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Design and implementation of microstrip directional coupler for satellite communication application

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***Abstract*— This paper proposes to design a microstrip directional coupler with a -10 dB coupling factor with high directivity working in S-band within frequency 2.25 GHz by using Aktarzad, ROW Botham and Jones way to give high accuracy. The calculation of shape ratio w/h and space ratio s/h synthesis by Bryant and Weiss technique. The paper takes all the representation of design by using the calculations of main parameters and Computer-aided design - CAD to arrive at the optimization case. The manufactured device by using Rogers 3003 microwave board and is measured by a spectrum network analyzer. The comparison between the results of software and practical measurements gives perfect close results. This paper shows the better steps to design the parameters of a microstrip directional coupler with high directivity.**

***Index Terms*—Microstrip directional coupler, high directivity, odd and even characteristic impedances, and satellite application.**

I. Introduction

The Directional coupler is the one widely uses as a microwave device, it consists of two individual directional and coupler terms, electrically consisting from two circuits by side so that they have on each other and that depending on just how close they are [1][6].

The coupler circuits will be microstrip lines couplers. The structure has the same widths of parallel microstrip lines. The calculations can describe the useful estimating degree of unwanted coupling between the waves on microstrip lines on the same substrate.

The odd and even mode of characteristic impedances (Zo_0 and Zo_e) have more significance than any parallel coupled lines within the substrate permittivity and the coupled structure [1].

There are important parameters for any coupler design like coupling factor C, Isolation I, transmission factor T, and directivity D. And must know the difference phase velocities by odd and even modes will cause the main effect of which is to degrade the directivity [2].

The important specification for a coupler will include:

The coupling factor C at the mid-band frequency (usually in dB), permittivity ε_r and thickness of the substrate of the board, the characteristic impedance of ports Z_0 (usually 50 Ω), bandwidth and center frequency, Lowest acceptable directivity D in dB, and the tolerance of coupling factor over the band (sometimes) [3] [4].

From all of this information, the designer must be find the widths of microstrip lines and the separation between them and the coupled region length and the insertion loss as a function of VSWR or the frequency required over the band, then the values of odd and even mode of characteristic impedances (Zo_0 and Zo_e) and the final synthesis problem is then identical to that a couple [5].

The manner of Bryant and Weiss to synthesis technique of the shape ratios (w/h and s/h) are determined from (Zo_0 and Zo_e), then using these values w/h and s/h, recalculate Zo_0 and Zo_e that means of the semi-empirical analysis formulae. And last step the compare the newly calculated value of Zo_0 and Zo_e with those originally required [6] [7].

Either synthesis technique by Akhtarzad is modified to obtain greater accuracy [8].

The coupler directivity is a quality factor of the directional coupler and is defined as the amount of power appearing at an uncoupled port [6].

Return loss could find by equations, response figures, or table [9] [10], see Table I and Table II.

TABLE I
VSWR TO RETURN LOSS CONVERSION CHART [9].

VSWR	Return Loss (dB)
1.098	26.612
1.099	26.528
1.100	26.444
1.102	26.281
1.104	26.120

TABLE II
VSWR TO RETURN LOSS AND OTHER PARAMETERS [10].

Return Loss (dB)	VSWR	Reflection Coefficient, Γ	Mismatch Loss (dB)	Reflected Power (%)	Through Power (%)
25	1.12	0.056	0.014	0.32	99.68
26	1.11	0.050	0.011	0.25	99.75
27	1.09	0.045	0.009	0.20	99.80

II. Design Calculations:

To design a (-10 dB) microstrip directional coupler must consider the following requirements:

1- Coupling factor $c' = -10\ dB$
2- Single microstrip feed line characteristic impedances Z_0 = 50 Ω
3- Substrate permittivity ε_r = 3
4- Thickness of board = 1.52 mm
5- System center frequency = 2.25 GHz.

