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Design and Verification of Strip Line Directional Couplers for Various Applications in RF and Microwave Communication Systems

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***Abstract*— Strip line version is the microwave integrated version of the microwave device that attracts towards miniaturization of the device without loosing the performance of the actual device. Compactness, lightweight, low loss, low cost, reproducibility and easy fabrication are the features of the miniaturized circuit. Design, fabrication of a 20 dB coupler operating from 2GHz to 8 GHz is carried out according to the procedure outlined The fabricated coupler is tested and results found to be encouraging. Also, the design and development of the multi octave bandwidth coupler operating from 6-18GHz and for a coupling value of 6 dB is carried out. For the design of this coupler, the offset parallel configuration is used. In this, the circuit is on both sides of the RT- Duriod of thickness of 5mil. The coupler has been fabricated and tested with Network Analyzer test setup. The basic parameters of the couplers i.e. Coupling, Return loss etc are measured. The experimental results are in close agreement with the theoretical predictions. A 20dB directional coupler finds a variety of other applications i.e. power monitoring, reflectometer, power divider, in radar systems, for the measurement of frequency etc in RF and microwave communications where as a 3dB coupler may be used for power-monitoring device in antenna applications**

Key words: stripline, reproducibility, reflectometer, miniaturization, power monitoring and radar systems.

I. INTRODUCTION

In today's microwave practice, the Directional Coupler has become a virtually indispensable measurement tool. Though it is well discussed with its basical form in waveguide version, state of art applications demands minaturisation of its size. The stripline version of the coupler reduces its size anormusly . These are passive microwave components used primarily for power division. In this paper, design, fabrication of stripline version of 20 dB and 6dB couplers is carried out according to the procedure outlined.

Designs of optimum asymmetrical directional couplers of two to six sections were published by Levy [1]. These coupler designs have an equal-ripple approximation to the mean coupling. They are optimum in the sense that they provide a maximum bandwidth for a given number of sections, a given mean coupling, and a given coupling tolerance. To date, however, the exact design of optimum symmetrical couplers, i.e., symmetrical couplers having an equal ripple approximation to the mean coupling, has been limited to couplers of at most three sections [2], [3]. Although symmetrical directional couplers of more than three sections can be synthesized on the basis of a firstorder theory [4] these designs did not maximize the bandwidth since they do not necessarily provide an equal-ripple approximation to the mean coupling. Furthermore, for strong coupling, the first-order theory does not guarantee physically realizable results. To meet the increasing requirement of micro-wave systems of compact size, lightweight, low loss, low cost, reproducibility and easy fabrication are required. Stripline configuration [5] in edge-coupled or end coupled configuration can be designed for broadband operation and low insertion loss,where the modified broadside-coupled transmission line structure is used as a circut element.

The directional coupler containing matched calibrated detectors in both ports of the auxiliary line which is used to sample or detect the power flowing in the forward and backward directions is known as 'Reflectometer'. This enables correct matching of antennas to be checked. With calibration the forward and reflected powers may be deduced which can be used for finding reflection coefficient and VSWR. The directional coupler finds a variety of applications i.e. power monitoring, reflectometer, power divider, in radar systems, for the measurement of frequency etc.[6] .

The problem is defined in sec.II. Design and fabrication of 20dB coupler is dealt in Sec.III. The 6dB coupler design explained in sec.IV.The results obtained using the coupler are explained in Sec.V. A set of tables for useful data is given at appendix for ready reference.

II. FORMULATION OF THE PROBLEM

This paper, discusses the design and development of the multi octave bandwidth couplers for microwave applications. A -20dB Coupler is presumed for design at frequency band of 2GHz to 8 GHz. The thickness of the dielectric thickness (*b*) is 1.55mm(0.062") and Dielectric is R.T. duroid [7] of constant(ε_r) 2.2. A 6dB coupler is to operate from 6 GHz. to 18 GHz. For the design of this coupler, the offset parallel configuration is used. In this, the circuit is on both sides of the RT- Duriod of thickness of 5mil (1.27mm). For the design of these couplers, strip line configuration is used because it is having less loss compared to microstrip configuration. For the design, the closed form suggestions of Crystal and Young[8] are given as Appendix as a ready reference .A 6dB coupler operates from.

