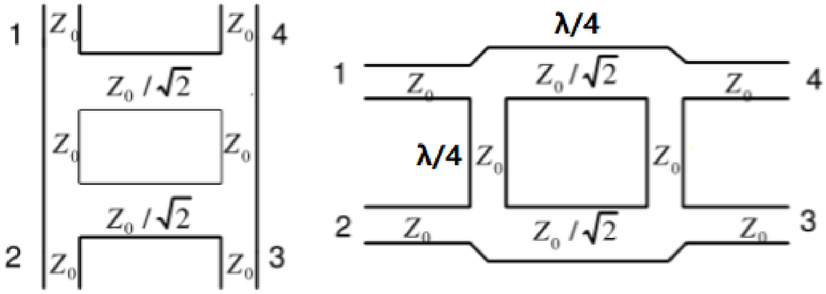
Recently, a lot of work focuses on the design of 3dB bridges. For example, Rui Zhu et al. [1] adopted a new type of special structure 3dB bridge to make the bridge performance further develop in terms of bandwidth, power and volume. Xin Zheng [2] proposed a bridge model with a cavity strip line structure, and achieved a miniaturized production mode of the device by adopting a design method of unequal height cavity. Anqing Li et al. [3] proposed a stripline cross-coupling cavity 3dB bridge with air as the medium to further improve the continuity of the bridge and modify the structural constraints of the input and output terminals. Xiao Wang et al. [4] proposed a scheme that selects the low-temperature co-fired ceramic manufacturing process and the stripline wide-side coupling type, so that the 3dB bridge can be miniaturized in the device configuration. Yadong Li et al. [5] proposed a structure setting using a square microstrip circuit in the 450MHz frequency band, which greatly reduces the space occupied by devices with linear power amplification performance in the circuit board, and effectively improves the traditional circular ring. The structure of a 3dB bridge. Chun Ni et al. [6] proposed a 3dB bridge design scheme under a special structure. Using this structure can increase the bandwidth to a new level, while making the directionality of the bridge more accurate and reducing the difficulty level of the product manufacturing process. Aiping Yong [7] proposed a square electric bridge with air plate line structure mode to achieve signal stability in the S-band range. Nowadays, 3dB electric bridges are mainly used in other microwave circuit systems such as attenuators and modulators. In addition, the application of the principles and characteristics of 3dB electric bridges in the field of satellite navigation shows a broad market prospect. Therefore, the application of 3dB electric bridge in the navigation frequency band of 1.4GHz has attracted wide attention. However, as far as we know, there are few reports on 3dB bridge research in the field of satellite navigation. Therefore, by consulting and retrieving the existing research in the database, combined with relevant data standards, this work experimented and tested the design and simulation of a 3dB electric bridge based on HFSS.

In addition, in China, the Beidou Navigation Satellite System network has been successfully established in 2020. Under the influence of this frequency, the use of this frequency band to serve China's social, economic and people's livelihood activities will have huge economic benefits and social repercussions. Therefore, this document has launched a novel 3dB electric bridge satellite navigation design.

2. Design principle and simulation model

2.1. Principle and preliminary design

The two-stage cascaded 3dB bridge in Fig. 1(a) is for widening the bandwidth. The longer the microstrip line, the greater the loss, and a compromise should be considered during design. Port 1 is the input, and port 3 and port 4 output. Ideally, port 2 has no output. In practice, a patch resistor can be added to absorb the output power. The output power of port 4 and port 3 are equal, which is half of the input power. The difference is 90°.



(A) Two-stage 3dB bridge (B) Single-stage 3dB bridge

Fig. 1 Schematic diagram of 3dB bridge

The 3dB bridge in this work only needs to cover a part of the navigation frequency band, but does not need to cover the whole frequency band. Therefore, in order to reduce the loss of the microstrip line, optimize the parameters, and improve the optimization efficiency, the design scheme uses a single-stage 3dB bridge (in Fig. 1(b)).

As shown in Fig. 2 and Fig. 3, since the 3dB bridge is a surface-symmetric four-port network, it can be reduced to a two-port network that is surface-symmetrical and loss-free and reciprocal when using the odd-even mode analysis method. A surface-symmetric two-port network to illustrate the basic principles of the odd-even mode analysis method.

