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Design, Development and Simulation of Microwave High Power Waveguide Dual Directional Coupler

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Abstract:-- **This paper deals with design, development and simulation of waveguide type dual directional coupler operating at microwave heating frequency of 2450MHz ± 25MHz (ISM Band). The Ansoft HFSS13.0 software is used for carrying out the parametric study of performance parameters i.e coupling factor, directivity, VSWR, impedance, return loss etc. of the designed coupler. The simulation of the dual directional coupler is carried out by varying the various parameters of the dual directional coupler for both the forward and reflected ports. These simulation results are verified with experimental results of the fabricated dual directional coupler only for a single measurement because of hardware limitation of the coupler. The emphasize of this paper is on the simulation results of the coupler for variation in loop plate width, loop hole, angular rotation of loop plate from 0º to 350º and coupling gap of the coupler.**

Index Terms- **Dual directional coupler, loop plate, loop hole, coupling, directivity**

I. INTRODUCTION

The principal application of dual directional coupler is in monitoring signals simultaneously in both directions, thus, these are used extensively for online monitoring of the forward and reflected power at the output of the high power transmitters/generators [1]. At VHF/UHF frequency range, loop type dual directional couplers are used. It consists of a segment of an auxiliary conductor located within either a coaxial line or a trough line and brought out through the wall to the desired connectors or terminations. The scope of this paper is to investigate the effect of different parameters on the coupling and directivity of the plate loop type dual directional coupler having high power handling capability in the main line.

At high power/frequencies, waveguide structures are used because of their low insertion loss and high power handling capability. The early use of a coupling aperture was the Bethe-hole waveguide directional coupler, which has a single round hole cantered in the common broad-wall between two waveguides, the axes of which were at an angle such that, at the design frequency, the electric and magnetic couplings to the branch waveguide cancel in one direction while add in the other [2]. A single loop dual directional coupler using co-axial line has been reported at 1320MHz [3]. But, the parametric study to facilitate design of this coupler is not available. In this paper, parametric analysis has been carried out at 2450MHz for evaluating the effects of variation of coupling gap between main and auxiliary (loop plate) line, loop hole on the wall of the waveguide, width of the loop plate and angular rotation of the coupling loop plate. Using the design data presented in this work, one can design a loop plate type dual directional coupler for wide range of coupling factor and better directivity. Parametric study shows that the coupling factor in the range of -60dB is achieved with higher directivity of the order of 40dB. These simulation results are verified with the experimental results. This paper mainly emphasizes on the parametric study of dual directional coupler for forward and reflected loops using Ansoft high frequency structure simulator (HFSS) [4].

II. PRINCIPLE OF OPERATION

Dual directional coupler is a four-port RF network circuit where all four ports are ideally matched and lossless. These couplers are passive devices which are used to couple a very small amount of the RF power travelling in the forward/reverse directions from one port to another port. Dual directional coupler works on the principle of interaction of the electromagnetic fields of coupling loops with the main line. The RF wave incident at the input port (port-1) couples fraction of power into coupled port and reverse coupled port (ports-3 and 4 respectively) without disturbing the flow of signal and transfer power to output port (port-2). A symbolic representation of the dual directional coupler is shown in Fig.1.

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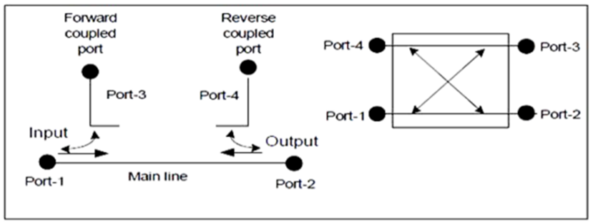

Fig.1. 4-port dual directional coupler

III. DESIGN, CONSTRUCTION AND FABRICATION OF THE COUPLER

The high power microwave waveguide dual directional coupler has been designed, fabricated and simulated using Ansoft HFSS software. All parts of the coupler are fabricated out of brass material. This waveguide loop coupler consists of a rectangular brass WR340 waveguide with rectangular flanges silver brazed at the input and output ends. The schematic diagram of the developed coupler is shown in Fig. 2. The length of the coupler is kept as λg, where λg is the guided wavelength. Coupling loops for forward and reflected power are mounted above a small hole in the broad wall of the waveguide. Two holes identical in size with diameter, D and separation, S (λg/2) are drilled on the broad wall of the waveguide. The diameter of the hole decides the value of the performance parameters i.e. coupling and directivity of the dual directional coupler. These coupling loops consists of small rectangular brass plate approximately 1mm thick soldered to the gold plated center conductor of N type female connector and other end of brass loop plate is terminated to ground through 50Ω SMD resistor. The threaded end of the N type connector is used for measurement of the forward and reflected coupled power.