III. COUPLER OF 20DB COUPLING FOR MICROWAVE APPLICATIONS

The lower limit of the frequency 'f_1' is i.e. 2GHz,. F_2 is the upper limit of the frequency specified 8GHz. , *fo* is the average of these frequencies i.e. 5GHz, Fractional band width is estimated as 1.2, Band width ratio 'B' is found as 4, These calculations are based on equations presented in appendix. Number of sections in coupler are assumed to be 5.
The implementation of suggestions in Tab.A.1 is based on the agreement of 'w' and 'B' of the design specifications with tabulated values. The at minimum possible ripple observable from Tab.A is 0.2, w is 1.32734, B is 4.94656, the normalized impedances of first three sections are obtained at minimum ripple 1.01016, 1.04183, 1.17873 respectively. The rest of sections have impedances of first and second sections due to design symmetry The center frequency is chosen as 5.35 GHz and the coupler covers a band of 1.8 to 8.9 GHz. The effective length of each section is λ/4(9.45mm in this design). These suggested values are closer to proposed specifications with respect to center frequency, maximum and minimum frequencies. Using equations of [8], the width and spacing for each section are estimated and tabulated in Table.1. These will form as design data for fabrication of strip line version of coupler in the problem. The 4th and 5th rows of the tables reveals that the design is in symmetry of the 4th and 5th sections with 2nd and first section of the coupler

TABLE1: DESIGN OF STRIPLINE DIRECTIONAL COUPLER

Section No.	Width(mm)	Spacing(mm)
1	1.28	1.61
2	1.26	0.91
3	1.23	0.27
4	1.26	0.91
5	1.28	1.61

IV. COUPLER OF 6DB COUPLING FOR ANTENNA POWER MONITORING APPLICATIONS.

For the design of this type of coupler, the tapered line techniques are used. The non-uniform line couplers are tapered gradually to permit usage without modification of physical coupling data based on infinitely long, uniformly coupled line calculations. The tapered line configuration is mainly used for the improvement of directivity. In stepped line couplers, there exists evanescent modes because of abrupt discontinuities between transition regions, but in tapered line couplers these will be negligible.
Here a non-uniform transmission line is treated whose characteristic impedance curve equals the even mode impedance of the coupler and the reflection coefficient of the transmission line is equal in magnitude and phase to the coupled arm response of the coupler.
The reflection coefficient distribution is given by

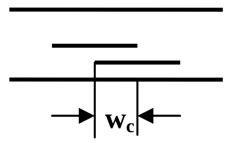

Figure1. Overlap Coupled parallel lines

$$p(u) = -\frac{1}{\pi}\frac{\sin^2\left(\frac{u}{2}\right)}{\frac{u}{2}} \quad (1)$$

A. Tapering Methodology

1. Obtain the weighting function
2. $$w_n = \frac{\pi}{4}(2n-1)\ln\left(\frac{Z_{\frac{N+3}{2}-n}}{Z_{\frac{N+1}{2}-n}}\right) \quad (2)$$

where $1 \le n \le \frac{N+1}{2}$, Z is the even mode impedance, *N* is the number of sections

3. The terms are applied to the function (2) i.e. the first weighting coefficient w_1 multiplies the ordinates of the first positive and negative lobes of (2) which extend to $|u| = 2\pi$, the next coefficient w_3 multiplies the ordinates of the second set of lobes for $|u|$ values between 2π and 4π etc. After all this, we will get a weighting function $p_w(u)$.
4. The even mode characteristic impedance for the distributed coupler can be obtained as described in Table 2

TABLE 2. EVEN MODE TAPERED IMPEDANCES FOR 6 DB COUPLER

Length	Z_{oe}	Length	Z_{oe}
0.0	1.00	0.500	2.479268
0.025	1.000555	0.525	2.403941
0.050	1.004437	0.550	2.201385
0.075	1.014269	0.575	1.935616
0.100	1.030975	0.600	1.672112
0.125	1.053230	0.625	1.453274
0.150	1.077579	0.650	1.295144
0.175	1.099388	0.675	1.195818
0.200	1.114585	0.700	1.144275
0.225	1.121637	0.725	1.125467
0.250	1.122829	0.750	1.122829
0.275	1.125293	0.775	1.121711
0.300	1.143558	0.800	1.114830
0.325	1.194195	0.825	1.099811
0.350	1.292312	0.850	1.078111
0.375	1.449059	0.875	1.053767
0.400	1.666629	0.900	1.031420
0.425	1.929492	0.925	1.014567
0.450	2.195868	0.950	1.004584
0.475	2.400609	0.975	1.000593
0.275	1.125293	1.000	1.000593
0.300	1.143558		

