Double Ridge Cross-Waveguide Bidirectional Coupler Using Algorithms Genetic Method And HFSS

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Abstract— An important microwave component is the 4 port directional coupler. This paper illustrates double ridge cross-waveguide bidirectional structure. The relationships between the scattering variables in this sort of network are fixed by the unitary condition. Such a network has the properties that it is a matched device with one adjacent port decoupled from any incident port. The object of this paper is to present some results of simulation on the coupling and directivity of double ridge cross-waveguide couplers in a field ridge waveguide. This results are obtain by Ansoft HFSS using the Finite Element Method (FEM) calculations and the Genetic Algorithms method, and which show good performance.

Keyword- Double ridge cross-waveguide; bidirectional coupler; optimisation; HFSS Software; Genetic Algorithm method; EFM method, E-plane, H-plane.

I. INTRODUCTION

A double ridge cross-waveguide bidirectional coupler is 4 ports, 180 degree hybrid splitter, realised in field waveguide. It has very similar properties to the rat-race coupler which is usually realized in micro-strip or strip-line. Like all of the coupler and splitter structures, the double ridge cross-waveguide bidirectional coupler can be used as a power combiner, or a divider. It is ideally lossless, so that all power into one port can be assumed to exit the remaining ports.

The Port 1 is the Σ (sum) port, and is sometimes called the H-plane port, and sometimes called the P-port for "parallel". A signal incident on port 1 equally splits between ports 2 and 3, and the resulting signals are in phase. Ports 2 and 3 are sometimes called the co-linear ports, because they are the only two that are in line with each other. Port 4 is the Δ (difference or delta) port, and is sometimes called the E-plane port, or the S-port for "series". A signal incident on the difference port splits equally between ports 2 and 3, but the resulting signals are 180 degrees out of phase.

This paper illustrates a well known and commonly used high frequency device. The main idea behind the double ridge cross-waveguide bidirectional coupler is to combine a TE and a TM waveguide splitter. In this particular case port 1 and port 4 are de-coupled, so one can expect S_{14} and S_{41} to have very low values. Viewing the electric fields gives a better understanding how the «Double Ridge Cross-Waveguide Bidirectional Coupler» works [1], [2].

II. OPERATION OF DOUBLE RIDGE CROSSS-WAVEGUIDE COUPLER BIDIRECTIONAL COUPLER

The 4 ports double ridge cross-waveguide bidirectional coupler is a classic component in microwave engineering. It is defined as a matched 4 ports network with one adjacent port decoupled from any input port, it's illustrated in (figure 1). The waveguide section containing ports 1 and 3 is sometimes referred to as the primary waveguide, while that containing ports 2 and 4 is denoted the secondary waveguide [3]. A scrutiny of the symmetry of this sort of network suggests the possibility of reducing the entries of the scattering matrix to linear combinations of odd and even modes. This may be done by taking ports 1 and 2 as a typical pair of input ports and ports 3 and 4 as typical output ports. The scattering matrix of the ideal, symmetric and lossless network with port 2 decoupled from port 1 is given in the usual way by:

$$s = \begin{pmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{pmatrix}$$

The relationship between the transmitted (S_{31}) and coupled (S_{41}) coefficients is given by the unitary condition:

$$S\,t\,.\,S\ {*}= 1 \tag{1}$$
$$|S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \tag{2a}$$
$$|S_{12}|^2 + |S_{23}|^2 + |S_{24}|^2 = 1 \tag{2b}$$
$$|S_{13}|^2 + |S_{23}|^2 + |S_{34}|^2 = 1 \tag{2c}$$
$$|S_{14}|^2 + |S_{24}|^2 + |S_{34}|^2 = 1 \tag{2d}$$
$$|S_{13}|^2 + |S_{14}|^2 = |S_{23}|^2 + |S_{24}|^2 \tag{3a}$$
$$|S_{13}|^2 + |S_{23}|^2 = |S_{14}|^2 + |S_{24}|^2 \tag{3b}$$
$$|S_{23}|^2 = |S_{14}|^2 \tag{4}$$
$$|S_{13}|^2 = |S_{24}|^2 \tag{5}$$
$$|S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \tag{6a}$$
$$|S_{13}|^2 + |S_{14}|^2 + |S_{34}|^2 = 1 \tag{6b}$$
$$|S_{12}|^2 = |S_{34}|^2 \tag{7}$$

