Analysis, Design and Fabrication of Microwave Passive Couplers

Shivakumar Swamy D.S
Department of Telecommunication Engineering
Siddaganga Institute of Technology, Tumakuru,
Karnataka, India – 572 103.

Shailaja .Y
Department of Telecommunication Engineering
Siddaganga Institute of Technology, Tumakuru,
Karnataka, India – 572 103.

ABSTRACT
This paper presents the complete analysis, design of microwave Parallel coupler using synthesis approach and Branch Line Coupler which has been fabricated using FR-4 PCB substrate material and tested in the lab environment successfully. The design of all above components is done using the IE3D simulation tool and tested its S-Parameter results with Vector Network Simulator (VNA). The design parameters with respect to the IE3D structures of the physical dimensions are optimized successfully using Matlab.

Keywords
Branch Line Coupler (BLC); FR-4 Substrate; IE3D tool; Parallel Coupler; Vector Network Simulator (VNA)

1. INTRODUCTION
In Modern Digital Communication world, operating at larger frequencies (MHZ to GHZ) for low loss transmission of power is one of the big challenging tasks. To overcome this problem miniaturization of microwave circuits took place through the development of planar transmission lines. These miniaturized devices are the newest generation of circuit boards with attractive features such as low profile, light weight, low cost, and ease of integration into arrays. These features made them ideal components of modern communications systems, particularly in cellular and WLAN applications. This complete transmission circuit can be realized and fabricated by thin film technology or by photolithography technology. In Stripline, all the entire fields lie within a homogeneous dielectric region. Microstrip has some of its partial field lines in the dielectric region, concentrated between the strip conductor and the ground planes and fraction in air region above the substrate. The microstrip transmission line cannot support a pure TEM wave, since the phase velocity is $C/\sqrt{\varepsilon r}$ in the dielectric substrate whereas the phase velocity of TEM fields in air region is 'C', this mode is called as Quasi-TEM mode of propagation. In practical implementations, however substrate is electrically very thin (d<<λ), so the fields are quasi TEM. Thus a good approximation for the phase velocity, propagations constant, characteristic impedance can be obtained from quasi-static approach. Due to this properties and easy to study the behavior of the components through experimentally, we are designing and analyzing the microwave Parallel Line Coupler using synthesis approach instead of using standard design graph approach and Branch Line Coupler at 2.5 GHZ respectively. These components are designed in IE3D EM Simulation tool and fabricated using FR-4 PCB substrate and tested its frequency response and S-Parameters using RF/microwave Vector Network Analyzer (VNA).

2. DESIGN AND ANALYSIS
The design and analysis microwave components is explained below one by one as follows.

2.1 Parallel Line Coupler
Microstrip directional coupler has found more applications in the microwave systems for measuring the transmitted and reflected power with accuracy. When two transmission lines are placed nearby each other with small coupling gap in between them because of the interaction of the electromagnetic fields of each line, power can be coupled between those lines. These lines are referred to as *Coupled transmission lines.* The power on the coupled line flows in the opposite direction to the power on the main line. Hence it is sometimes called a *backward coupler.* One can achieve high directivity and tight coupling with microstrip configuration is carried out by matching the even and odd mode effective phase velocities by using additional capacitance in odd mode. This paper gives the three steps design [1] procedure with accurate formulas which include the physical length at the desired operational frequency. This designer requires the pre knowledge of port termination impedances, the coupling level and operational frequency. And this designed component is validated through experimental check.

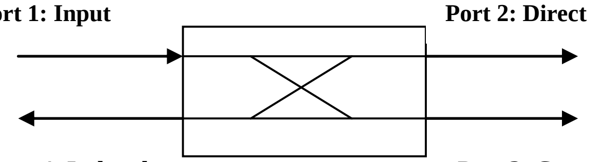

Fig 1: Directional Coupler

2.1.1 Formulations
Initially the designing parameters will be unknowing to the designer. In Practical applications, we preferably use the termination impedance of 50 Ω. Thus the matched system is obtained when characteristic impedance is 50 Ω is given by

$$Zo = \sqrt{Zoe \times Zoo}$$

Which is equal to port impedance 50 Ω.
In design of coupled transmission lines when finding Zoo and Zoe we use the following approximate synthesis technique:

a) With given Zo (single line characteristic impedance), ε_r (relative dielectric constant of the substrate) and C (coupling of the coupled lines) determining shape ratios for equivalent single microstrip lines.

b) Next, finding the shape ratio (w/h) and the spacing ratio (s/h) for the desired coupled microstrip by using the single line shape ratios found in first step.