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A- The odd and even characteristic Impedances

The odd and even mode of characteristic impedances (Zo_0 and Zo_e) are important parameters to design a parallel coupled transmission line. These impedances are according to functions of the degree of coupling factor (C) and the characteristic impedance (Zo) (often 50 Ω) of single line terminating. The relationships between Zo_0 and Zo_e and physical dimensions of coupled transmission lines are major for the designer (including the substrate permittivity ε_r). Analysis of odd and even mode of characteristic impedances (Zo_0 and Zo_e) as a function of Shape ratio (w/h), Spacing ratio (s/h), and permittivity of substrate material (ε_r) [6].

The following results were calculated according to the above requirements.

$$Zo_o = Zo\sqrt{\frac{1-10^{c'/20}}{1+10^{c'/20}}} \quad (1)$$

= 36 Ω

$$Zo_e = Zo\sqrt{\frac{1+10^{c'/20}}{1-10^{c'/20}}} \quad (2)$$

= 69.37 Ω

B- The characteristic impedances approximation calculation of coupling around -10 dB or more so

$$Zo = \sqrt{Zo_e Zo_o} \quad (3)$$

= 49.973 Ω

To calculate the single microstrip characteristic impedances are

$$Zo_{so} = \frac{Zo_o}{2} \quad (4)$$

=18 Ω

$$Zo_{se} = \frac{Zo_e}{2} \quad (5)$$

= 35 Ω

C- Shape ratio w/h and Spacing ratio s/h

The shape ratio of w/h and s/h are found from Zo_0 and Zo_e by two universal graphs, equations, or with aid of software [12]. Both cases must go with two stages. The fir stage involves the determination of an equivalent single microstrip ratio (w/h). The second stage has the required shape ratio (w/h) and spacing ratio (s/h) of coupled microstrip structure to the equivalent of single microstrip shape ratios. The final results will be independently about the permittivity of substrate for a considerable range and are given by Akhtarzad, Row Botham, and Jones, not only by graphical form but also by formulas [6][8].

D- Calculations of w/h and s/h

$$g = \cosh\left(\frac{\pi s}{2h}\right) \quad (6)$$

= 1.03

Where

S= 0.24,

h = 1.25 and

$$d = \cosh\left(\pi\frac{w}{h} + \frac{\pi s}{2h}\right) \quad (7)$$

= 275.6

1) $$\left(\frac{w}{h}\right)_{so} = \frac{2}{\pi} cosh^{-1}\left(\frac{2d-g-1}{g-1}\right) + \frac{4}{\pi\left(1+\frac{\varepsilon r}{2}\right)} cosh^{-1}\left(1+2\frac{\frac{w}{h}}{\frac{s}{h}}\right) \quad (8)$$

= 8.64

2) $$\left(\frac{w}{h}\right)_{se} = \frac{2}{\pi} cosh^{-1}\left(\frac{2d-g+1}{g+1}\right) \quad (9)$$

= 4

3) $$\frac{s}{h} = \frac{2}{\pi} cosh^{-1}\left[\frac{\cosh\left[\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)_{se}\right] + \cosh\left[\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)_{se}\right] - 2}{\cosh\left[\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)_{se}\right] - \cosh\left[\left(\frac{\pi}{2}\right)\left(\frac{w}{h}\right)_{se}\right]}\right] \quad (10)$$

= 0.149

E- Coupling region length

The maximum degree of coupling occurs when the length of the coupling region is made λgm, where λgm is the mid-band wavelength.