Where:

$$|S_{23}| = |S_{14}| \tag{8a}$$
$$|S_{13}| = |S_{24}| \tag{8b}$$

The performance of any non ideal bidirectional coupler is defined in terms of coupling, losses of insertion, isolation and directivity factors:

- Losses of insertion: $S_{31,\ S13}$
- Coupling: $S_{41,}\ S_{32}$
- Isolation: $S_{21,}$ S4$_3$
- Directivity: S_{41}/S_{21}

One solution is: $S_{41} = j\beta$ and $S_{31} = \alpha$

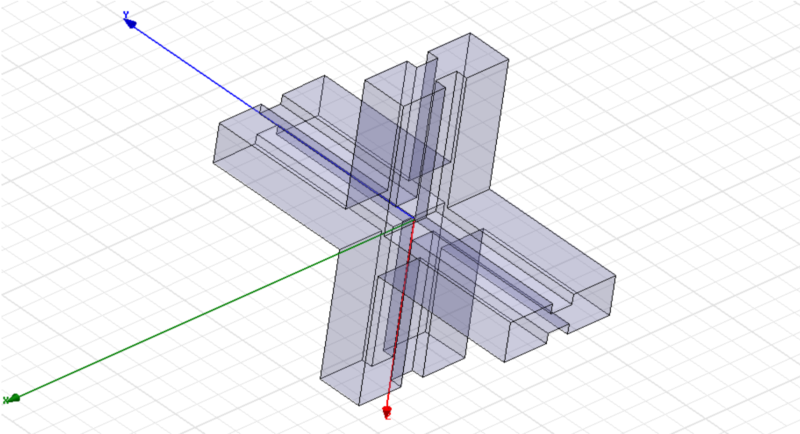

Fig.1. Schematic diagrams of 4 ports of double ridge cross-waveguide bidirectional coupler.

III. Simulation and Optimisation of Double Ridge Cross-Waveguide Bidirectional Coupler

Opposing polarities as it splits between ports 2. The interior dimensions of the waveguide are 50 mm by 20 mm. This is not a standard waveguide size. You can tell that Ansoft is run by mathematicians, not microwave engineers, or they would have picked a "real" waveguide band. Below is the model show in figure 2 and 3.

A. Simulation of double ridge cross-waveguide bidirectional coupler

The The simulator of structures high frequency of Ansoft HFSS (High Frequency Structural Simulator) is a software package (EM) electromagnetic double alternation allowing the electromagnetic calculation of a structure in 3D and the different proprieties as discontinuities [4], fields, and propagations. HFSS is used in several electromagnetic fields and in particular in the field of Telecommunications for the simulation of satellites antennas. A double ridge cross-waveguide directional coupler has been designed for feeding RF power.

Port match at E plane arm has been achieved through inductive iris which cancels out capacitive discontinuity in this arm of the Tee. Capacitive post has been utilized in the H arm of the Tee to achieve port matches in this arm. Further improvement in the port return loss (better than 50 dB) has been achieved by utilizing a conical post in the main waveguide line. This has helped in achieving port return loss of better than 50 dB at all ports. The isolation parameters obtained from these simulations are better than 90 dB between port 3 and 4 whereas it is better than 60 dB for port 1 and 2.

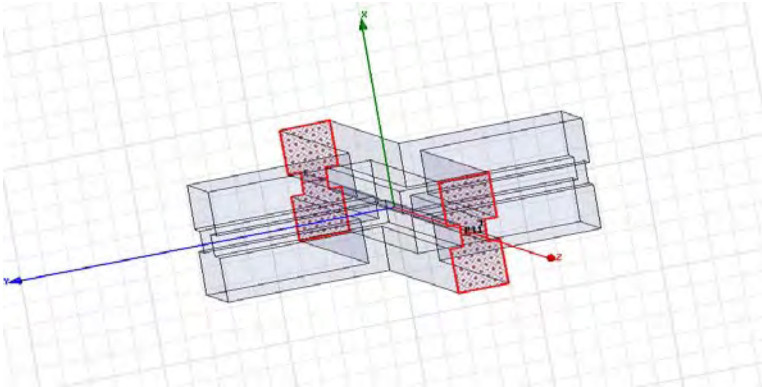

Fig. 2. 3D model for double ridge cross-waveguide bidirectional coupler.