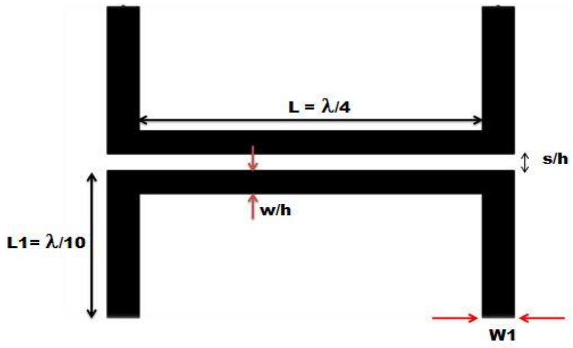

Fig 2: Microstrip Parallel Line Coupler

The even mode and odd mode impedance is found by

$$Zoe = \sqrt{\frac{1+10^{c/20}}{1-10^{c/20}}}\ ;\ Zoo = \sqrt{\frac{1-10^{c/20}}{1+10^{c/20}}}$$

Where $C = 10^{-c/20}$

Now finding the Physical dimensions. Where (s/h) gives the spacing ratio of the coupler.

$$\frac{s}{h} = \frac{2}{\pi}\, Cosh^{-1}\left[\frac{Cosh\left[\frac{\pi}{2}(w/h)'_{se}\right] + Cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)'_{so}\right] - 2}{Cosh\left[\frac{\pi}{2}(w/h)_{so}\right] + Cosh\left[\frac{\pi}{2}\left(\frac{w}{h}\right)_{Se}\right]}\right]$$

Where $(w/h)_{se}$ and $(w/h)_{so}$ are the shape ratios for the equivalent single case that corresponds to even and odd mode geometry respectively. $(w/h)'_{se}$ and $(w/h)'_{so}$ are the modified versions of shape ratios.

And (w/h) is the corrected shape ratios for the single transmission microstrip line.

$$\frac{w}{h} = \frac{8\sqrt{\left[\exp\left(\left(\frac{R}{42.4}\sqrt{(\varepsilon r+1)}\right)-1\right]\frac{7+\left(\frac{4}{\varepsilon r}\right)}{11}+\frac{1+\left(\frac{1}{\varepsilon r}\right)}{0.81}}}{\left[exp\frac{R}{42.4}\sqrt{(\varepsilon r+1)}\ -1\right]}$$

Where R=Zoe/2 or R=Zoo/2

Zose = Zoe/2; Zoso=Zoo/2

$$(w/h)_{se} = \left(\frac{w}{h}\right) \mid R = Zose\ ;$$

$$(w/h)_{so} = \left(\frac{w}{h}\right) \mid R = Zoso;$$

The Corrected term $(w/h)'_{so}$ is given as

$$(w/h)'_{so} = 0.78(w/h)_{so} + 0.1(w/h)_{so}$$

Substituting all these above in (s/h) gives the shaping ratios. Finally (w/h) for the coupled lines is given by

$$(w/h) = [1/\pi\ \cosh^{-1}(d)] - [\tfrac{1}{2}\left(\tfrac{s}{h}\right)]$$

$$\text{Where}\ d = \frac{\cosh[(\pi/2)\,(w/h)_{se}]\,(g+1)+g-1}{2}$$

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

The physical length of coupler is given by

$$L = \frac{\lambda g}{4} = \frac{C}{4f\sqrt{\varepsilon eff}}\ mm$$

TABLE 1: Design Parameters of Parallel Coupler at 2.5 GHz for Zo=50Ω, h=0.8 mm

Material	**(ε_r)**	**Coupling (db)**	**w/h (mm)**	**s/h (mm)**	**Length (mm)**
Teflon	2.08	-13	2.85	0.32	22.50
RT Duroid	2.50	-13	2.53	0.36	20.88
FR-4	4.30	-13	1.75	0.46	16.67

Since the cost of FR-4 material is reasonable and more availability in the market we have opted it for fabrication study.

