Waveguide Directional Coupler Modeling for S Band Frequency

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Abstract— The directional coupler is a passive microwave device that can be used for power measurement, it couples power at the input port to the coupled port. It's design of depends on various parameters such as transmission line used in the design, operating frequency of the device, amount of coupling desired and the required directivity. In this paper a modeling of rectangular waveguide directional coupler is presented numerically. The rectangular waveguide used is WR284, a standard waveguide to operate for the frequency range between 2.60 - 3.95 GHz. For High power application of directional coupler needs lower coupling and high directivity so the amount of coupling is desired to be around 60 dB with minimum directivity of 30 dB is used for the design. The design is simulated with the help of microwave CST studio.

Key words: Directional Coupler, Passive Microwave Device, Rectangular Waveguide, High power microwave measurements, Aperture Coupling

I. INTRODUCTION

Directional couplers are one of the passive microwave device, which are operated inside the microwave measuring instruments, so that it can be used to combine various instruments to form very complex measuring system. In most of the cases, passive microwave devices will either combine, split and/or phase shift the microwave signals when it propagates through the microwave transmission lines. Hence, directional couplers are component in almost every microwave applications for measuring the power levels of the signals in the system, working at high power levels [1].

Couplers are four port microwave device. Four ports can be achieved by using two similar transmission line or different microwave transmission line. Depending upon the structure of the transmission line used coupler types may vary as microstrip, stripline, waveguide and coaxial line [2]. Selection depends of transmission line upon the application of the coupler. The four port of the directional coupler are: Input port, Through port, Coupled port, Isolated port as shown by fig. 1 and 2. The physical property of transmission line used with and coupling method provides us different coupler structures, having different advantages and disadvantages. Hence the selection of structure is dependent of the application used for. Microstrip and stripline couplers provides god broad band properties but they gives more losses at high power. Waveguide bethe hole couplers are mostly used at high power application where the bandwidth is related with directivity[1].

This paper discussed about the coupler to be used for high power applications, preferably at 50MW. For such high operating power waveguides are selected over microstrip and stripline. High power microwave systems used for gen-eration of high intensity electric fields which can be used for vulnerability and susceptibility testing of electronic systems. For the measurement of power at source end in these kind of systems a very low coupling and high directivity directional coupler is required [3]. The design proposed in the paper satisfies the application with 60dB coupling and 30 dB directivity.

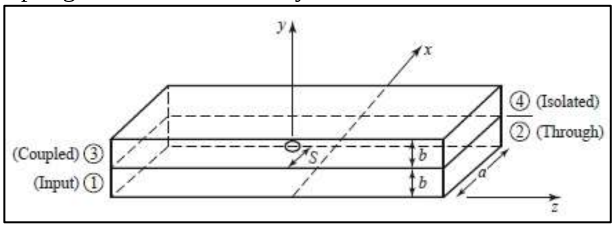

Fig. 1: Basic Bethe Hole Parallel Guide Directional Coupler [4]

In Earlier days calorimetric method was used in the measurement of high power microwave signals in the mi-crowave system. In this methodology, the output signal from the microwave system is passed through the water to generate heat from water vapor. Then the power is calculat-ed from amount of the heat generated by vapors [5]. The results generated from this technique is affected by various conditions such as water pressure, water flow rate, room temperature. Futher it also has many disadvantages like lower accuracy, affected by environmental conditions. To make results independent from such ambient conditions, directional couplers are opted, Which certainly provides much better accuracy as well as less affected by the envi-ronmental conditions, also they are easy to install and re-place in the microwave system. Also it's easy to monitor output power spectrum.

Several researchers worked in the field mentioned to showing various kinds of structures to improve directivity and coupling for the directional coupler with various wave-guide structures. Like composite distribution, which provides smaller ripple, higher directivity and wider bandwidth used for the combination of rectangular and cylindrical waveguide[6]. Also, crossed waveguide broad wall direc-tional coupler shown in [7], gives lower limit to directivity by the use of magnetic polarisability and electric polarisability ratio for small apertures. Here small apertures refers the apertures with small radius compared guide wave-length.Work from [5] shows the effect of aperture numbers and separation on coupling.