B. *Optimization of double ridge cross-waveguide bidirectional coupler*

The application of the *Genetic Algorithm "AGs"* [5], enables us to solve the problem of synthesis of the waveguides coupler "Double ridge cross-waveguide bidirectional coupler". In our application, we put forward the characteristics of AGs in their applications to optimization [6] the dimensions of the double ridge cross-waveguide bidirectional coupler. In fact, many parameters influence the solution of the problem by the genetic algorithm. After several tests, we noted that a good precision with a relatively acceptable computing time are obtained by applying the following parameters:

- Number of individuals: 30.
- Number of generations: 100.
- Probability of mutation: 0.02.
- Probability of crossing: 0.8.
- Coding of 16 bits.
- Select by Russian roulette.
- Tolerance error = 0.001.ε.
- Terminals variations [3.5 to 6] GHz.

The results of different S-parameters for double ridge cross-waveguide bidirectional coupler are show in figure 3.

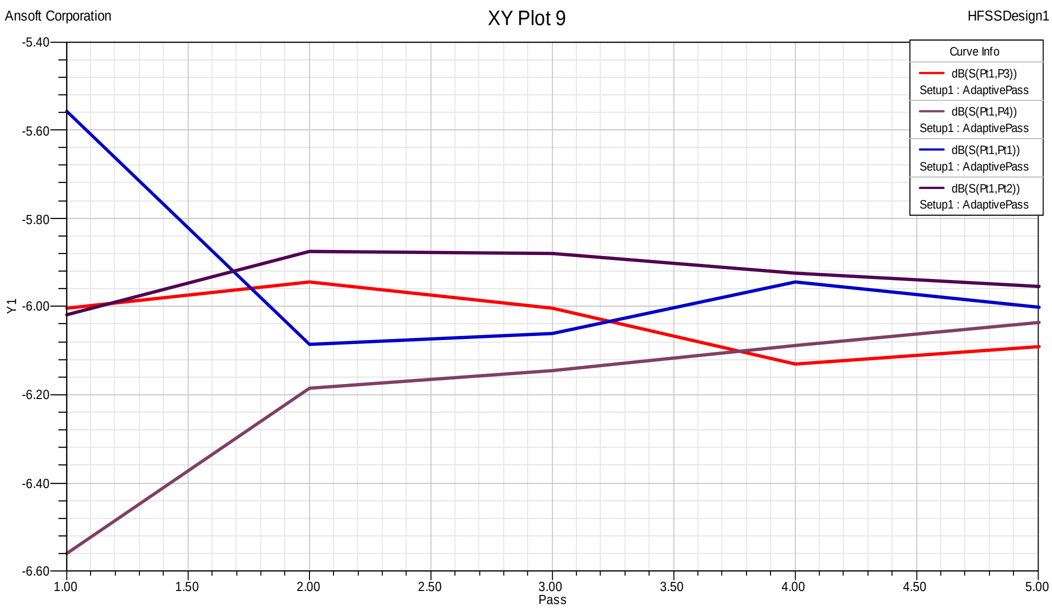

Fig. 3. Different S-parameters for double ridge cross-waveguide directional coupler.

The S-parameters of the four ports network, including the transmission coefficient between sum and delta ports, which is better than -5.80 dB. The input match S_{11} could be better, which would require some tuning. Guess that's why you'd never buy a double ridge cross-waveguide bidirectional coupler from Ansoft HFSS [7], [8]. He suggests adding tuning to the Σ and Δ arms.

Without any matching components placed in the waveguide port of the double ridge cross-waveguide bidirectional coupler, the return losses for each port of the double ridge cross-waveguide bidirectional coupler [9] has been observed in HFSS simulation software. The return loss for only port 1 is shown in figure 4. It can also be found that for other ports also return losses are below -6.02 dB**.**