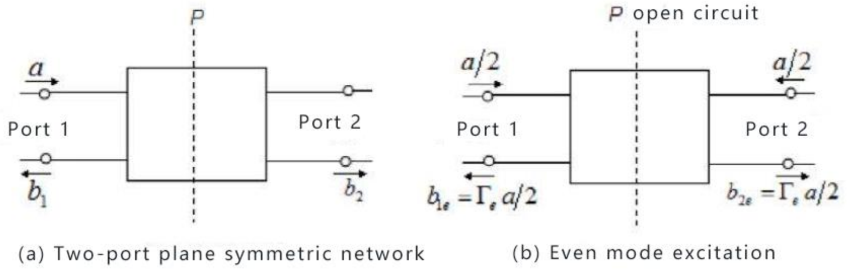


Fig. 2 Schematic diagram of a two-port network

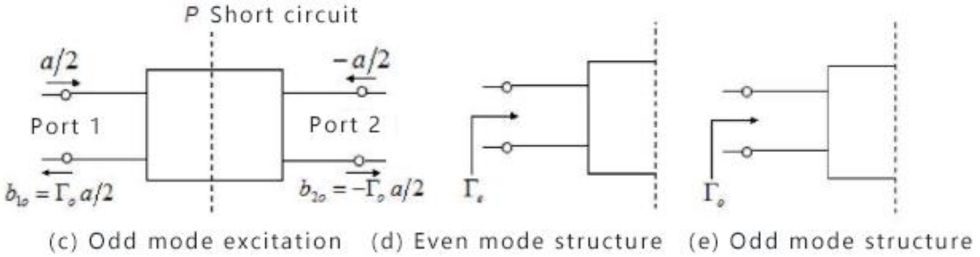


Fig. 3 Even and odd mode excitation of two-port plane symmetric network

The principles of application stacking are:

$$b_1 = b_{1c} + b_{1o} = \frac{a}{2}\ (\Gamma_c + \Gamma_o) \tag{1-1}$$

$$b_2 = b_{2c} + b_{2o} = \frac{a}{2}\ (\Gamma_c - \Gamma_o) \tag{1-2}$$

From the definition of reflection coefficient and transmission coefficient, the reflection coefficient Γ and transmission coefficient T of the original network can be obtained as:

$$\Gamma = \frac{b_1}{a} = \frac{1}{2}\ (\Gamma_c + \Gamma_o) \tag{1-3}$$

$$\Gamma = \frac{b_2}{a} = \frac{1}{2}\ (\Gamma_c - \Gamma_o) \tag{1-4}$$

According to the above analysis, the scattering parameters of a two-port symmetric network can be obtained from the symmetry and reciprocity of the network as:

$$S=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}=\begin{bmatrix} \Gamma & T \\ T & \Gamma \end{bmatrix}=\frac{1}{2}\begin{bmatrix} (\Gamma_C+\Gamma_O) & (\Gamma_C-\Gamma_O) \\ (\Gamma_C-\Gamma_O) & (\Gamma_C+\Gamma_O) \end{bmatrix}=\frac{1}{2}(S_C+S_O) \tag{1-5}$$

According to the design principle, the impedance value of each segment and the line width and line length values that need to be optimized are shown in Fig. 4.

The conventional FR4 dielectric board changes due to the dielectric constant of the dielectric polarization. Therefore, RO4003 is selected as the dielectric material. The dielectric constant of the dielectric board is 3.55 and the height is 0.72 mm. The dielectric loss of this dielectric board is small.

In order to match the commonly used radio frequency port, the impedance Z_0 is 50 ohms, and the working center frequency is 1.4GHz. Using the microstrip line calculator can calculate each microstrip according to the impedance value in the Fig. 4, the dielectric constant of the dielectric plate and the thickness of the dielectric plate. The line length and line width of the line. The length and width of each line are shown in Fig. 5.