Thus the microstrip parallel line coupler is designed and analyzed at frequency (f_0) = 2.5 GHz, For FR-4 Substrate dielectric constant (ε_r) = 4.3 , Coupling (C) = $-13\ dB$ and having thickness (h) with 0.8 mm. Where, W_1 = Width of the coupler feed for impedance $Z_0 = 50\ \Omega$. This is also calculated by basic microstrip equations [2]. And feed length L_1 = (λg/10).

TABLE 2: Calculated Physical Dimensions of Microstrip Parallel Line Coupler

Frequency (f_0) in GHz	2.50
Dielectric constant (ε_r)	4.30
FR4 Substrate Thickness (h) in mm	0.80
Coupling (C) in dB	-13
Width of the Coupler Patch (W) in mm	1.234
Length of the Feed line (L) in mm	16.70
Coupling Gap (S) in mm	0.30
Width of the feed (W_1) in mm	3.05
Length of the feeding patch (L_1) in mm	6.66

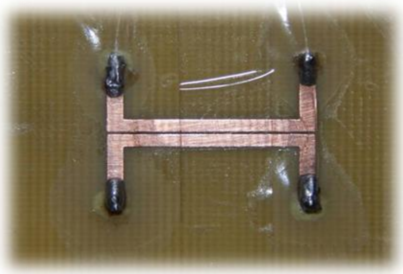

Fig 3: Fabricated Parallel Line Coupler using FR-4 Substrate.

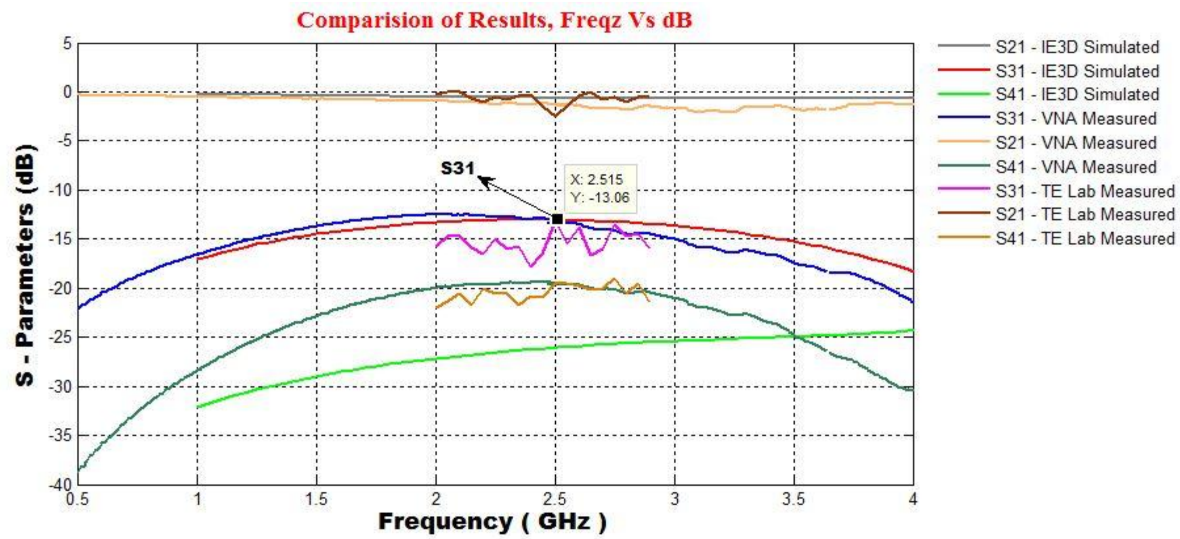

Fig 4: Parallel Coupler Return Loss, S31= -13 dB at 2.5 GHz.