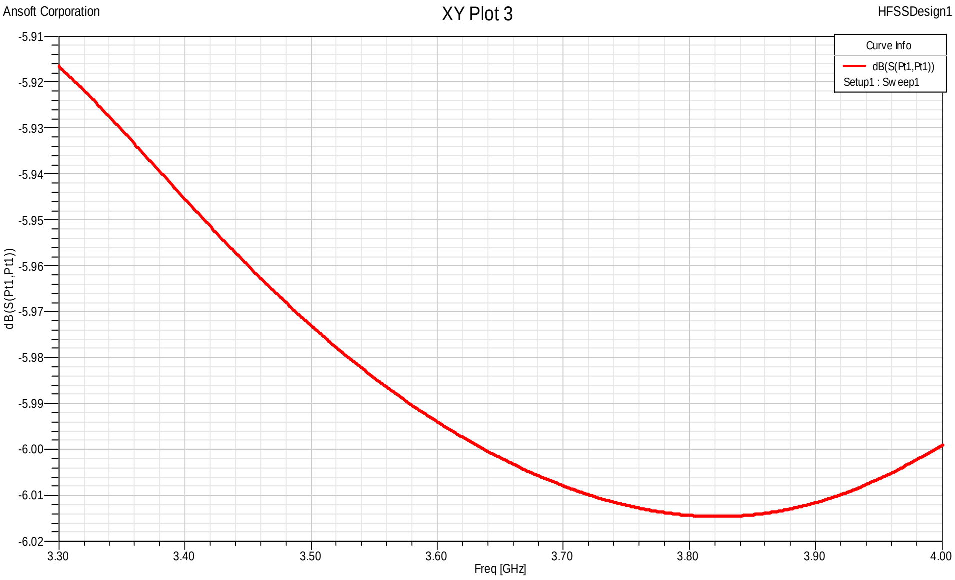

Fig. 4. Return loss at port 1 (S_{11}) Db

The signal entering the port 1 will not appear at port 4, whereas the signal entering the port 4 will not appear at port 1, so port 1 and 4 is decoupled to each other. The isolation between port 1 and port 4 is below -6.02 dB in the band from 3.5 GHz to 6 GHz as shown in figure 5. The signal of the all ports is the same.

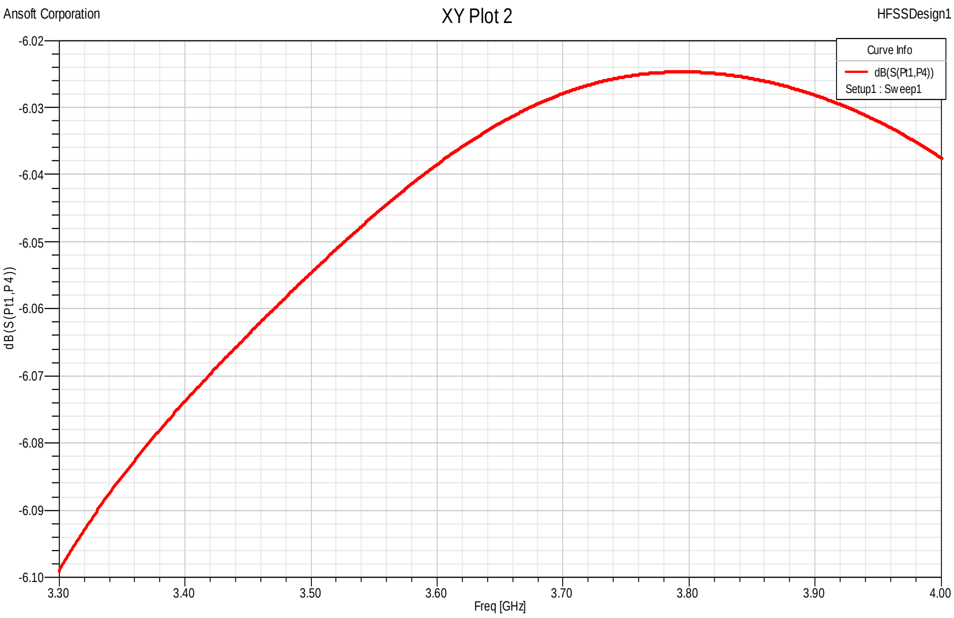

Fig. 5. Isolation between port 1 and 4 (S_{14}) or port 4 and 1 (S_{41}) dB.

The figure 6, illustrate the rapport (S_{24}/S_{42}). It's equal to 1.

