Int'l Journal of Computing, Communications & Instrumentation Engg. (IJCCIE) Vol. 3, Issue 1 (2016) ISSN 2349-1469 EISSN 2349-1477

A Compact GSM/ISM Dual-Band 3-dB Hybrid Branchline Coupler Using Unequal Line Lengths and Center-Tapped Stubs on Series Arms

Kumari Khusboo[1], Raghuvir Tomar[2], and Prakash Bhartia[3]

***Abstract*—**The design of an unequal-length 3-dB hybrid branchline coupler with center-tapped open stubs on series arms is described. The design has been implemented for GSM (900 MHz) and ISM (2.45 GHz) dual-band operation. Simulation results have been verified against experimental results. The agreement between the two sets of results is found to be quite satisfactory. The size reduction, compared to the conventional design, is almost 50 percent. The design is scalable to other frequency-bands, and to substrates other than the one used.

***Keywords*—**RF, Microwave, Microstrip, Branchline Coupler, MIC, Dual-Band, Compact.

I. Introduction

COMPACT dual-band designs of radio frequency (RF)/microwave components are gaining increasing importance in today's communication systems [1]-[20]. Of these components, the 3-dB hybrid branchline coupler (BLC), schematically shown in Fig. 1, is a key component in applications like phase-shifters [15], antenna arrays [16]-[17], power amplifiers [18]-[19], mixers [20], etc.

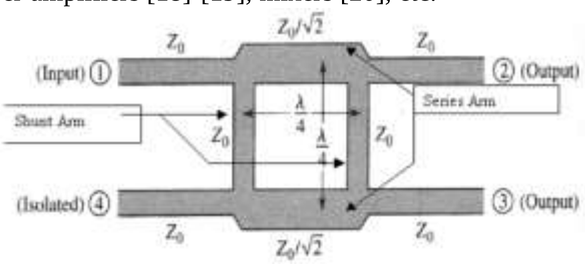

Fig. 1: The conventional 3-dB hybrid branchline coupler (BLC)

This coupler is a four-port component which divides the power coming at the Input Port (Port 1) into two almost-equal powers appearing at the Direct Port (Port 2) and the Coupled Port (Port 3), with hardly any power coming out of the Isolated Port (Port 4). In addition, because of the quarter-wave-long microstrip lines used in both series and shunt branches, there exists a 90-degree phase-shift between the two output ports (Ports 2 and 3). The design, in principle, is good at a single frequency only, which is called the center-frequency or the design-frequency. In practice, the 3-dB hybrid can yield an acceptable performance over a bandwidth as high as 10 percent of the center-frequency.

The conventional design shown in Fig. 1 consists of two series arms and two shunt arms which are of equal electrical length (90 degrees) at the center-frequency, and are of almost-equal physical length. The series arms are made of microstrip lines having characteristic impedance equal to $0.707Z_0$ where Z_0 is the port impedance which has been assumed to be the same for all four ports, the most commonly used value being Z_0=50 Ω. The characteristic impedance of the shunt arms is equal to Z_0. The construction is almost 'square' in shape.

The main disadvantages of the conventional BLC shown in Fig. 1 are its almost-single-frequency operation and the large design size. To overcome the design size problem, Toker *et al* [1] suggested the use of an unequal-length BLC shown in Fig. 2.

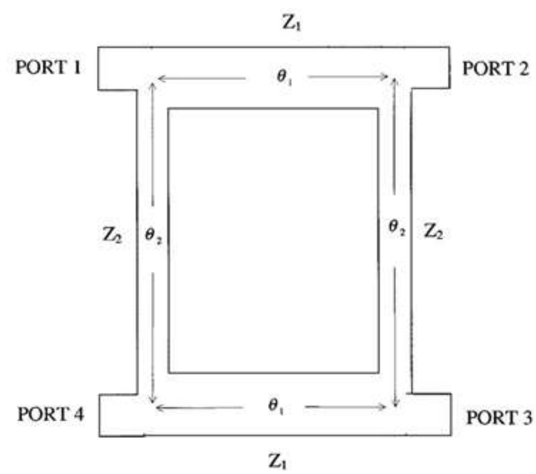

Fig. 2: The 'unequal-length' 3-dB hybrid branchline coupler (BLC)

In this design, the electrical lengths θ_1 and θ_2, and the characteristic impedances Z_1 and Z_2 of the series and shunt arms, are made different, which gives an additional flexibility in the design, and helps in substantially reducing the design

[1]HSET, SRHU, Dehradun, India.
[2]LNMIIT, Jaipur, India.
[3]NATEL Engineering Co.,Inc., Chatsworth, California, U.S.A.

size. The detailed analysis and the resulting design equations for the 'unequal-length' BLC are available in [1].