As a rough first approximation will lose the coupling amount perhaps less than – 10 dB and we can consider that uncoupled, the width of the microstrip evaluates the mid-band wavelength. To avoid the error rise to 10 % or more, the odd mode and even mode of wavelength should be taken for greater accuracy [6].

$$\lambda = \frac{c}{f} = \frac{3*10^8}{2.25*10^9} \quad (11)$$

= 133.33 mm

$$\lambda_{gm} = \frac{\lambda}{\sqrt{\varepsilon_r}} = \frac{133.33}{\sqrt{3}} \quad (12)$$

= 76.98 mm

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Quarter wavelength

$$\frac{\lambda_{gm}}{4} = 19.24 \text{ mm} \quad (13)$$

F- Directivity

Directivity is a quality factor of the directional coupler and we can define it as the amount of power that will appear at the uncoupled port and can express as the Isolation minus coupling [11] as shown below.

$$Directivity = Isolation - Coupling \quad (14)$$
$$= 20.51 - 10.407$$
$$= 10.105\ dB$$

G- Return loss

In the construction of a solid homogeneous medium, without air gaps, the voltage standing ratio VSWR becomes the most limiting parameter of frequency on coupler directivity [11] [13]. Return loss according to VSWR in dB is expressed in the equation below. See Table I.

$$Return\ losse\ (dB) = -20\ log_{10}\left[\frac{VSWR-1}{VSWR+1}\right] \quad (15)$$
$$= 26.444\ dB$$

III. SIMULATION DESIGN AND ANALYSIS

The directional coupler was designed by using Genesys software according to theoretical calculations and analyzed by simulation measurements, the sketch of schematic and layout are shown in figures 1 and 2 respectively

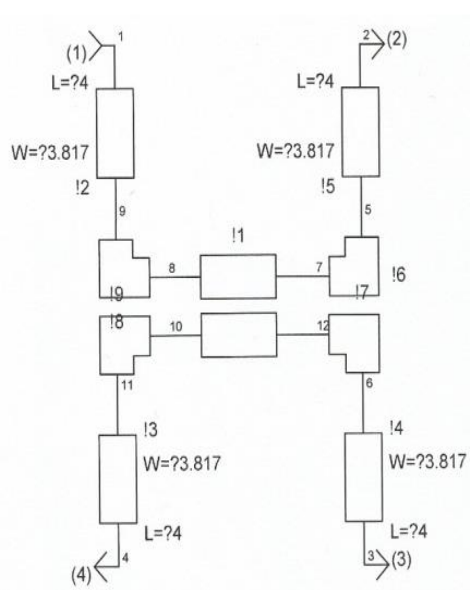

Fig.1: Schematic of directional coupler

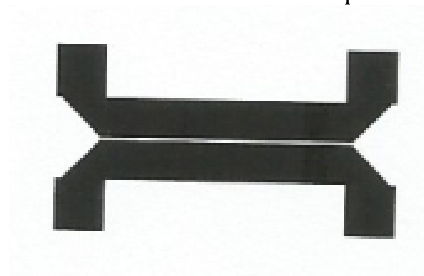

Fig. 2: Layout of directional coupler

1- VSWR for all ports are (1.094) in mid-band (2250 MHz) as shown in Figure 3.
2- The coupling factor in the mid-band is (-10.012 dB) as shown in Figure 4.
3- Input impedance in mid-band (50.8 – j 4.18) ohm, Figure 5.
4- Isolation between the ports in mid-band as following according to Figure 6.
   S12 = S34 = -0.523 dB
   S13 = S24 = -23.664 dB
   S14 = S23 = -10.012 dB
5- Characteristic Impedances for all ports in mid-band as shown in figure 7.
   S11 = (51.888 – j 4.18) Ω
   S22 = (51.888 – j 4.18) Ω
   S33 = (51.888 – j 4.18) Ω
   S44 = (51.888 – j 4.18) Ω

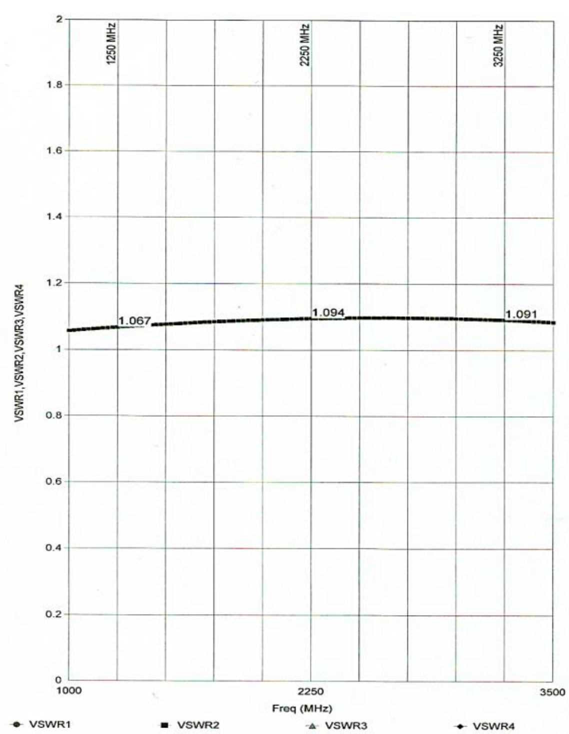

Fig. 3: VSWR of ports

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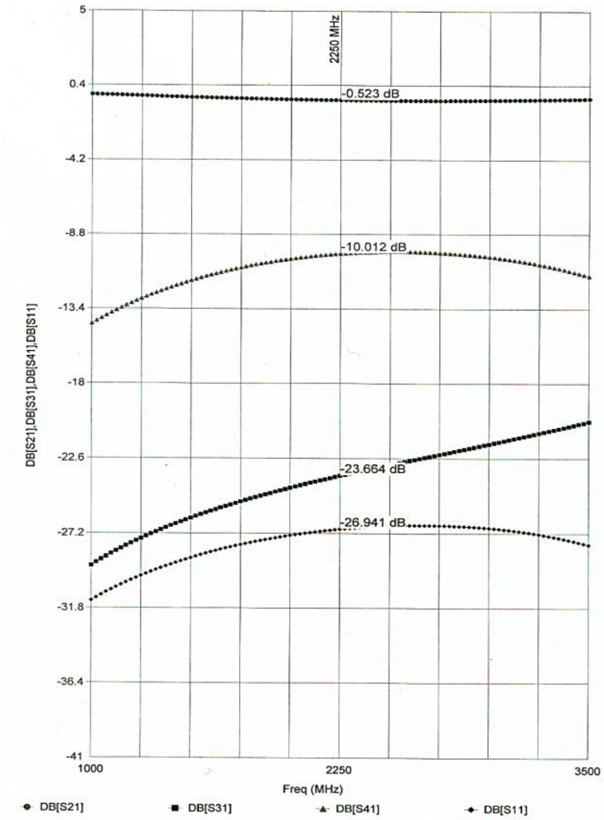