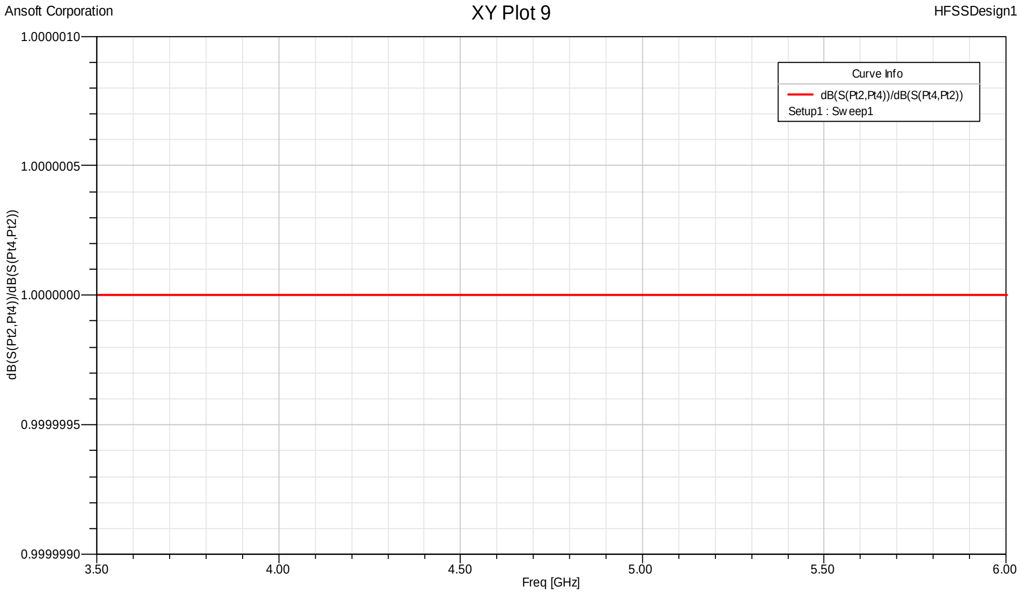

Fig. 6. The rapport (S_{24}/S_{42}).

The figure 7, illustrate the coefficient of transmission S_{24}. It's equal to 3dB.

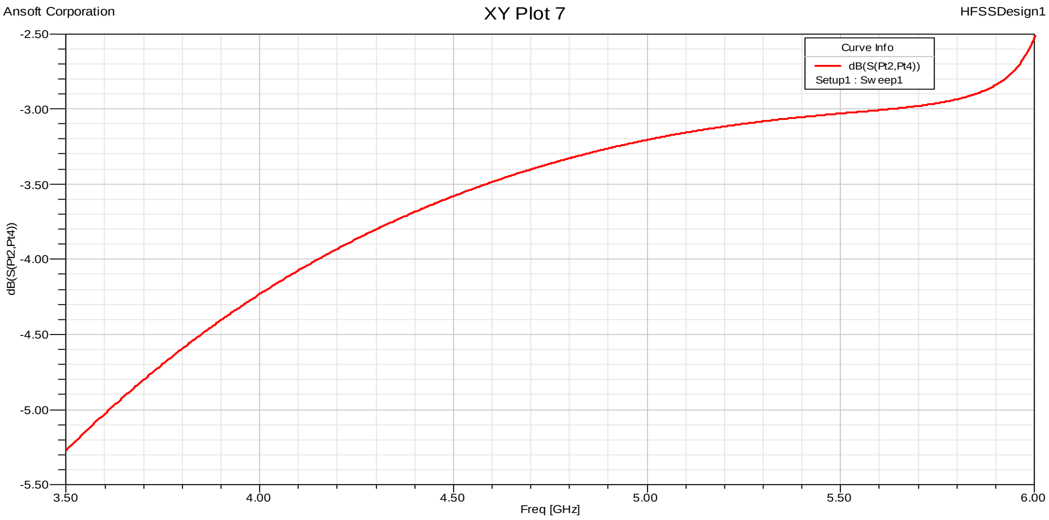

Fig. 7. Coefficient of transmission (S_{24}) dB.

The figure 8 shows the phase of the transmission coefficients out the Co-linear ports, when driven by the delta port. The difference is of 180 degree. The phase of transmission coefficient between port 2 and 3 when signal entering at port 1. It can easily be stated from the figure that when signal entering port 1, it will equally divide and appear at port 2 and 3 with opposite phase.

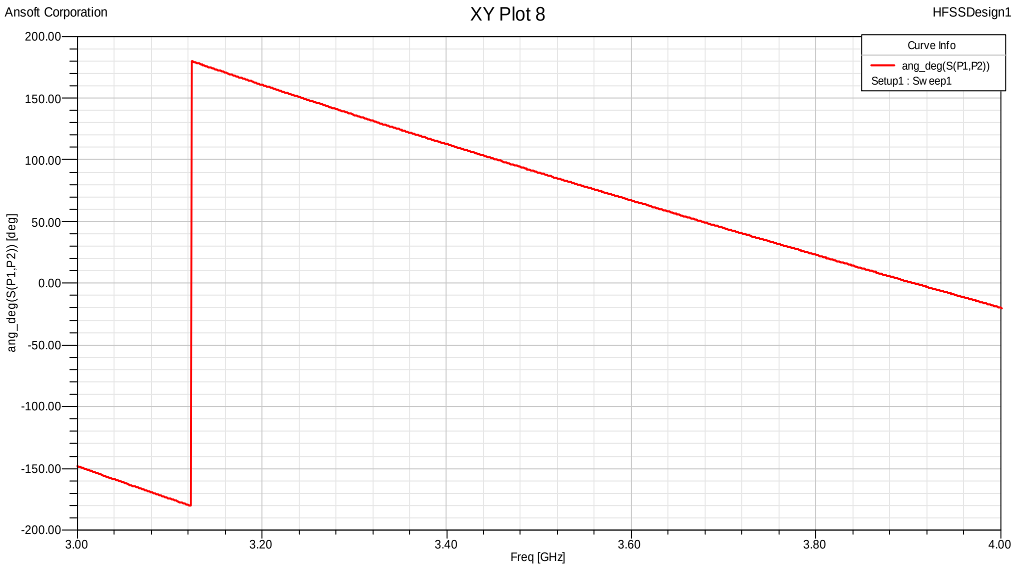

Fig. 8. Phase of transmission coefficients out the co-linear ports for double ridge cross-waveguide bidirectional coupler.

IV. COMPARISON OF DOUBLE RIDGE CROSS-WAVEGUIDE BIDIRECTIONAL COUPLER AND MAGIC –TEE COUPLER

An Ideal magic tee or hybrid tee is a 4-port microwave passive reciprocal device and is a combination of E and H plane tees. Out of four arms the two side arms are called as collinear arms and remaining two are H and E arms (port 1 and 4), which are crossed polarized or electromagnetically decoupled from each other. If power is fed in H arm (port 4), it will be equally divided in phase to two side arms and if power is fed in E arm (port 1) it will be equally divided out of phase. Similarly if the collinear arms will be fed equal powers, these will be added at port 4 and subtracted at port 1. The magic tee is commonly used for duplexing, mixing and impedance measurement in high frequency structures. The structure of Magic Tee in X band [10] has been designed using HFSS software, it's illustrate in figure 9 in which port 2 and port 3 has been assigned to two collinear arms, whereas port 1 and port 4 for E and H arm respectively.

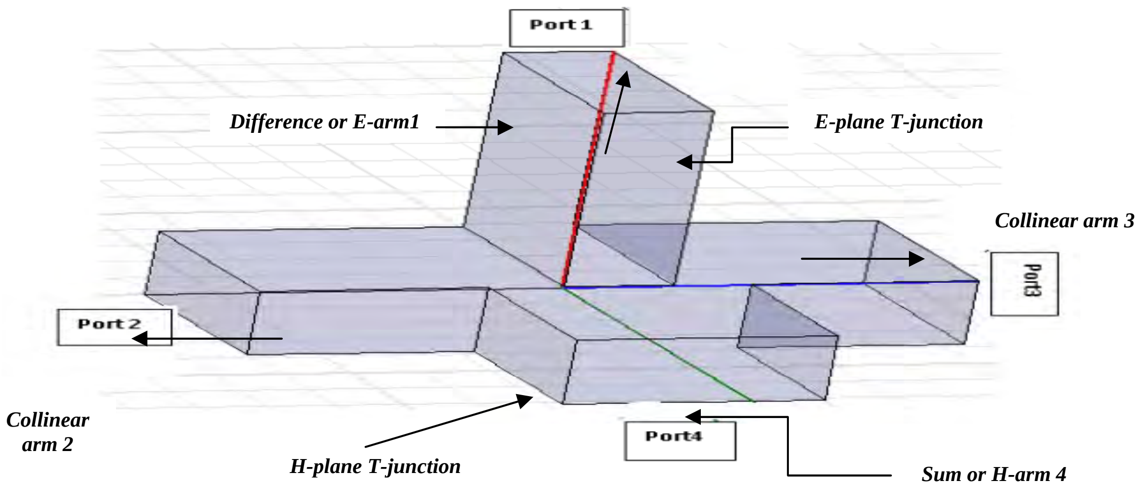

Figure 9. Diagram of Magic Tee using HFSS.

The figure 10 shows the phase of transmission coefficient between port 2 and 3 when signal entering at port 1. It can easily be stated from the figure that when signal entering port 1, it will equally divide and appear at port 2 and 3 with opposite phase of the magic-tee structure. The difference is of 180 degree. It's the same results of the double ridge cross-waveguide bidirectional coupler, which it's shown in figure 8.

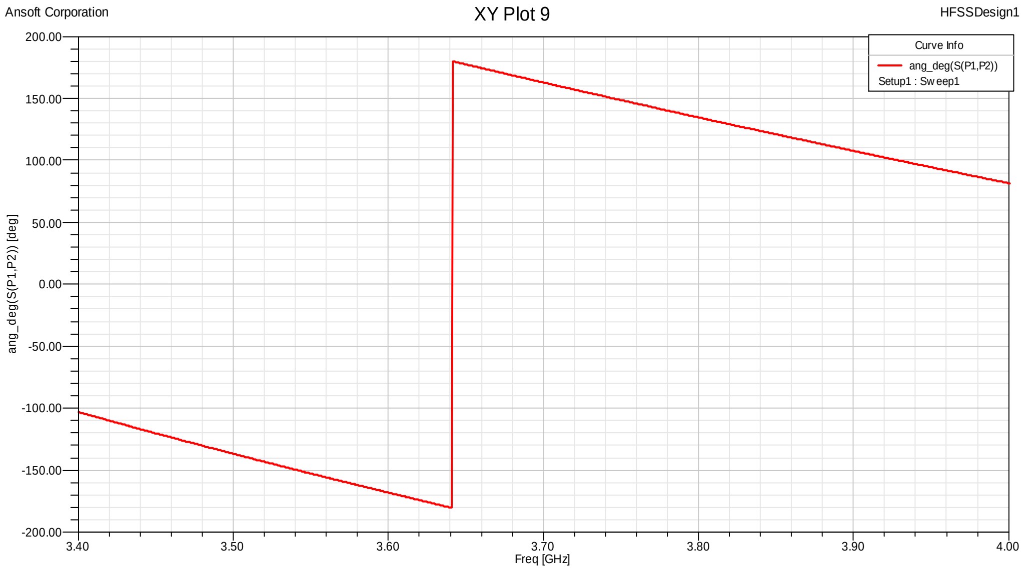

Fig. 10. Phase of transmission coefficients out the co-linear ports for Magic Tee.

Without any matching components placed in the waveguide port of the magic tee, the return losses for each port of the magic tee has been observed in HFSS simulation software. The return loss for only port 1 is shown in figure 12. It can also be found that for other ports also return losses are below -10 dB**.** The signal entering the port 1 will not appear at port 4, whereas the signal entering the port 4 will not appear at port 1, so port 1 and 4 is decoupled to each other. The coefficient of transmission S_{12} and S_{13} is -2.86 dB. The coefficient of reflection S_{11} is equal -11 dB. The isolation between port 1 and port 4 is below -60 dB in the band from 3.4 GHz to 4 GHz as shown in (figure 11) for magic-tee structure.

The comparison of different results of double ridge cross-waveguide directional coupler structure, they illustrate that the coefficient of reflection (return loss) S_{11} is below -6.02 dB in the port 1. The coefficient of transmission S_{12}, S_{13} is below -6.02 dB and the coefficient of isolation S_{14} is also to equal at -6.02 dB in the band from 3.4 GHz to 4 GHz as shown in figure 3. It is noted that the various ports of one it same coefficient of transmission which is equal to -6.02 dB.

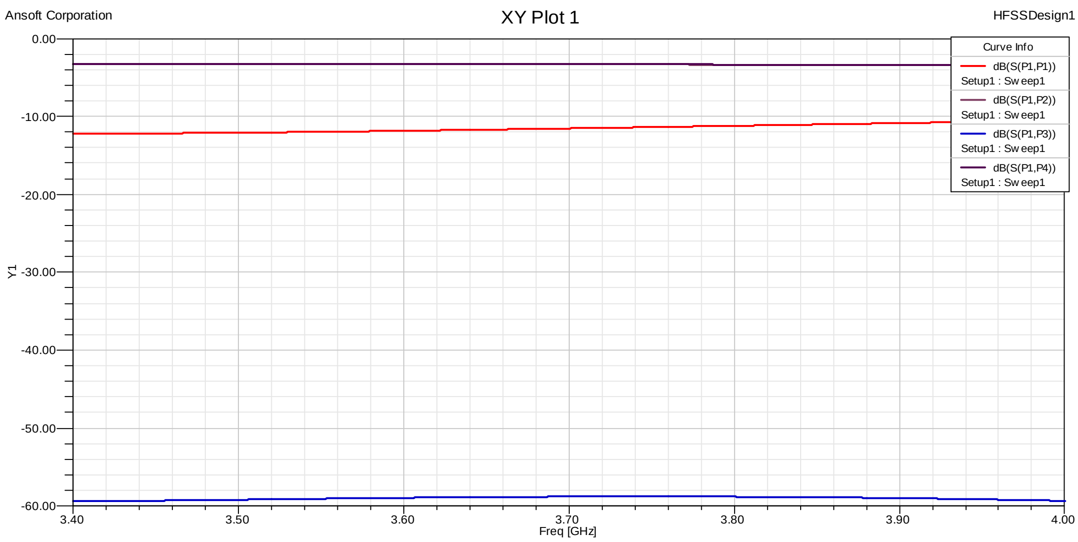

Fig. 11. Different S-parameters for Magic Tee coupler.