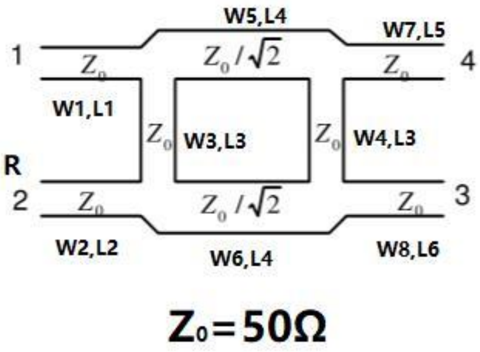
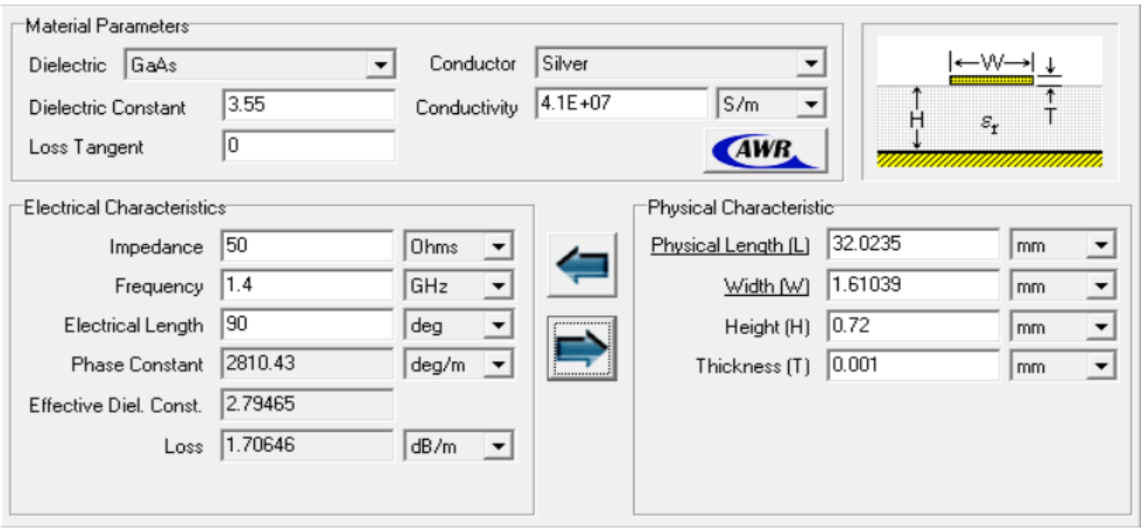


Fig. 4 The schematic diagram of the 3dB bridge designed in this article



Material Parameters
Dielectric: GaAs
Dielectric Constant: 3.55
Loss Tangent: 0
Conductor: Silver
Conductivity: 4.1E+07 S/m

Electrical Characteristics
Impedance: 50 Ohms
Frequency: 1.4 GHz
Electrical Length: 90 deg
Phase Constant: 2810.43 deg/m
Effective Diel. Const.: 2.79465
Loss: 1.70646 dB/m

Physical Characteristic
Physical Length (L): 32.0235 mm
Width (W): 1.61039 mm
Height (H): 0.72 mm
Thickness (T): 0.001 mm

Fig. 5 Microstrip line calculator design interface

The microstrip line data shown in Fig. 5 was modeled in ANSYS Electronics Desktop. In order to avoid the "capacitance effect" of the microstrip line at right angles from deteriorating the performance of the 3dB bridge, cut corners at the right angles. However, the microstrip will cause the imbalance of the equivalent magnetic current on both sides of the strip line will produce parasitic radiation. In order to reduce the impact of the 3dB bridge on the receiver or other radio frequency devices, a shielding box is made, and the 3dB electrical appliances are placed inside the shielding box. The input end is welded with an SMA head, and the shielding box is fixed with M2.5 screws, but the VSWR will appear burrs after the shielding box is added. This phenomenon maybe cause by the weak resonance between the shielding box and the metal ground of the 3dB bridge, and the corner cut also cause the frequency offset of the 3dB bridge, which can be improved by optimizing the line length and line width of the 3dB bridge. In order to achieve circular polarization, a 3dB bridge needs good isolation. Increase isolation resistance at port 2, reduce S_{43}, reduce cross polarization, and improve axial ratio. The isolation resistor adopts 0805 package, and the resistance value is selected as 100 Ω.

2.2. HFSS modeling and optimization settings

ANSYS Electronics Desktop is a radio frequency microwave circuit and system design and simulation tool software that provides strong support for circuit and system design. The design, simulation, optimization of the square bridge, and the prototype of the main microstrip structure are all completed in ANSYS Electronics Desktop software.

HFSS is the world's first commercialized three-dimensional structure electromagnetic field simulation software, which has been widely used in aviation, electronics, semiconductors, computers and other fields. With its unparalleled simulation accuracy and reliability, fast simulation speed, easy-to-use operation interface, and stable and mature adaptive meshing technology, HFSS has become the preferred tool and industry standard for high-frequency structural design.

According to the schematic diagram, modeling in HFSS is shown in Fig. 6.

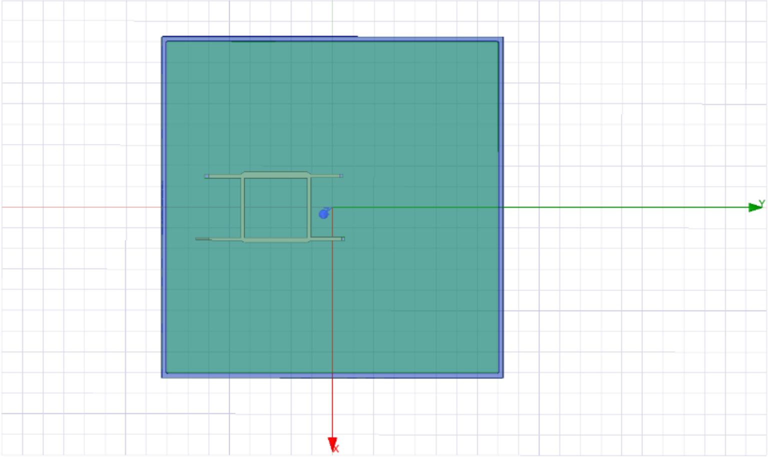


Fig. 6 HFSS model diagram

The solution targets are S_{11}, S_{14}, S_{13}, S_{34}, and the standing wave ratio VSWR. By optimizing the line length and width of each section of the microstrip line, the standing wave ratio VSWR, S_{34} and S_{11} are reduced, and the microstrip line material is set to copper. Optimizing S_{14} and S_{13} to between -3dB and -3.1dB, with a loss of about 0.1dB, can meet the needs of engineering design. It is also necessary to solve the phase values of S_{14} and S_{13}. To meet the needs of engineering design, the phase difference between S_{14} and S_{13} is between 85° and 95°.

The optimized parameters are shown in Table 1.

Table 1 Optimization parameters

Name	Initia Value	Evaluated Value
a	160mm	160mm
b	160mm	160mm
w1	1.69mm	1.92mm
l1	15mm	15.8mm
w2	1.69mm	1.25mm
l2	15mm	15.4mm
w3	1.69mm	1.64mm
l3	32.02mm	30.59mm
w4	1.69mm	1.5mm
l4	31.33mm	30.6mm
w5	-2.85mm	-2.86mm
l5	15mm	14.35mm
w6	-2.85mm	-2.38mm
l6	31.33mm	14.96mm
w7	1.69mm	1.61mm

w8	1.69mm	1.49mm
c	1.7mm	1.7mm

3. Results and Discussion

After HFSS optimization, the field distribution result of the 3dB bridge is shown in Fig. 7.

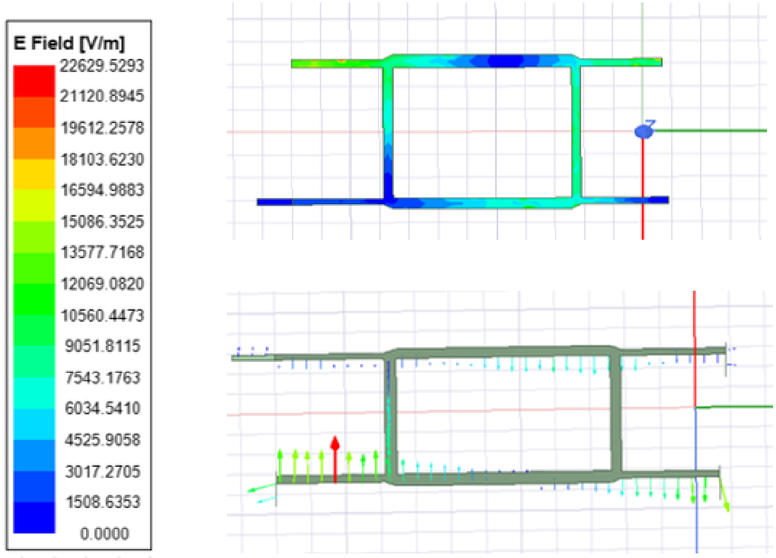


Fig. 7 The field distribution results of the 3dB bridge designed in this paper

As shown in Fig. 7, the field distribution of the 3dB bridge is basically symmetrical. And the signal is transmitted from port 1 to the two output ports, the energy intensity is basically the same, and the phase is obviously not synchronized.