Fig. 4: Coupling factor of directional coupler

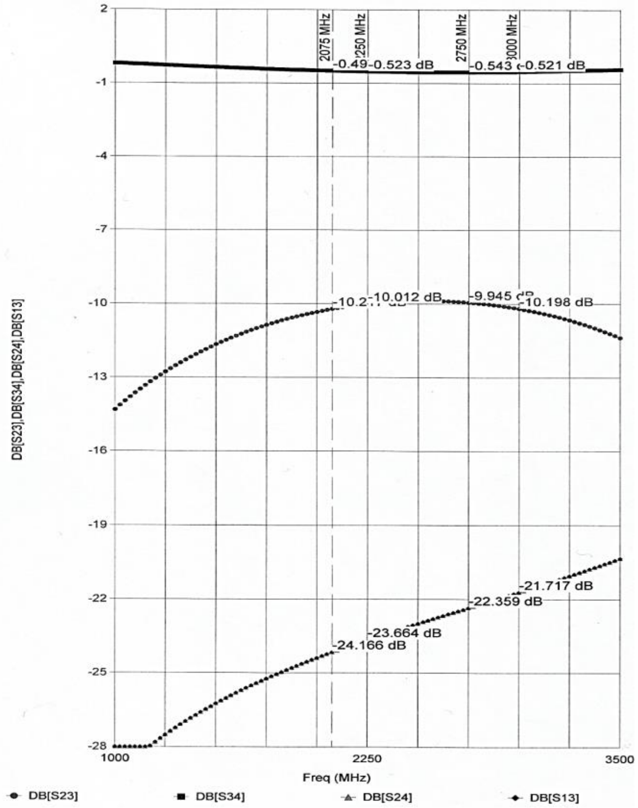

Fig. 6: Isolation between the ports

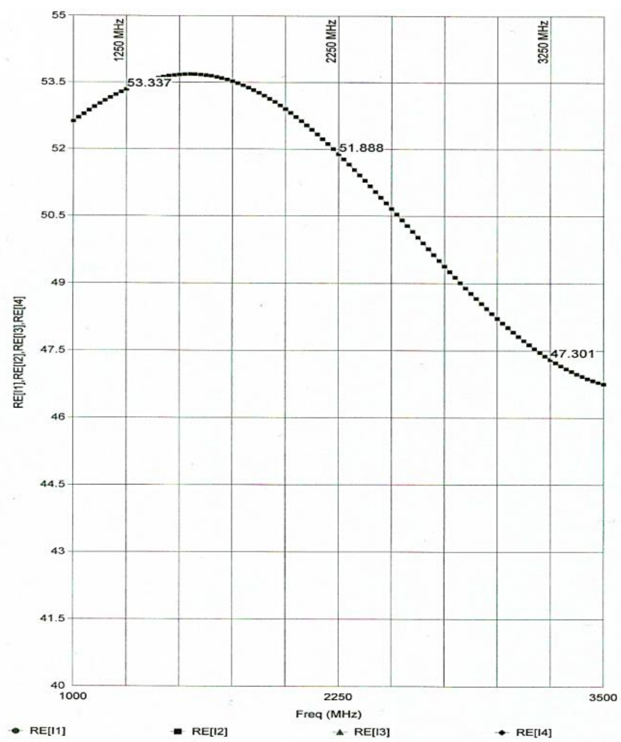

Fig. 5: Input impedance of directional coupler

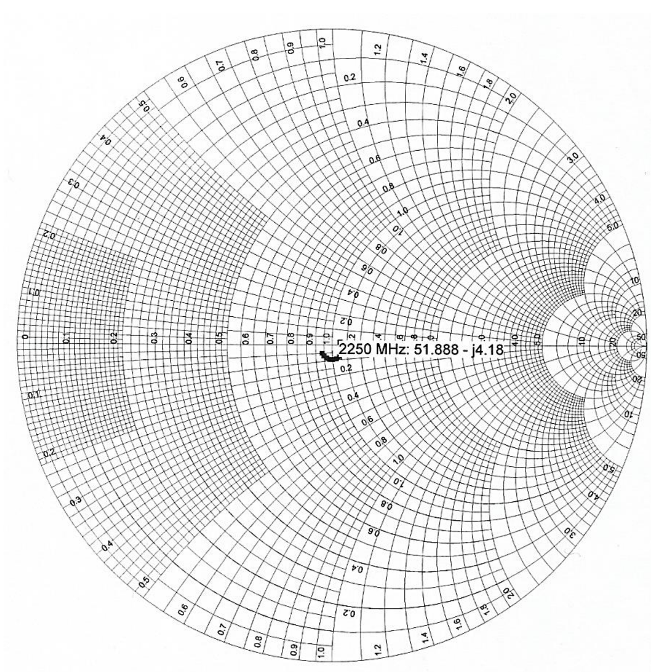

Fig. 7: Characteristic impedances of ports

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IV. PRACTICAL MEASUREMENTS

Manufactured the directional coupler by Using Rogers 30003 microwave board see Figure 8, after manufactured made practical measurements by spectrum network analyzer (hp-Agilent- 8510 A), as shown in figures 9,10,11,12 and 13 respectively.