To overcome the single-frequency limitation, Park [4] suggested the use of center-tapped stub lines on the series arms, as schematically shown in Fig. 3. This design not only reduces the design size by almost 50 percent (since the length of the shunt arms reduces to almost half that in the conventional design) but is also capable of giving dual-band operation, without significantly sacrificing the phase relationship between ports 2 and 3 for both frequency-bands [4].

In this article, the results of a theoretical and experimental investigation on designing, building, and testing a compact dual-band 3-dB hybrid branchline coupler (BLC) for GSM and ISM frequency-bands are reported. The dual-band operation is realized for 900 MHz (GSM) and 2.45 GHz (ISM) frequency-bands. The low-loss substrate material used is R0435B (supplied by Amitec Electronics Pvt. Ltd., New Delhi [21]), having dielectric constant=3.48, thickness=0.762mm, and loss-tangent=0.004.

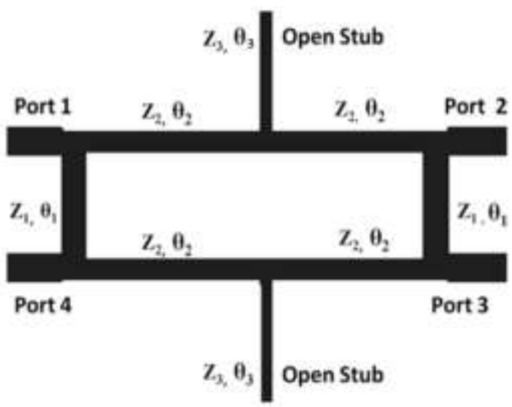

Fig. 3: The 'unequal-length' 3-dB hybrid branchline coupler (BLC) with center-tapped open stubs for dual-band operation

II. Coupler Design

The coupler that was designed and tested is photographically shown in Fig. 4. The design equations reported in [1] and [4] were used to design this coupler, along with equations available in [22] for calculating the widths and lengths of the microstrip lines. The effects of the various T-junctions were accounted for, using the formulation available in [23]. Open stubs were used since they are easier to fabricate, compared to short-circuited stubs. The two center-frequencies were chosen to be 900 MHz and 2.45 GHz. The characteristic impedance of all ports was chosen to be 50 Ω, since this value matched the characteristic impedance of the Vector Network Analyzer used for obtaining experimental data.

The characteristic impedance of the shunt lines was chosen to be Z_1=66.67 Ω which led to the value of the characteristic impedance of the series lines being Z_2=58.58 Ω and also led to $\Theta_1 = \Theta_2$= 48.58 degrees, through the use of the following equations [1],[4],[14]:

$$\theta_1 = \theta_2 \quad (1)$$

$$Z_1 = Z_0 / \sin\theta_1 \quad (2)$$

$$Z_2 = Z_0 (\sin\theta_1 + 1.414\tan\theta_1)/(2\tan^2\theta_1 - \sin^2\theta_1) \quad (3)$$

The stub-susceptance was computed using the following equation:

$$B_s = (Z_1 + 2Z_2 - Z_1\tan^2\theta_1)/[\tan\theta_1(Z_1+Z_2)Z_2] \quad (4)$$

The optimized physical dimensions of the design follow.

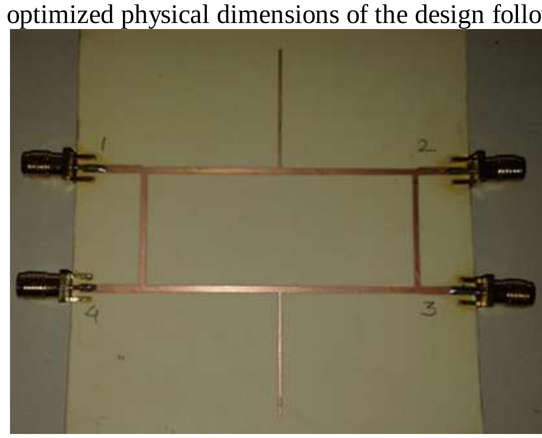

Fig. 4: A photograph showing the experimental prototype of the unequal-length dual-band branchline coupler (BLC) for GSM and ISM frequency-bands

Width of the shunt lines W_1 = 1.73 mm; Length of the shunt lines L_1 = 25.11 mm

Width of the series lines W_2 = 2.21 mm; Length of the series lines L_2 = 24.87 mm.