In this paper, a rectangular waveguide directional cou-pler design with 3 GHz center frequency is discussed. Paper isdivided in three sections, namely basics of directional coupler in section II, design methodology III and last ses-sion IV which will provide the comparative results for the design.

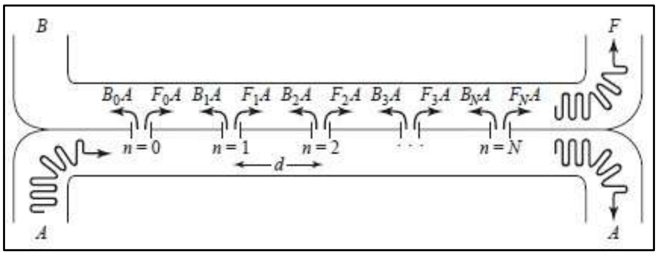

Fig. 2: Geometry Of N+1 Hole Waveguide Directional Coupler[4]

II. DIRECTIONAL COUPLER

Directional couplers are commonly used as measuring device in microwave instruments where it takes the sample of the input power of the signal to measure its amplitude provided at a port. Here waveguides are used as microwave transmission lines, hence called Waveguide Directional-Coupler. General structure of the Bethe hole waveguide directional coupler is shown in fig. 1. An ideal coupler can be characterized completely by the specifications as coupling factor (C), and isolation (I) or directivity (D). Coupling shows the amount signal power that is to be taken from the input for the calculation [8]. The coupling between the two waveguides is achieved by means of the apertures between it at the common broad walls as shown in fig 3.

The single aperture coupler provides narrow bandwidth, so to improve the bandwidth multi-hole apertures are intro-duced [9]. Its principle and operation is similar to as the multi section quadrature wavelength transformer. The struc-ture of multi-hole coupler is shown by the fig 2.

For the working of the multi aperture directional cou-pler, all the signals coming at the coupling port end needs to be in phase with each other, so that it should get summed up and produce the equivalent output. While the signals at isolated port end should be out of phase so as to get cancel out and produces no output at that port. The difference between the power levels at this two port is given by the directivity of the directional coupler. This can be achieved by having proper separation between the apertures, ideally λg/4 as the signal would travel same distance in both waveguides, before it could arrive at coupling port, thus getting in-phase signal while for isolated port the signal would have to travel different distance in two waveguides, hence getting out of phase signal resulting cancellation [8]. This is observed in 2.

For a directional coupler every input will produce two waves forward wave and backward wave given as, A+ 10 and A10 It is defined for single hole coupler. when it comes about the multi hole coupler it will change as in equation (1) and equation (2).

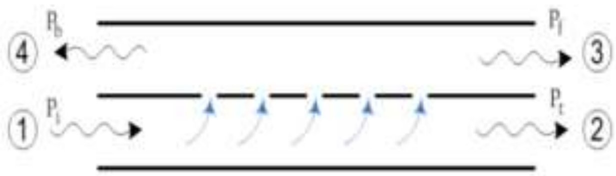

Fig. 3: Aperture Coupling In Waveguide Directional Coupler [4]

$$F = Ae^{j\beta Nd}\sum_{n=0}^{N} F_n \tag{1}$$
$$B = A\sum_{n=0}^{N} B_n e^{-2j\beta Nd} \tag{2}$$

As coupling coeff are proportional to polarizabilities αe and αm, which is further proportional to r^3_n. Hence we have, Fn = kf r^3_n and Bn = kb r^3_n .

Hence have coupling from equation above Coupling and directivity is given as,

$$C = -20\log\left|\sum_{n=0}^{N} F_n\right| \quad \text{(dB)} \tag{3}$$
$$C = -20\log\left|\sum_{n=0}^{N} k_f\right| - 20\log\left|\sum_{n=0}^{N} r_n^3\right| \quad \text{(dB)} \tag{4}$$
$$D = -C - 20\log|k_b| - 20\log S \quad \text{(dB)} \tag{5}$$

Where,

$$S = \left|\sum_{n=0}^{N} r_n^3 e^{-2j\beta nd}\right| \tag{6}$$

Depending upon the distribution the radius is found by using the equation 6. In this paper the distribution is chosen as Chebyshev Distribution. and the detailed design is dis-cussed in next section, section III.