Then, the result of HFSS simulation transmission coefficient is shown in Fig. 8.

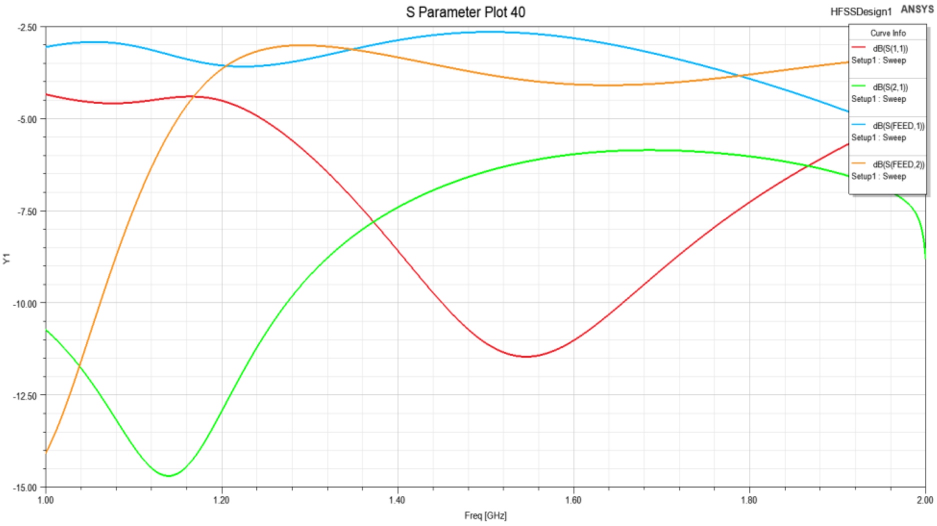


Fig. 8 HFSS simulation transmission coefficient

The Fig. 8 shows the simulation results of the 3dB bridge. Since the stripline material is not an ideal conductor, loss will be used. Its transmission coefficient is about -3.1dB, ideally -3dB, so this network has a loss of 0.1dB. In Fig. 8, the red line is the reflection coefficient of the input port.

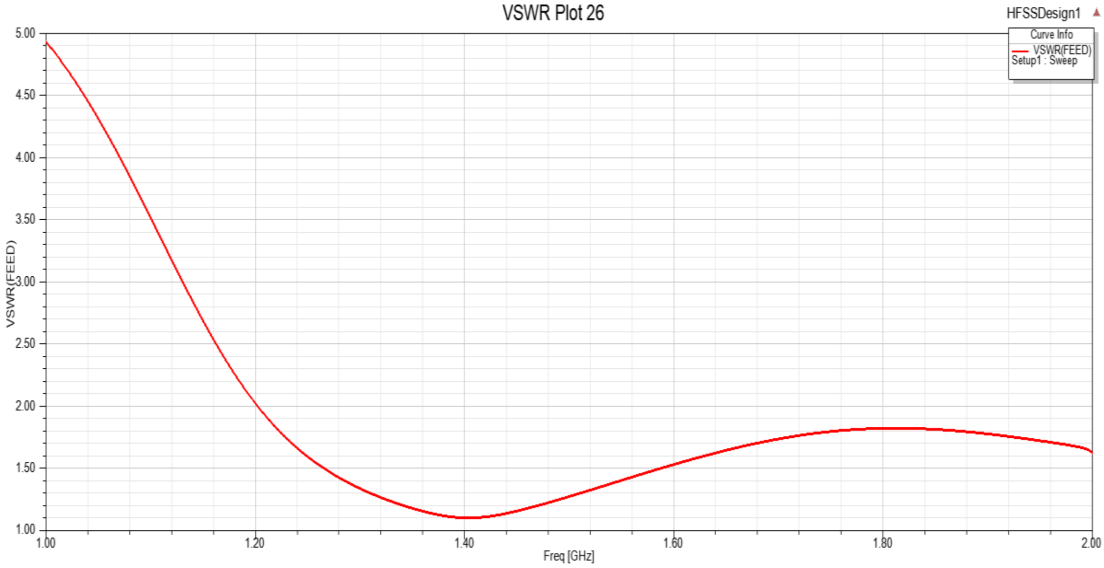


Fig. 9 The standing wave ratio of the 3dB bridge designed in this article

In Fig. 9, the standing wave ratio is less than 3 in the working frequency range, which basically meets the design requirements.