Width of the two open stubs W_s = 0.7475 mm; Length of the two open stubs Ls = 25.73 mm

III. Comparison of Simulation Results and Experimental Results

Fig. 5 shows a comparison of simulation results and experimental results for S_{11} and S_{21} of the coupler whereas Fig. 6 shows the same for S_{31} and S_{41}. The agreement between the two sets of data is quite satisfactory. The minor discrepancies that are observed can be attributed mainly to a) the actual substrate properties being somewhat different from those assumed and b) fabrication tolerances in line widths and line lengths. A sharp minimum in the coupling values is seen at around 1.65 GHz which will help in improving the isolation between the two frequency-bands of operation.

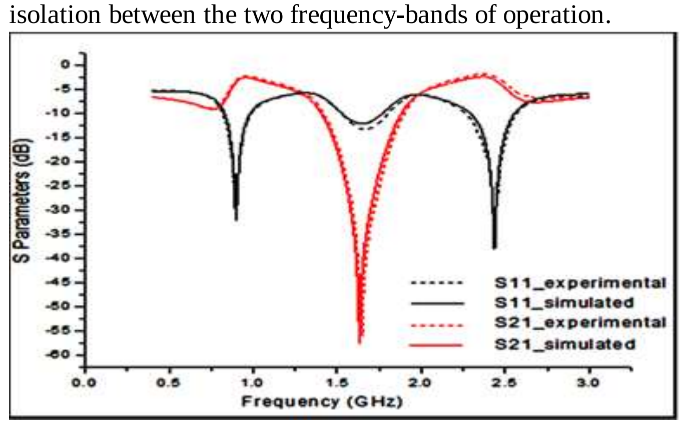

Fig. 5: Simulated and experimentally-measured performance (input return loss and direct-port coupling)

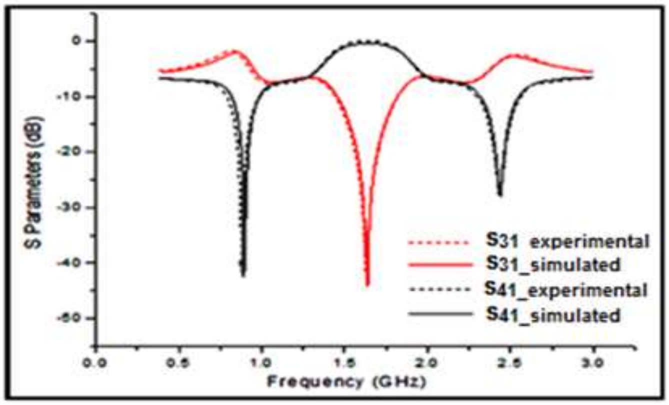

Fig. 6: Simulated and experimentally-measured performance (coupled-port coupling and isolation)

IV. CONCLUSION

A small-size dual-band 3-dB hybrid branchline coupler for ISM and GSM frequency-bands has been designed, optimized, built, and tested. The use of unequal line lengths helps in reducing the design size by almost 50 percent. The use of center-tapped stubs helps in realizing dual-band operation. The design is scalable to other frequency-bands and to substrates other than the one used.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance provided by the Indian Institute of Technology at Kanpur, in carrying out this work.

REFERENCES

[1] C. Toker, M. Saglam, M. Ozme, and N. Gunalp, "Branch-line couplers using unequal line lengths," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 718-721, April 2001. http://dx.doi.org/10.1109/22.915448

[2] C.-W. Tang and M.-G. Chen, "Synthesizing microstrip branch-line couplers with predetermined compact size and bandwidth," *IEEE Trans. Microwave Theory Tech.*, vol. 55, pp. 1926-1934, September 2007. http://dx.doi.org/10.1109/TMTT.2007.904331

[3] R.S. Tomar, P. Pramanick, and P. Bhartia, "The use of 3D electromagnetic simulation tools in the design of Microwave Integrated Circuits:An Accuracy Assessment,"in *IEEE Int. Conf. on Microwaves, Communications, Antennas and Electronic Systems*, Tel Aviv, 2009.

[4] M.-J. Park, "Dual-band unequal length branch-line coupler with center-tapped stubs," *IEEE Microwave and Wireless Components Letters.*, vol. 19, pp. 617-619, October 2009. http://dx.doi.org/10.1109/LMWC.2009.2029734

[5] K.-S. Chin, K. -M. Lin, Y. –H. Wei, T. –H. Tseng, and Y. –J. Yang, "Compact dual-band branch-line and rat-race couplers with stepped-impedance-stub lines," *IEEE Trans. