DESIGN OF PLANAR MAGIC-TEE FOR Ku-BAND APPLICATIONS

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Abstract: This paper describes the design of a waveguide planar Magic-Tee for Ku-Band applications using Riblet short-slot coupler and a delay line waveguide phase shifter which introduces 90^0 phase shift by varying its dispersion characteristics. Planar waveguide magic tee acts as a two way in- phase power divider in a transmitting mode and as mono-pulse sum and difference in the receiving mode. Sum and difference pattern are often used in monopulse radars for angle tracking. Simulated results with Ansoft HFSS are presented, which show good performance.

Introduction

A monopulse comparator is used in a radar system for determining the azimuth and elevation of a target. Waveguide monopulse comparators are also called Magic-Tees, hybrid rings. A directional coupler can be designed for arbitrary power divisions, while hybrid rings usually have equal power divisions. The design of a monopulse comparator can be carried out using printed hybrid rings, air-line hybrid rings or by using waveguide hybrid rings. If there is a necessity of low loss and better power handling a waveguide power divider is best suited. As our requirement is similar to the above mentioned we have chosen a planar waveguide monopulse comparator to fit our design needs.

The selected structure however should cater to the critical system requirements ,like achieving a good monopulse slope which determines the tracing accuracy.

Hence a Riblet short-slot coupler is chosen which has advantages like low VSWR and accurate 90^0 phase shift over a minimum of 15 % bandwidth. Further 90^0 phase shift is achieved by using a waveguide phase shifter which fulfills the monopulse requirement of 180^0 phase difference to produce sum and difference beams.

The design of magic-tee involves three stages, first Riblet short-slot coupler followed by phase shifter and then integration of coupler and phase shifter.

I Theory and Design of Directional Coupler

The advantages of Riblet short-slot directional coupler include equal power splitting, high isolation, low VSWR and accurate phase shift over desired bandwidth and also its compactness compared to other waveguide couplers[1].

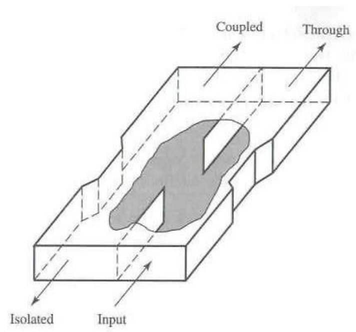


Fig 1: A Riblet short-slot coupler

As can been seen from Fig.1 a Riblet coupler is made of two parallel waveguides with common center wall. The slot cut in the central region acts a coupling region by introducing 90^0 phase shift to the coupled port. Coupling and isolation are achieved by proper choosing of slot region dimensions such that excited TE_{10} (even) & TE_{20} (odd) modes are added at the coupled port and cancelled at the isolated port.

As our operational frequency is 16.5GHz (λ =18.18mm) with a bandwidth requirement of around 12.12 %, we have chosen standard waveguide (WR51) and hence our dimensions are **a=12.95 mm** and **b= 6.48 mm** (Full height).In the coupling region, λ_c =4a for TE_{10} (even) mode and λ_c =2a for TE_{20} (odd) mode. The guide wavelength of a waveguide is given by

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}$$

Subsequently even and odd mode guide wavelengths are calculated as per below given equations.

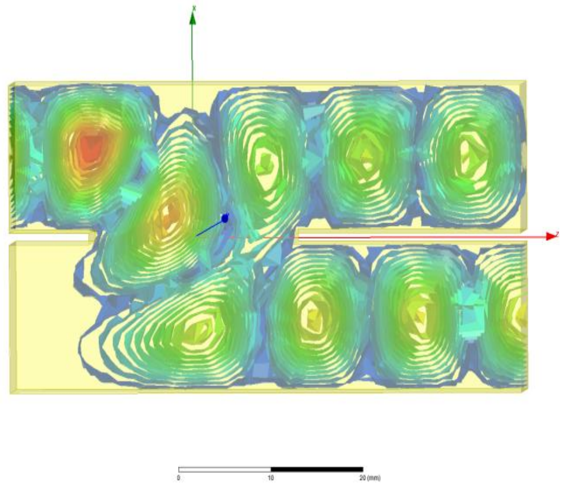
$$\lambda_{ge} = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{4a}\right)^2}} \quad \textbf{= 19.4 mm}$$

$$\lambda_{go} = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2a}\right)^2}} \quad \textbf{= 25.5 mm}$$

For phase shift of 90^0 , **L = 10.4mm** is obtained as per below equation.

$$\varphi = 2\pi\left(\frac{L}{\lambda_{ge}} - \frac{L}{\lambda_{go}}\right)$$

The design is carried out using Ansoft HFSS 3D EM software and optimized for the requirements.



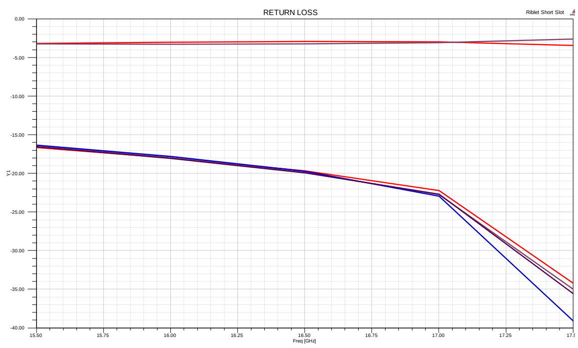


Fig 3: S - parameters of coupler

II Design of delay line waveguide Phase shifter

As Riblet coupler gives one 90˚ phase shift, the other 90˚ phase shift is achieved using a delay line wave-guide phase shifter. The propagation constant β_i of a waveguide is a function of waveguide cross section $\boldsymbol{a}$, and is given by

$$\beta_i(\omega) = \sqrt{\omega^2 \varepsilon\mu - (\pi/a_i)^2}$$

Hence by changing ***a*** , the dispersion characteristics of the waveguide will change. The length and width of phase delay line is calculated as per equations given in [2].

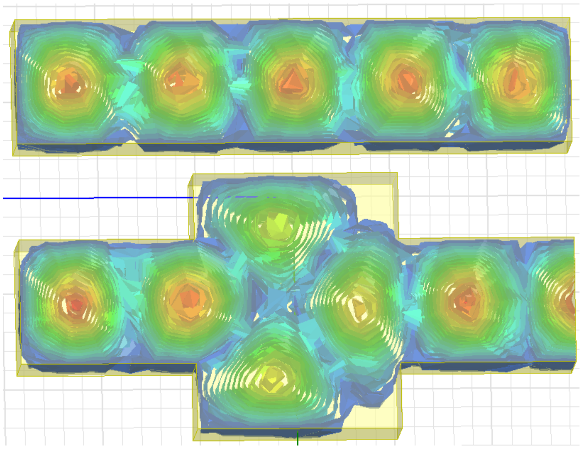


Fig 4: 90° phase shifter

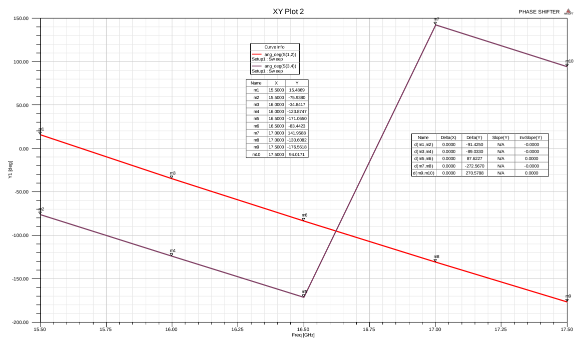


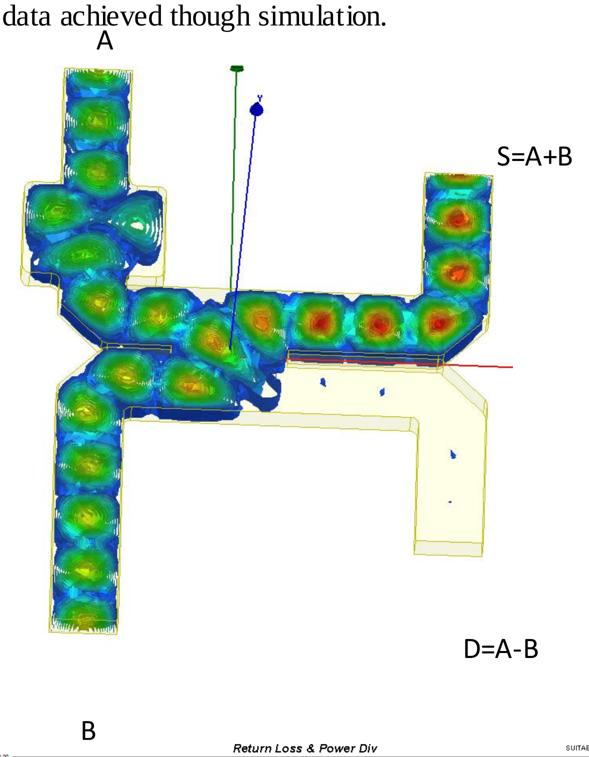
Fig 5: Phase diff between Two W/G lines

Freq	S-D (deg)	S-A(dB)	S-B(dB)
15.5GHz	**-178.99**	**-3.10**	**-3.28**
16.0GHz	**-180.79**	**-3.03**	**-3.12**
16.5GHz	**-180.88**	**-2.98**	**-3.22**
17.0GHz	**-178.41**	**-2.96**	**-3.12**
17.5GHz	**187.21**	**-2.95**	**-3.29**

Fig.5 above shows phase difference between left arm (without phase delay line) and right arm (with phase delay) over full bandwidth is within $90^0 \pm 4^0$

III Design of Monopulse Comparator

A monopulse comparator is obtained by combining the Riblet coupler and delay line phase shifter, which will give sum and difference outputs of two inputs. That means if A and B are the inputs, A+B and A-B are obtained at the other two-ports . Power division and phase shifts obtained are within requirements. Isolation is also better than -17dB. As Riblet coupler can give better phase matching over a good bandwidth, the achieved phase error is less than 8^0. Table.1 shows the data achieved though simulation.



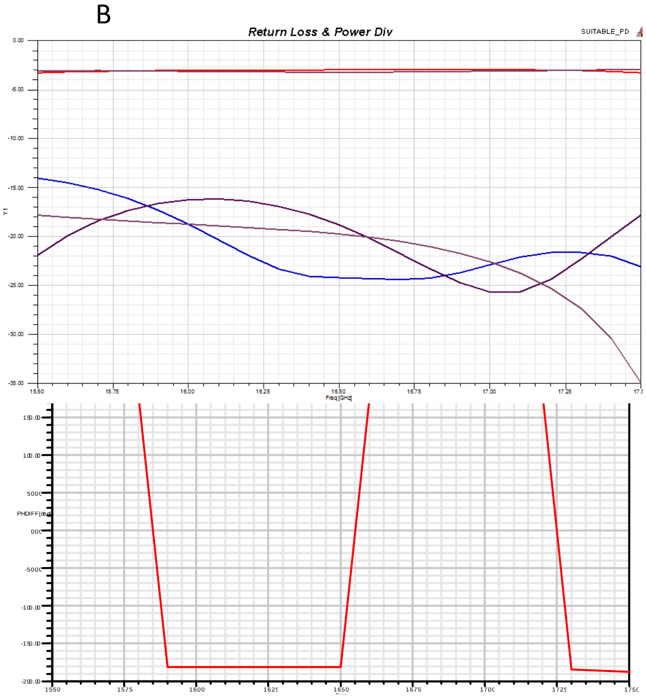


Fig 8 : Phase difference between Sum and difference ports

A Ku-Band monopulse comparator is designed by using Riblet short slot coupler and delay line phase shifter which is planar, can handle more power ,good isolation , less lossy and compact in the class of waveguide comparators.

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Dr. A K Singh obtained his Ph.D. in 1991 in electronics engineering from Banaras Hindu University, Varanasi (INDIA). He joined Electronics & Radar Development Establishment (LRDE), Bangalore in November 1991 and presently heading the R&D group involved in the design & development of 3D Low Level Active Aperture Radar and Antenna / Array Antenna systems. He has served as a chairman of technical program committee of International Radar Symposium (India) (IRSI-2007), Co-chairman, technical program committee of IEEE International Symposium on Microwaves in 2008, International correspondent & member of IEEE Radar conference (France) in 2009 and member of various other international & National conferences. He has authored more than 90 research papers in different international / national journals and symposiums. He has 3 copyrights and 3 patents to his credit.