Fig. 8: Manufactured directional coupler

1- VSWRs in mid-band (2250 MHz)
   S11 = 1.11, S22 = 1.227, S33 = 1.133 AND S44 = 1.304
2- Coupling factor = -10.4 dB
3- Input impedance = (47.033 – j 4.162) Ω
4- Isolation between ports
   S12 = S34 = - 0.88 dB
   S13 = S24 = - 20.5 dB
   S14 = S23 = - 10.40 dB
5- Characteristic impedances for all ports
   S11 = (47.033 – j 4.162) Ω
   S22= (49.334 – j 10.105) Ω
   S33 = (52.215 – j 6.009) Ω
   S44 = (55.506 - j 12.912) Ω

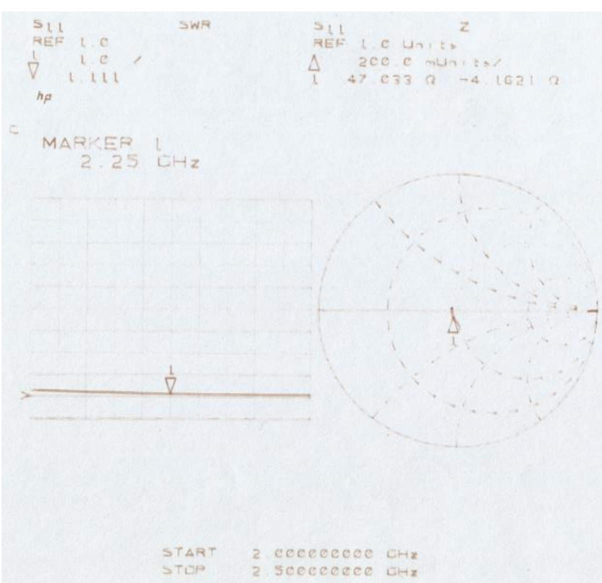

Fig 9: VSWR and input impedance of port 1.

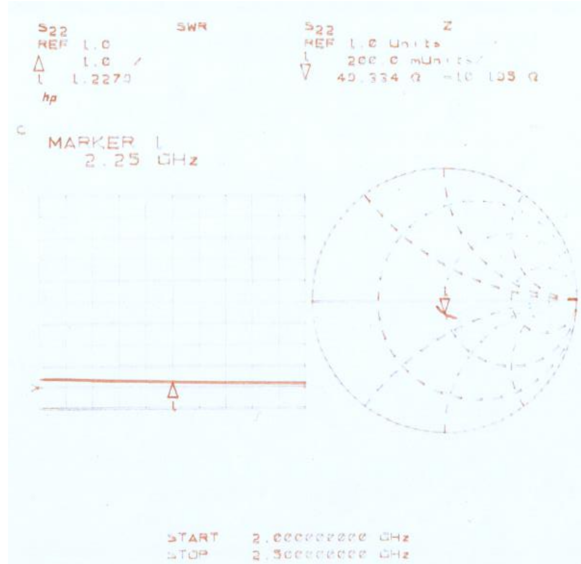

Fig. 10: Fig 9: VSWR and input impedance of port 2.

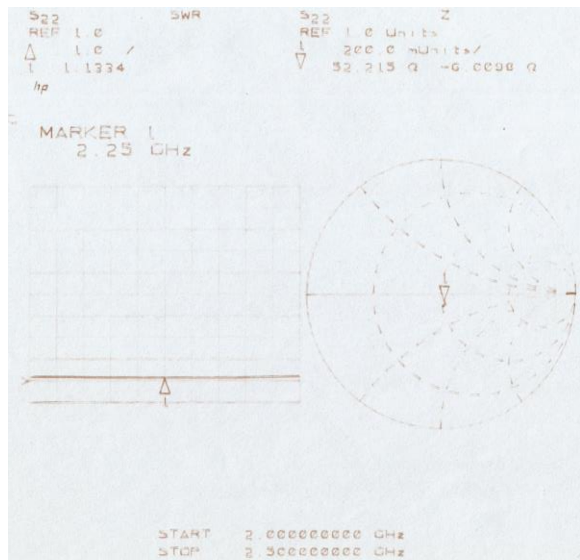

Fig 11: VSWR and input impedance of port 3.