III. DESIGN PROPOSED

For the design of directional coupler, the operating fre-quency with frequency range and center frequency, required coupling and minimum directivity should be known. For the proposed design the operating frequency range is S band frequencies (2.6 GHz - 3.95 GHz) with the center frequency as 3 GHZ is selected. As waveguides are usedas transmission lines we have standard waveguide defined for the particular frequency range. In frequency band of our interest i.e. 2.60 3.95 GHz, WR284 waveguide is a standard waveguide defined. The inner dimensions (a x b) of the waveguide are 7.214 x 3.404 cm [4]. Coupling between these two waveguides is achieved by using apertures and it is governed by small aperture coupling theory proposed by Bethe [10], later improved by Cohn and McDonald [11]. By small coupling aperture theory, apertures can be represented as an infinitesimal electric dipole and/or an infinitesimal magnetic dipole and the fields generated by these dipoles gives the coupling [4]. Depending upon the aperture placement it is classified as Broad wall coupler or Side Wall coupler.Design proposed follows broad wall coupling as it gives more surface.Hence, the apertures are placed between the common broad wall between two waveguides to achieve the coupling between the waveguides.

The coupling required and minimum directivity speci-fied for the design are 60 dB coupling and 30dB minimum directivity. Depending upon the operating frequency, cou-pling and minimum directivity, and calculations are made to find out design specifications by using the fields equations. For TE10, the field equations are given as,

$$E_y = A\sin\left(\frac{\pi x}{a}\right)e^{-i\beta z} \tag{7}$$
$$H_x = \frac{A}{Z_{10}}\sin\left(\frac{\pi x}{a}\right)e^{-i\beta z} \tag{8}$$
$$H_z = \frac{j\pi A}{\beta a Z_{10}}\cos\left(\frac{\pi x}{a}\right)e^{-i\beta z} \tag{9}$$

Where,

$$Z_{10} = \frac{k_0\eta_0}{\beta} \tag{10}$$

These field equations will give amplitude of the wave. Depending upon the type of distribution with the use of equation 3, 5 and 6, will give the value of the S, in terms of distribution. Here, chebyshev distribution is used so the formula reduces to equation 11 and 12, depending upon the number of apertures.

For even N,

$$S = \left|\sum_{n=0}^{N} r_n^3 e^{-2jn\theta}\right| = 2\sum_{n=0}^{N/2} r_n^3 \cos(N-2n)\theta \quad (11)$$

For odd N,

$$S = 2\sum_{n=0}^{(N-1)/2} r_n^3 \cos(N-2n)\theta = k|T_N(\sec\theta_m \cos\theta)| \quad (12)$$

The design procedure followed along with design issues is discussed as:

A. *Selection of Waveguide:*

There are standard rectangular waveguides defined over the entire frequency range. In frequency band of our interest i.e. 2.60 3.95 GHz, WR284 waveguide is a standard waveguide defined. It's dimension is 72mm x 34mm. It is used for the design.

B. *Type of Distribution:*

Chebyshev coupler has good Depending upon the type of response chebyshev (equal ripple) or binomial (maximally flat) response for the directivity varies. For broad band performance over the binomial one, but requires good manufacturing accuracy [1]. Hence, here design is made with chebyshev distribution.

C. *Number of Coupling Apertures:*

The number of apertures are so chosen that it should give required coupling and directivity. The effect of changing aperture numbers are shown in the fig. 4.

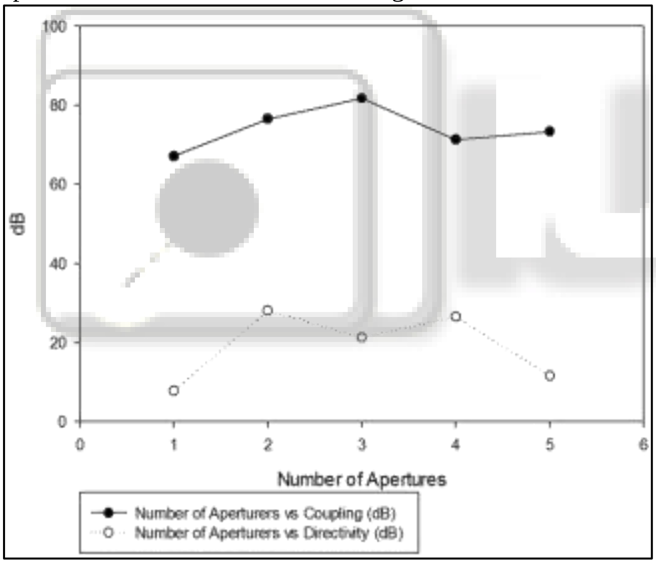

Fig. 4: Coupling and Directivity Compared With Number of Apertures

D. *Radius of Coupling Apertures:*

Radius of the apertures are dependent on the minimum directivity specified. It can be directly specified by the formula. As the number of apertures changes its, the radius of apertures need to keep good cupling also changes with that. It is shown in fig. 4.

E. *Separation between Coupling Apertures:*

After choosing number of apertures and their radius, it is must to know the separation d between the apertures as it directly affects directivity. Ideally separation should be λg/4. But it is seen that if the separation is kept below the λg/4 then the directivity is decreases. Also for the standard value,it does not provide good result. But if the separation is kept little above the standard value, it will shows good results for directivity. But again affects if the separation is made too high.

F. *Type of Bend in Secondary Waveguide*

The bending of secondary waveguide is useful when the device is to be connected to system. Depending upon the slope and shape of the bend, directivity changes. Coupling is mostly unaffected by changing the bending of the secondary waveguide.

IV. RESULT AND DISCUSSION

The waveguide directional coupler is designed with the specifications mentioned below:

Operating Frequency	:	3GHz
Waveguide Dimension	:	72.14 mm x 34.04 mm
Aperture Position from wall	:	18.035mm
Separation between Apertures	:	36mm
Radius of apertures	:	4mm

The values of radius of apertures for chebyshev distribution is calculated from equation 11 and 12. For the proposed design structure, coupling and directivity comparison over given frequency range for this design is given by fig. 5 respectively.

V. CONCLUSION

A method of design of waveguide directional coupler using rectangular waveguide with aperture coupling is pre-sented here with the supportive numerical analysis and are verified using simulation using microwave CST studio. Good amount of coupling is observed by keeping the sepa-ration between the apertures little greater than the g/4. Also the coupling is improved by keeping different radius for different aperture pairs. Introducing a bend in the secondary waveguide will not affect the coupling but coupling is seems to be improved. Hence, a 4 aperture directional coupler with 60dB coupling and 30dB minimum directivity with 3GHz as center frequency is designed.

In rectangular waveguide it is easy to provide excitation but the attenuation increases with frequency. The model is analysed numerically and simulated using simulation tools and under the fabrication, so the testing results on VNA are yet to observe.

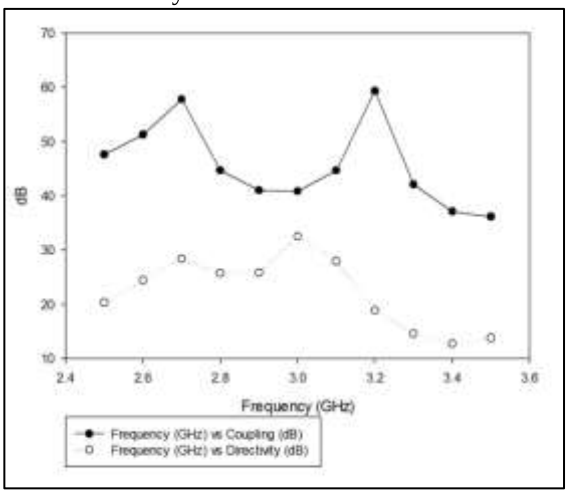

Fig. 5: Coupling and Directivity Vs Frequency

VI. ACKNOWLEDGEMENT

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