Cohn [9] derived the impedance relations for parallel strips, one above the other between ground planes. This configuration requires three dielectric layers and provides maximum coupling for a layer thickness. For this configuration, shown in figure variation in coupling can be easily achieved by offsetting the strips without changing the thickness of the dielectric layers

$$Z_{oe}(u) = \exp\left[2 \int_{u=-(N+1)\pi}^{u} p_w(u)\right] \qquad (3)$$

after obtaining the even mode impedances in this way, the design equations are applied to get the required parameters.
The condition for the tightest coupling is given by crystal and young

$$\frac{1-\rho_{\max} s}{\sqrt{\rho_{\max}}} = \frac{\sqrt{\varepsilon_r}}{60\pi^2} Z_o \log_e 4 \qquad (4)$$

The design equations suggested by Mathei, Young and Jones [4] are used for finding out the width and spacing. For the required coupling and for the required frequency band of operation[8] w= 1.07404, B= 3.31984 for a ripple value of 0.2. The normalized impedances are Z1= 1.12090, Z_2= 2.14693 (Tab.B). Number of sections are 3. For this procedure and equations follwed for 20dB couper are used.
The center frequency is chosen as 12 GHz. To these impedances, the tapered line technique is used by dividing the overall length of the coupler in to 41 different sections. The impedances are tabulated as in Tab.2 These impedances are applied to the design equations to obtain the width and offset values which are tabulated as in Tab. 3.

TABLE3. WIDTH AND OFFSET VALUES FOR 6 DB COUPLER

w	w_c	w	w_c
1.4027	-2.613	0.6862	0.478
1.4027	-2.613	0.7002	0.440
1.4026	-2.183	0.7466	0.347
1.4020	-1.553	0.8317	0.232
1.3997	-1.139	0.9553	0.115
1.3942	-0.855	1.1009	0.008
1.3852	0.665	1.2288	-0.111
1.3749	-0.544	1.3108	-0.250
1.3666	-0.477	1.3482	-0.374
1.3625	-0.450	1.3602	-0.436
1.3618	-0.445	1.3618	-0.445
1.3603	-0.436	1.3625	-0.449
1.3487	-0.376	1.3665	-0.476
1.3121	-0.253	1.3747	-0.542
1.2312	-0.114	1.3850	0.661
1.1042	0.006	1.3940	-0.850
0.9583	0.11	1.3996	-1.131
0.8341	0.229	1.4020	-1.552
0.7481	0.345	1.4026	-2.165
0.7009	0.439	1.4027	-2.613

V. FABRICATION OF THE DESINGED STRIP LINE COUPLERS

With the individual design data of the proposed couplers, the coordinates are generated in the required aristo format for the printed circuit. The circuit is fabricated using the photolithographic techniques. The circuit constructed is mechanically packed as a flat plate construction which is ready for testing.