2.2 Branch Line Coupler [BLC]

Branch line coupler at microwave frequencies can be realised using a number of quarter wavelength long transmission lines by adopting *stepped impedance approach*. It has found many applications like power divider, combiner, Balance amplifier and Balance mixtures. This makes it an important component in wireless communication. BLC is also known as a 3 dB quadrature hybrid coupler with a 90 degree Phase difference in the outputs of the through and coupled arms. It has got two main transmission lines with characteristic impedance $Zo/\sqrt{2}$, and two shunt transmission lines with characteristic impedance Zo. Thus the area of the BLC is (λ/4) ×(λ/4), which occupies the large space in the low frequency range. Hence the size reduction of the BLC becomes an important criterion.

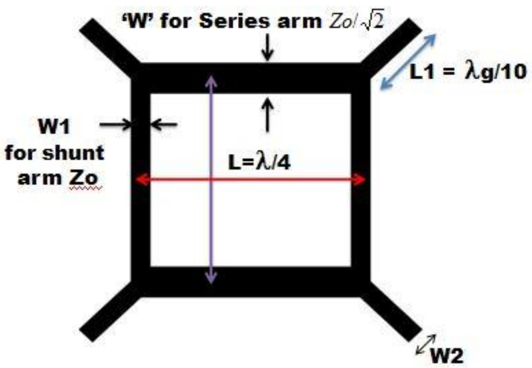

Fig 5: Microstrip Branch Line Coupler.

The geometry of BLC is calculated according to the impedance choice of the series and stub microstrip transmission lines. We can calculate the (w/d) ratios of the lines by basic microstrip width calculation formulae [2]. The physical length of coupler is given by

$$L = \frac{\lambda g}{4} = \frac{C}{4f\sqrt{\varepsilon eff}}\ mm$$

Thus the microwave Branch line coupler is designed and analyzed at frequency (f_0) = 2.5 GHz, For FR-4 Substrate dielectric constant (ε_r) = 4.3 and having thickness with 0.8 mm. Where, W_2 = Width of the coupler feed for impedance $Z_0 = 50\,\Omega$. This is also calculated by basic microstrip equations [2]. And feed length L_1 = (λg/10).

TABLE 3: Calculated Physical Dimensions of Microstrip Branch Line Coupler	
Frequency (f_0) in GHz	2.50
Dielectric constant (ε_r)	4.30
FR4 Substrate Thickness (h) in mm	0.80
Characteristic impedance (Zo) in Ω	50
Width of the Shunt arm (W) in mm	1.51
Width of the Series arm (W1) in mm	2.58
Length of the Branch (L) in mm	16.76
Width of the feed (W_2) in mm	3.05
Length of the feeding patch (L_1) in mm	6.70

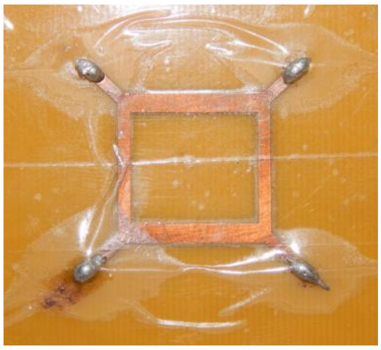

Fig 6: Fabricated Branch Line Coupler using FR-4 Substrate.

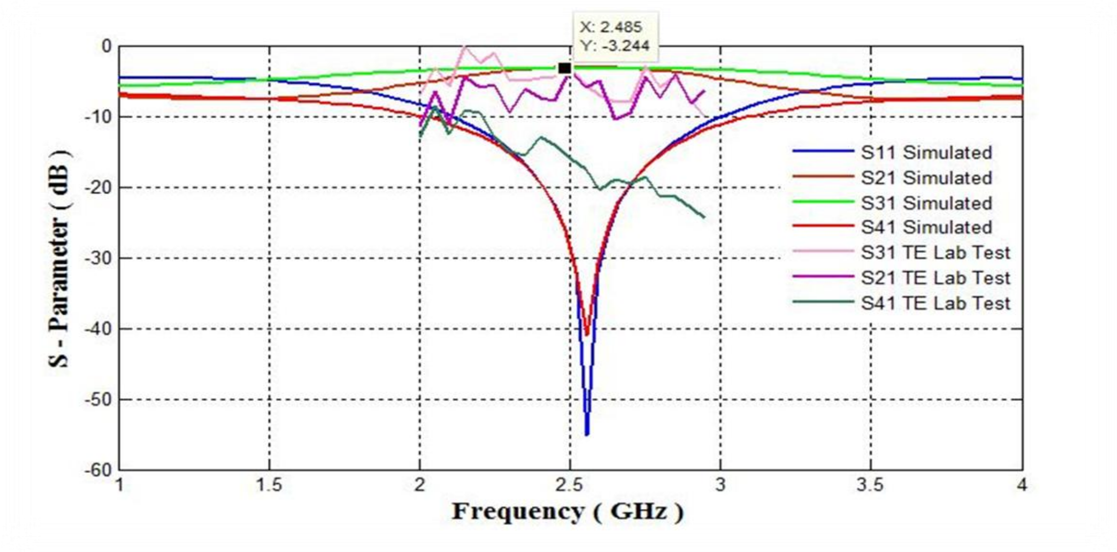

Fig 7: Branch Line Coupler Return Loss, S31= -3 dB at 2.51 GHz.

3. CONCLUSION

This paper contains the complete analysis, design of planar microwave couplers like Parallel Line coupler, Branch Line Coupler. The design of these components is done using the IE3D simulation tool, fabricated the same structures using available FR-4 PCB substrate material and tested its S-Parameter results with Vector Network Simulator (VNA) successfully. The Prototype structures performance is validated through both simulations and experiments, where good agreement with the theoretical prediction is observed. The application of this type of hybrid couplers is found in the development of high-power RF switches is under consideration and as well educational study purpose.

4. REFERENCES

[1] The complete design of microstrip directional couplers using the synthesis method by Abdulla Eroglu. [ieee transaction on instrumentation and measurements propagation letters, vol. 13, 2014). Microwave Engineering by David M. Pozar.

[2] Realization Of Miniaturized Quadrature Hy-Brid Coupler With Reduced Length Branch Arms Using Recursively Loaded Stubs by Rowdra Ghatak, and Biswajit Sarkar, Progress in Electromagnetics Research Letters, Vol. 43, 45 (54,2013).

[3] Gupta, K. C. Microstrip lines and slotlines / K. C. Gupta, Ramesh Garg, I. J. Bahl. Artech House Dedham, Mass. 1979.

[4] Miniaturization Of Branch-Line Couplers Using Open Stubs And Stepped Impedance Unit Cells with Meandering Transmission Lines, Circuits and Systems**:** An International Journal (CSIJ), Vol.1, No.3, July-2014**.**

[5] Kraus J. D. *Antennas,* 2d Ed. McGraw Hill: Boston, Ma, 1988.

[6] Balanis C. A. Antenna Theory: Analysis and design, 2d Ed, Wiley: New York, NY, 1997**.**

[7] K. Chang, Microwave ring circuits and Antennas, *John Wiley & Sons, 1996.*

[8] S. Kumar, C. Tannous, T. Danshin,“A Multisection Broadband Impedance Transforming Branch-line Hybrid”, IEEE Trans. Microwave Theory and Techniques, Vol. 43, No. 11, 1995.

[9] Fooks, E. H. Microwave engineering using microstrip circuits, Prentice Hall New York 1990.

[10] Design of Directional Coupler Using Synthesis Method on Defected Ground Structure by Rohit Samadhiya, Neeraj Sharma, Abhishek Tripathi, Sriram Gupta, Praveen Sharma, International Journal of Information and Computation Technology (IJICT) ISSN 0974-2239 Volume 3, Number 10 (2013).