As it’s mentioned above, the obtained results by the “AGs” are accurate and satisfactory, but the optimization procedure takes a very important computational time.

V. THE E-FIELD OF DOUBLE RIDGE CROSS-WAVEGUIDE BIDIRECTIONAL COUPLER

The figure 12 shows the E-field [11] vectors for signals entering the sum port, then the delta port. Now you can see how the delta port excites opposing phases in the co-linear arms.

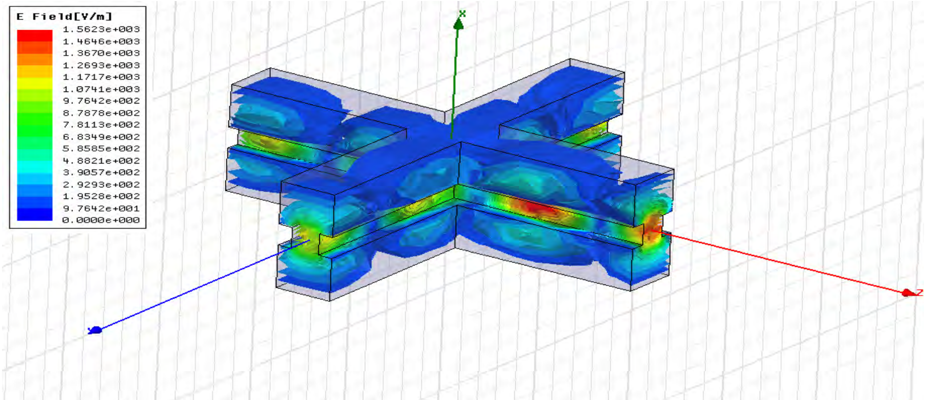

Fig. 12. The E field in the ridge cross-waveguide directional coupler.

The figure 13 shows the H-field vectors for signals entering the sum port, then the delta port.

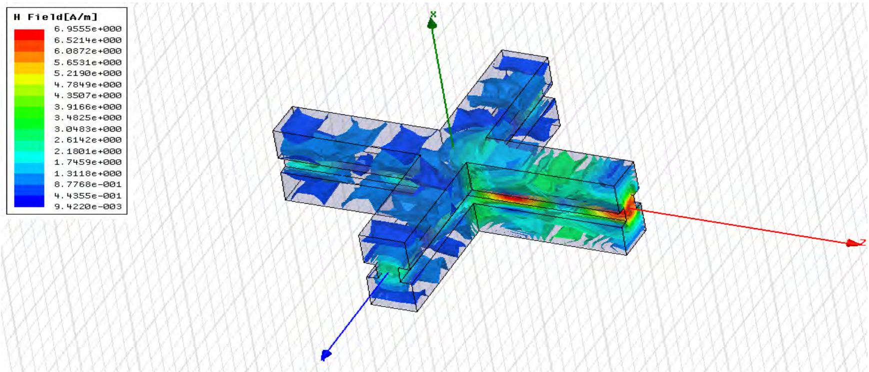

Fig. 13. The H field in the ridge cross-waveguide bidirectional coupler.

An approximate determination of the dominant-mode fields in ridge waveguides at all frequencies has been made. Evaluations of the fields along the walls of a commercially standard double-ridge guide having a usable frequency range from 3.5 to 6 GHz were carried out, and graphs drawn so that the results could be applied to practical situations. The graphs were used to design some ridge waveguide directional couplers. Both cross-waveguide and broad-wall couplers were made in single-ridge waveguides and in double-ridge waveguides, using cross sections approximating those of the above commercially available ridge guides.

VI. CONCLUSION

These couplers have been designed to handle high power. Like conventional double ridge cross-waveguide bidirectional coupler, these devices can be used as 3dB power combiners, 3dB power dividers, or as phase combiners. One ridge cross-waveguide bidirectional coupler is a tow way combiner, and multiple couplers can be joined to form 4, 8 and higher order combiners.

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