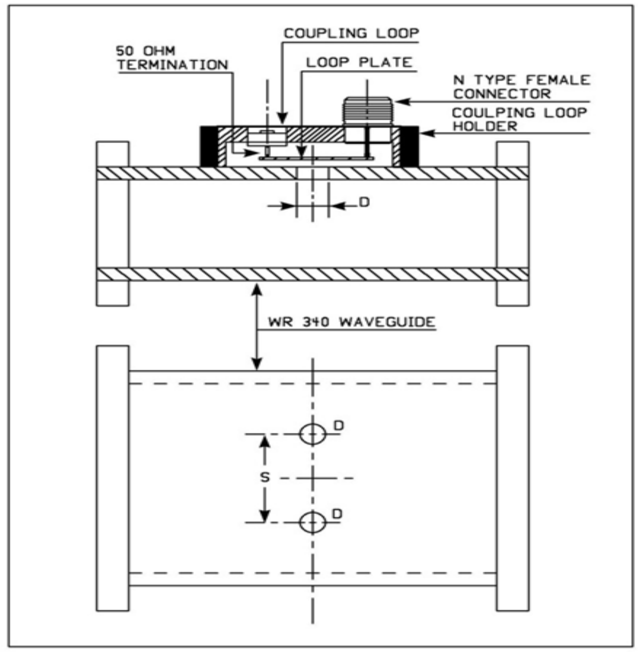

Fig.2. Schematic of dual directional coupler

Both the coupling loops are cylindrical and identical in construction. The mounting arrangement of the loops on waveguide is made such that loops can be rotated and locked to desired position to simultaneously adjust the coupling and isolation for improvement in the directivity, which is figure of merit of dual directional coupler [5]. Photograph of the fabricated dual directional coupler is shown in Fig.3

Fig.3. Fabricated 4-port dual directional coupler

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IV. SIMULATION RESULTS AND DISCUSSION

The theoretical design of dual directional coupler is performed using Ansoft HFSS at 2450MHz ± 25MHz. Scattering parameters for forward coupling factor, reverse coupling factor, impedance, VSWR, insertion loss, return loss for all ports are simulated and presented in this research paper. The computation of these values are obtained by varying the width of the loop plate, loop hole, angular rotation of coupling loop from 0º to 350º in steps of 10º and the coupling gap. The HFSS modeling of the dual directional coupler is shown in Fig. 4(a) & 4(b).

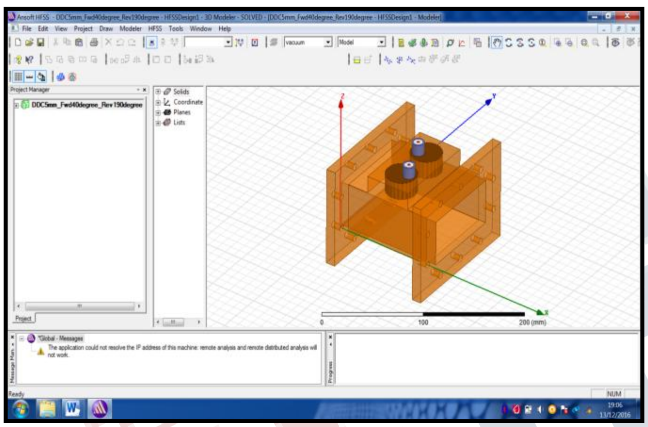

Fig.4(a). HFSS model- Isometric view

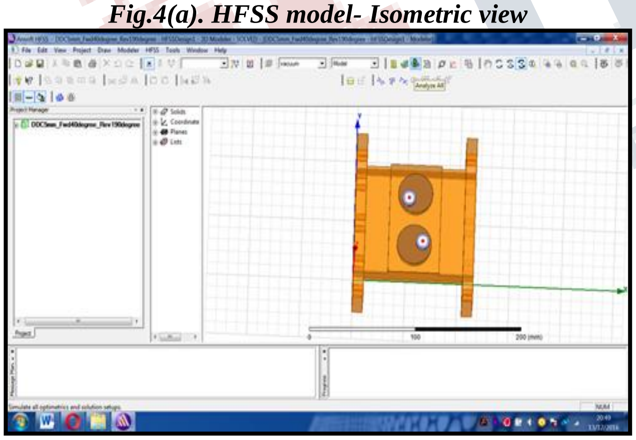

Fig.4(b). HFSS model- Top view

A. Effect on coupling and directivity due to variation in loop plate width and coupling gap

The schematic for the dual directional coupler with angular rotation (0º-350º) for forward and reverse coupling port is shown in Fig.5. The HFSS simulation for loop plate widths 1,2,3,4,5,6,7,7.6,8,9.5mm with coupling gap of 0.5mm and 1mm were carried out.

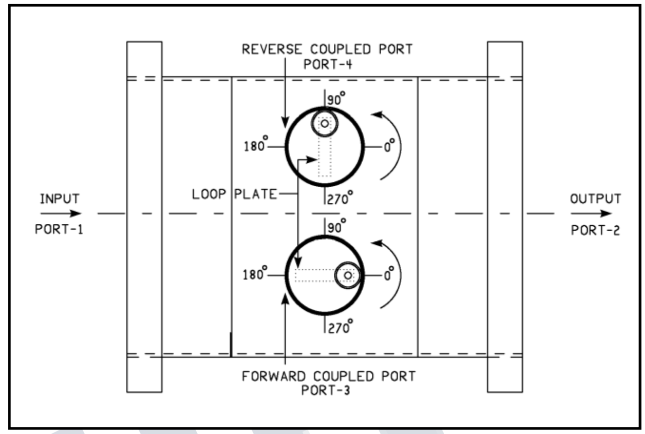

Fig.5. Angular rotation of coupling loops (0-350º)

The simulation results of coupling and directivity for variation in the loop plate width and coupling gap are shown in Fig. 6, 7, 8 and 9. For this analysis, the position of the forward loop is rotated and fixed such that we get approximately -60dB ± 2dB coupling then reverse loop is rotated from 0º to 350º to check the position of the loop at which maximum directivity is achieved. This simulation was repeated for all loop plate widths varying from 1mm to 9.5mm. From the simulation results of graph 8 and 9 it is observed that at 90º position of reverse port, maximum directivity is achieved because of improved cancellation of electric and magnetic field in reverse direction. The value of coupling factor is observed within the required range.

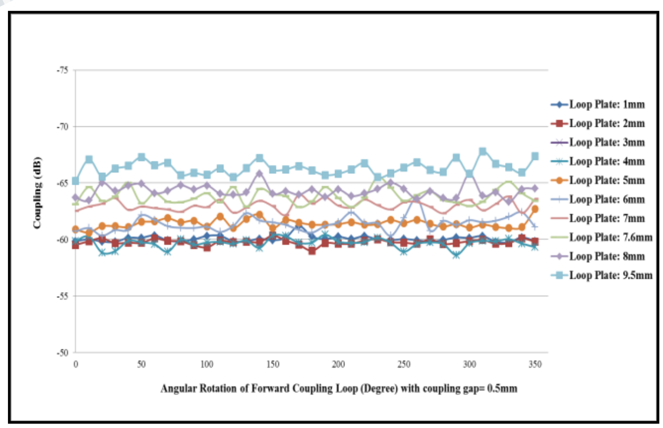

Fig.6. Effect on coupling due to variation in the loop plate width and coupling gap= 0.5mm

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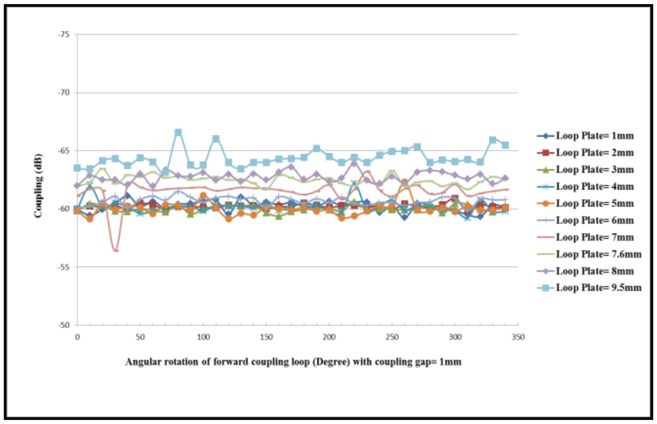

Fig.7. Effect on coupling due to variation in the loop plate width and coupling gap= 1mm

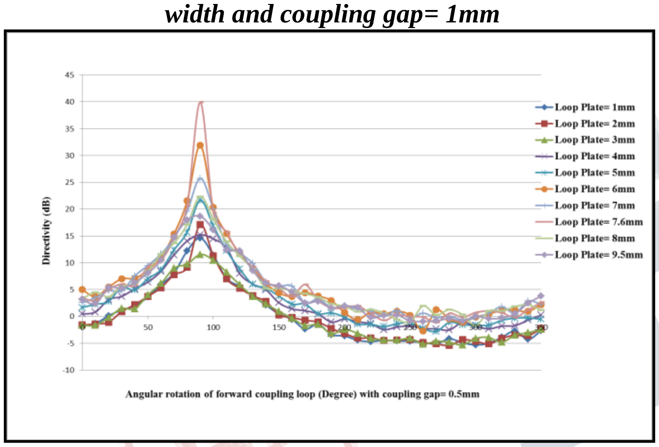

Fig.8. Effect on directivity due to variation in the loop plate width and coupling gap= 0.5mm

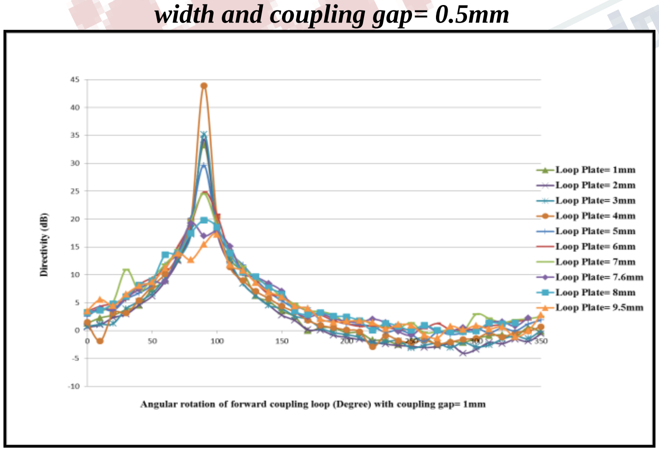

Fig.9. Effect on directivity due to variation in the loop plate width and coupling gap= 1mm

B. Effect of loop plate width on coupling and directivity

The simulation is carried out for fixed value of plate thickness 1mm, the plate length of 18mm and plate width is varied from 1mm to 9.5mm. To study this effect, all the simulation experiments were carried out with 6mm coupling hole for forward and reverse ports with coupling gap of 0.5mm and width varying from 1mm to 9.5mm. This simulation is repeated for coupling gap of 1mm. From the simulation it is observed that for a 1mm coupling gap, 6mm loop hole and 4mm loop plate width maximum directivity of 43.9223dB and coupling factor of -60.2283dB is achieved. From this simulated data, the coupling factor value closed to -60dB ± 2dB and maximum directivity values are chosen for respective width of loop plate and plotted as shown in Fig. 10.

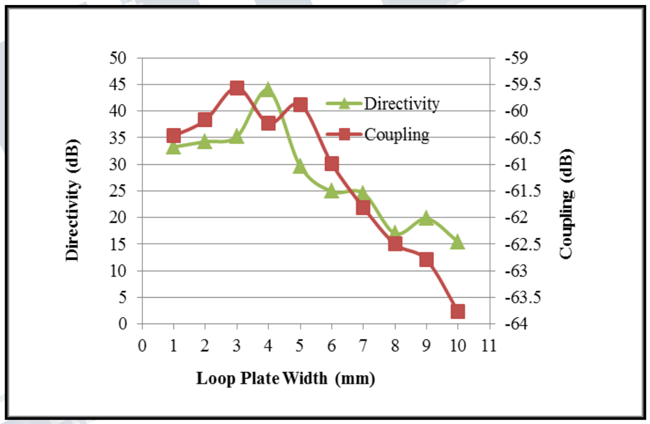

Fig.10. Effect on coupling and directivity due to loop plate width

C. Effect on coupling and directivity due to loop hole

For this simulation, the above mentioned example in SectionIV-B (Coupling gap-1mm, Loop plate width- 4mm and Loop hole-6mm) of maximum directivity is chosen and for this case the loop hole is varied from 1mm to 6mm. The simulated results are shown in Fig. 11.

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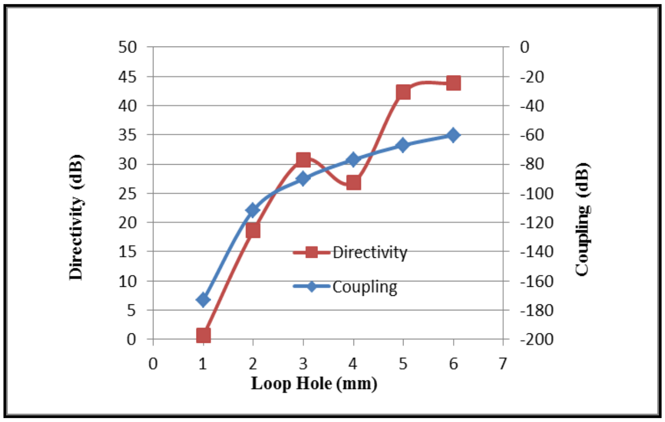

Fig.11. Effect of loop hole on coupling and directivity

From the simulation it is observed that as the loop hole diameter increases the coupling increases from -170dB to -60dB because of increase in electric and magnetic field components leaking from the loop holes. The directivity variation from 0.5dB to 43dB is observed for minimum to maximum loop hole size respectively. The increase in directivity with increase in loop hole size is observed because of improved cancellation of electric and magnetic field in reverse direction.

V. EXPERIMENTS AND RESULTS

The simulation results were verified with the experimental results i.e using fabricated dual directional coupler but because of hardware/fabrication limitations, it is not possible to do all the parametric study on the fabricated dual directional coupler. Therefore, the following case as mentioned in SectionIV-B where maximum directivity is achieved has been taken for measurement

Loop Hole- 6mm
Coupling Gap- 1mm
Loop Plate width- 1,2,3,4,5,6,7,7.6,8,9.5mm

The scattering parameter measurements of the coupler were carried out with the help of the Vector Network Analyzer. The experimental results are shown in Fig. 12. From the plot it is observed that the experimental results are in well agreement with the simulation results of SectionIV- B

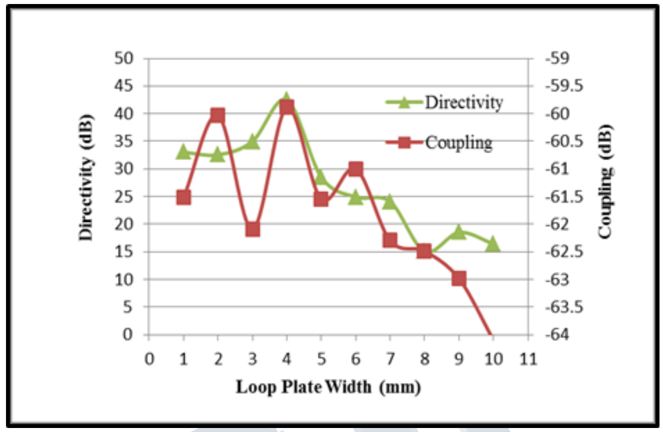

Fig.12. Experimental results of the fabricated coupler

VI. CONCLUSION

The effect of different parameters that influences the coupling and directivity of a plate loop type dual directional coupler has been investigated at 2450MHz. The other parameters of dual directional coupler like impedance input return loss, output return loss, input VSWR, output VSWR and insertion loss have negligible effect due to variation in different parameters of coupling loops. It is also observed that the values of various simulation results are almost constant over the entire bandwidth of 2450MHz frequency. The parametric study simulation results at 2450MHz presented in this paper can be used to design dual directional couplers at other frequencies with suitable scaling factor for the coupling loop. The designed, developed dual directional coupler is simple in design and easy to fabricate

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