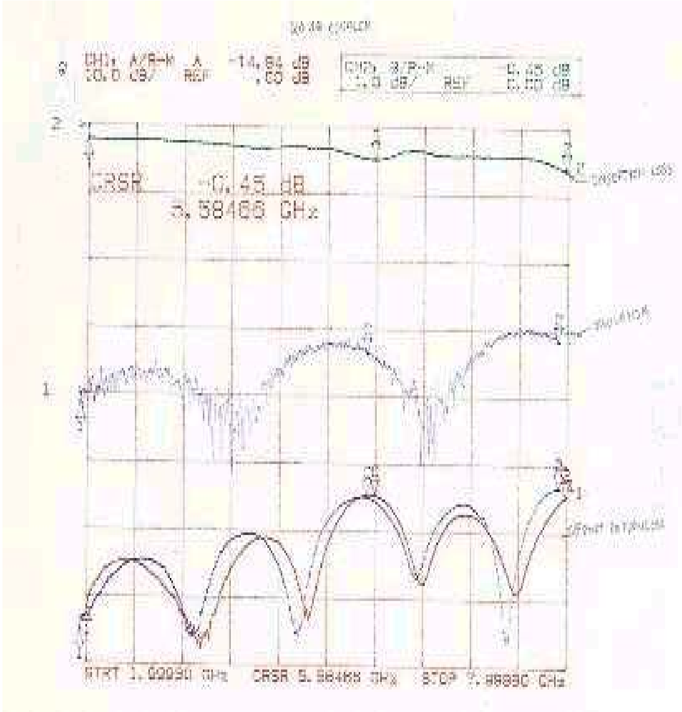

Figure1: Insertion Loss and Isolation of -20dB

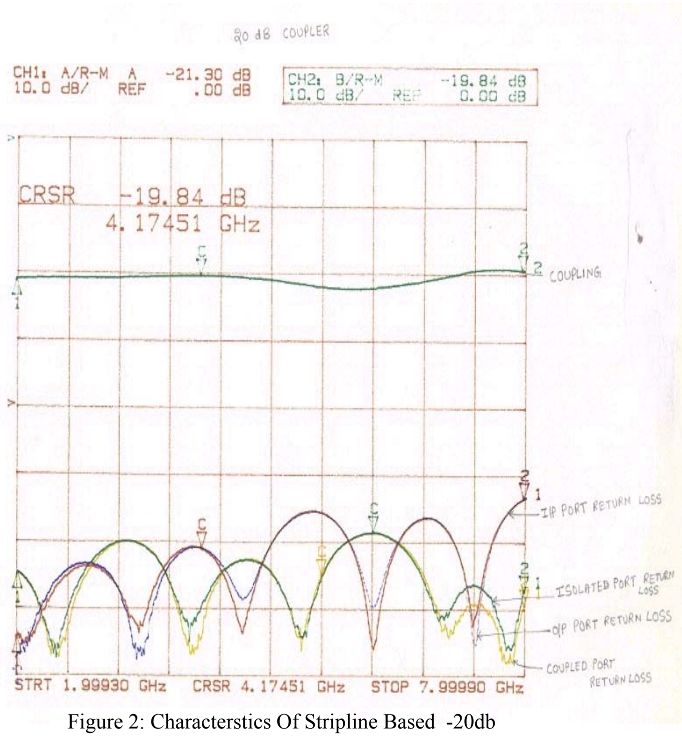

Figure 2: Characterstics Of Stripline Based -20db Coupler From Network Analyzer.

VI. RESULTS AND DISCUSSION

Charactersiation of designed coupler involves fabrication and testing with net work analyzer. With the design data, the coordinates are generated in the required aristo format for the printed circuit[10]. The circuit is fabricated using the photolithographic techniques [11].

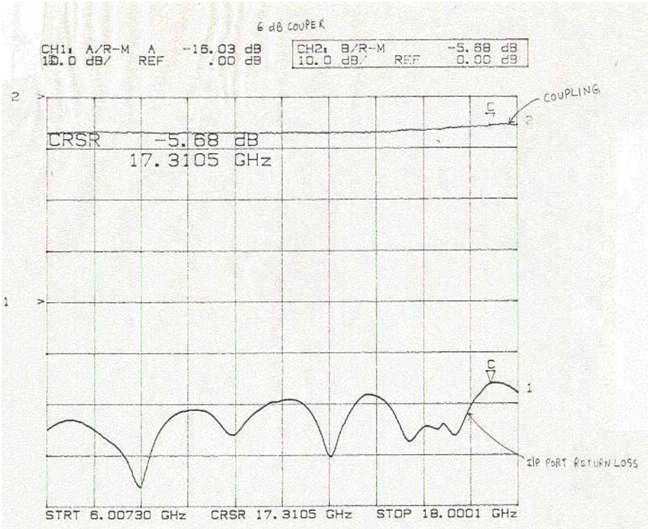

Figure 3. Plot of coupling and input port return loss of a 6db coupler

The fabricated coupler has been tested with the Network Analyzer at IMPACT laboratory of Osmania University. The results obtained thus are plotted as shown Fig.1 and Fig.2. From the Fig.2, the coupling of -19.84 dB is obvious in the desired frequency range. The deviation from this value during 4.17451 GHz to 6.99 Is less than 5 percent of this value. This could be probably due to minute errors of fabrication. It is to be understood that specifications are approximated as per suggestions of Tab.A. Better accuracy to the specifications may lead to the accurate results. Input port return loss, isolated port return loss and coupled port return losses are well below the acceptable level at all the frequencies. Successful implementation of this design may be carried out for better couplings such as 3dB using the procedure outlined.

A. Tested Results Coupler of 6 dB Coupling Coefficient.

In this design, 6dB coupling, frequency range form 6GHz to 18GHz, Dielectric constant (ε) as 2.2 with thickness (b) of 1.55mm (0.062inches), f_1 and f_2 are 6 GHz and 18 GHz respectively are considered. The RT duriod is the dielectric for the design. (see Tab.4)

TABLE 4. VALIDATIING THE DESIGN OF 6 DB COUPLER

S. No.	Parameter	Designed values in dB	Experimental values in dB
1	Coupling	6±1	6±0.5
2	Return loss	>15	>16
3	Insertion loss	<2.5	<2.25
4	Isolation	>19	>17

From the table, it is observed that the designed and experimental values are at good agreement. Also, this may confirm the experimental validity of the design. The slight deviation in experimental values could be due to errors in assembly and connectors. The results are also plotted as shown in Fig.3. From the plot, one may see the reasonable constancy of coupling for entire band of the design. The return loss found to a maximum value of 2.25 dB.

VII. CONCLUSIONS

The Directional Coupler has become a virtually indispensable measurement tool in the area of microwave engineering. Though it is well discussed with its basical form in waveguide version, state of art applications demands minaturisation of its size. The stripline version of the coupler reduces its size anormusly. The design of microstrip version of two multi octave bandwidth directional couplers for differenent applications is carried out in this paper. The design and development of the 20dBcoupler operating from 2-8GHz is carried for general microwave applications. . In this paper, design, fabrication of strip line version of a 20 dB coupler is carried out using photolithographic techniques outlined. The relevant and tables are provided in appendix for ready reference.

APPENDIX

TABLE A.1: SUGGESTED VALUES OF VARIOUS PARAMETERS FOR A 20DB COUPLER

Ripple value (δ)	Z_{oe1}=Z_1	Z_{oe2} =Z2	Z_{oe3}= Z_3	Fractional band width (w)	Band width ratio(B)
0.20	1.01016	1.04183	1.17873	1.32734	4.94656
0.40	1.01406	1.04855	1.18767	1.45350	6.31936
0.60	1.01747	1.05386	1.19463	1.52888	7.49038
0.80	1.02066	1.05851	1.20073	1.58261	8.58338
1.00	1.02371	1.06280	1.20638	1.62420	9.64410

TABLE A.2: SUGGESTED VALUES OF VARIOUS PARAMETERS FOR A 20DB COUPLER

(δ)	Z_1	=Z2	w	B
0.1	1.10298	2.09445	0.91996	2.70356
0.2	1.12090	2.14693	1.07404	3.31984
0.3	1.13625.	2.18999	1.17223	3.83226
0.4	1.15038	2.22865	1.24518	4.20931
0.5	1.15381	2.26458	1.30345	4.74258
0.6	1.17680	2.29968	1.35201	5.17291
0.7	1.18952	2.33360	1.39364	5.59673
0.8	1.20208	2.36724	1.43006	6.01830
0.9	1.21454	2.40072	1.46241	6.44068
1.0	1.22696	2.43431	1.49156	6.86621

The selection of values are based on agreement of design specifications at minimum ripple at reasonable tolerance. Another coupler of 6dB for power monitoring purpose of antennas is also dealt. For the design of these couplers, strip line configuration is used because it is having less loss compared to microstrip configuration. The fabricated coupler is tested using Network Analyser of IMPACT laboratory of osmania Univeristiy, Hyderabad. The results thus obtained are close to the specifications and thus are encouraging. The directional coupler finds a variety of other applications i.e. power monitoring, reflectometer, power divider, in radar systems, for the measurement of frequency etc. Successful implementation of these designs prompts that design may be carried out for better couplings such as 3dB using the procedure outlined . The strip line Directional coupler is developed in the specified frequency band. This coupler gives better directivity performance in comparison to micro strip coupler. The printed strip line is small in size and preferably useful for high frequencies and can be used for power monitor applications in antennas. Here the multi section coupler is designed since it is required to have multi octave bandwidth. The relevant tables used in design appears in appendix for ready reference.

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