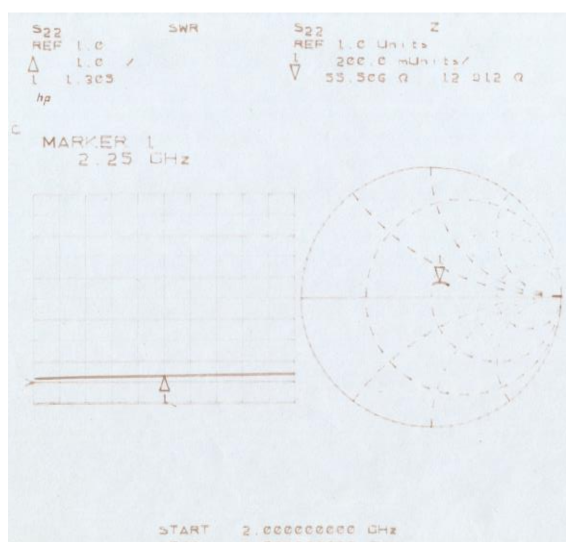

Fig 12: VSWR and input impedance of port 4.

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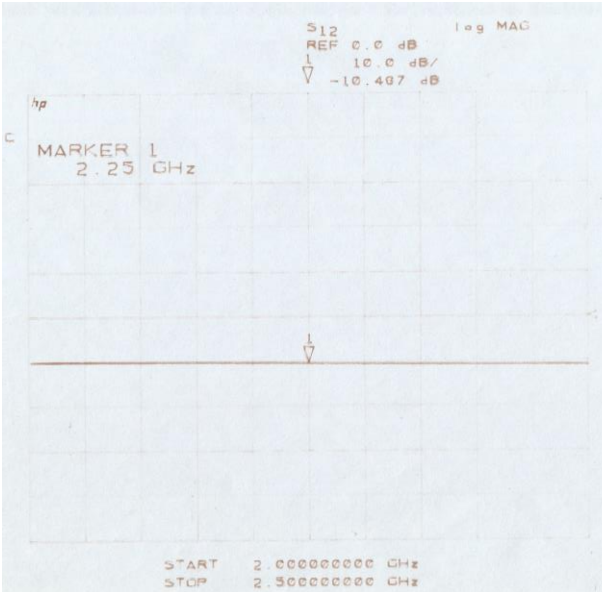

Fig 13: Coupling factor of Directional Coupler

V. Comparison between Software and Practical measurements as shown in table III.

TABLE III
COMPARISON BETWEEN SOFTWARE AND PRACTICAL MEASUREMENTS

Parameter	Software measurements	Practical measurements
VSWR	S11 = 1.094, S22 = 10.94 S33 = 10.94, S44 = 1.094	S11 = 1.111, S22 =1.227 S33 = 1.133, S44 =1.305
Coupling factor	-10.012 dB	-10.4 dB
Input impedance	(50.888– j 4.18) Ω	(47.033 – j 4.162) Ω
Isolation	S12 = S34 = -0.523 dB S13 = S24 = -23.664 dB S14 = S23 = -10.012 dB	S12 = S34 = - 0.88 dB S13 = S24 = - 20.5 dB S14 = S23 = - 10.40 dB
Characteristic impedances	S11= (51.1888 – j 4.18) Ω S22= (51.1888 – j 4.18) Ω S33 = (51.1888 – j 4.18) Ω S44 = (51.1888 – j 4.18) Ω	S11 = (47.033 – j 4.162) Ω S22= (49.334 – j 10.105 S33 = (52.215 – j 6.009) Ω S44 = (55.506 - j 12.912