Standing wave ratio calculation formula was follow,

$$\mathrm{VSWR} = \frac{(1+\Gamma)}{(1-\Gamma)} \tag{1-6}$$

S_{11} is the input reflection coefficient, which describes the ratio of the incident voltage to the reflected voltage, but in the case of matching each port, the reflection coefficient of S_{11} is Γ, and the standing wave ratio can be solved by the reflection coefficient Γ of S_{11}.

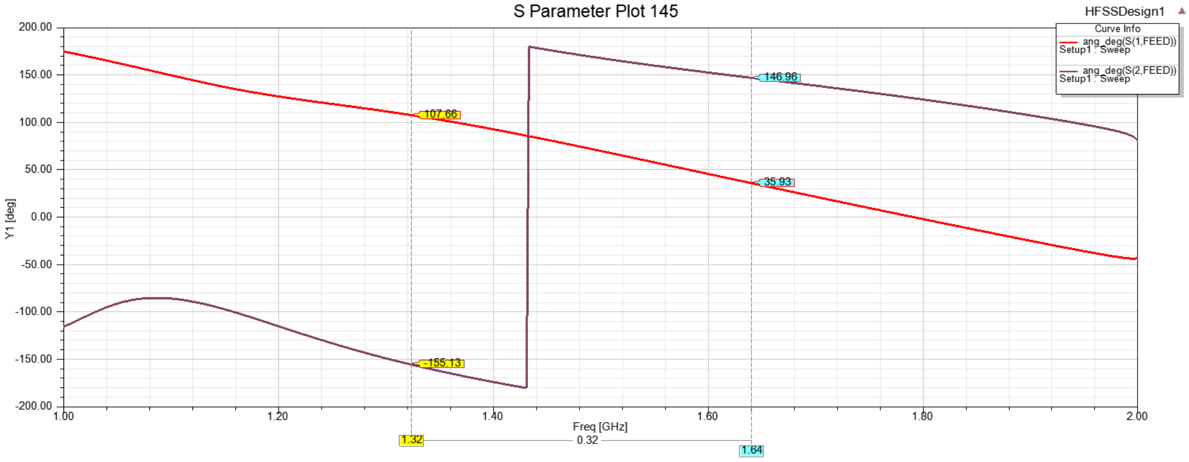


Fig. 10 Phase difference between S_{13} and S_{14}

As shown in Fig. 10, the phase difference of the two output ports is 90° in turn. The phase difference of each output port in Fig. 10 is 87°～91°, which does not exceed the error of ±5°, which meets the design requirements.

4. Conclusion

In summary, based on the design principles of microwave circuits, this work designed a 3dB bridge for navigation frequency bands, which can cover multiple navigation frequency bands, and realizes that the input signals are two channels and produce a 90º phase difference. First, the working principle of the 3dB bridge is introduced. On this basis, the line length of each microstrip line is mathematically constrained to meet the specific output position. Through HFSS simulation optimization, S_{13} and S_{14} are between -3dB and -3.1dB. There is a loss of 0.1dB. This engineering application allows the phase difference between S_{13} and S_{14} to be between 85º and 95º, with an error of about ±5º, which meets the requirements of engineering design. In the design and simulation process of RF passive devices, many complicated parameter data and graphic structure settings will be encountered, and the simulation experiment needs to be adjusted multiple times to achieve the best results according to the engineering requirements. At the same time, with the increasing number of different types of satellites, the functions involved in it have shown centralization and focus. Among them, the corresponding frequency band resources in the satellite navigation field are gradually becoming saturated and the domestic the Beidou Navigation Satellite System is developing in three steps. Under the background of the successful completion of the strategy, it is meaningful to think about how to apply multiple frequency bands and frequency density to the navigation and positioning direction. In the existing designs serving the satellite navigation field, most of them are by changing the 3dB bridge model structure and the expansion of the bandwidth range are improved, but both play an important role in achieving model miniaturization. There are still shortcomings in satellite navigation services in multiple frequency bands. Therefore, this work is based on the design and simulation of a novel 3dB bridge in the navigation frequency band of HFSS. The designed network is suitable for the needs of satellite navigation in multiple frequency bands, and has a certain significance in engineering requirements.

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