TABLE IV
THE PRACTICAL SPECIFICATIONS OF MANUFACTUREDMICROSTRIP DIREC COUPLER

Frequency band	1.25 – 3.25 GHz
Coupling factor	10 dB
Coupling deviation	± 1 dB
Insertion loss	0.2 dB
Directivity	10.105 dB
Input Impedance	50 Ω
Input VSWR	1.21: 1 (maximum)
Power	15 w
Connectors	Type SMA (female)

VI. Conclusion

This paper designed and implemented the Microstrip Directional coupler within 10 dB coupling factor with frequency band 1.25 to 3.25 GHz used in satellite communication and different applications. Using Akhtarzad, ROW Botham, and Jones and Bryant and Weiss manners to calculate the parameters of the directional coupler. The main parameters within center frequency 2.25 GHz to achieve and improve the impedance mismatching to arrive at 50 Ω and try to have high directivity within 10.105 dB and return loss 26.444 dB versus 1.11 VSWR. The comparison between the simulation results and practical measurements was closely for implemented microstrip directional coupler.

In implementation Using Rogers 3003 board has a substrate permittivity ε_r = 3 and thickness of the board (h) = 1.52 mm. This paper shows the correct steps to design and implement the microstrip directional coupler.

VII. References

[1] S. Uysal, (1993). *Nonuniform line microstrip directional couplers and filters*. Boston: Artech House.

[2] HHV. Tas and A. Atalar, (2013). "Using Phase Relations in Microstrip Directional Couplers to Achieve High Directivity," *IEEE Transactions on Microwave Theory and Techniques*, vol. 61, no. 12, pp. 4063-4071.

[3] Pu M, Yao N, Hu C, Xin X, Zhao Z, Wang C, Luo X (2010). Directional coupler and nonlinear Mach-Zehnder interferometer based on metal-insulator-metal plasmonic waveguide. Opt Exp 18:21030– 21037

[4] Jia Wang, Tianqing Ling, (2019). Novel broadband design of SIW directional coupler, IET International Radar Conference.

DOI: http://doi.org/10.24086/cocos2022/paper.810

[5] Robert Smolarz, Slawomir Gruszczynski, Krzysztof Wincza, (2017). Multisection Ultra-Broadband Directional Coupler Designed in MMIC Technology, IEEE Access, doi: 10.1109/ACCESS.2021.3061384.

[6] Bryant, T.G., and Weiss, J.A., (1968, December)."Parameters of Microstrip transmission lines and coupled pairs of microstrip lines, IEEE Trans..MTT-16, No.12, 1021-1027.

[7] J. Ha and Y. Lee, (2013), "Miniaturized quasi-asymmetric forward-wave coupled-line coupler with arbitrary coupling level," IEEE MTTS International Microwave Symposium Digest (MTT), Seattle, WA, pp. 1-3.

[8] Akhtarzad, S., ROW Botham, T.R., and Jones, P.B., (1975, June)," the design of coupled Microstrip lines, IEEE Trans., MTT-23, No.6, 486-492.

[9] https://www.amphenolrf.com/vswr-conversion-chart. (2022), Return Loss to VSWR Conversion Chart.

[10] https://www.markimicrowave.com, (2016), return-loss-to-vswr and main parameters.

[11] Edwards T.C., (1983, February) "Foundation for Microstrip Circuit Design", John Wiley and Sons Ltd.

[12] Firas M. Zeki Mahmood and Adil H. Aldalawie, (2019), "Design and Implementation a Non-uniform Helical Antenna in Frequency Range of 450–850 MHz for Ultra-high frequency Television Application", Cihan University-Erbil scientific journal- SUESJ, DOI: 10.24086/cuesj.v3n2y2019.pp75-79.

[13] Firas M. Zeki Mahmood, (2013), "Design and implementation of circularly polarized microstrip patch antenna to construction array For Spin–Stabilized Satellites with octagonal shape", Al-Yarmouk university journal, vol. 1, p. 1-17.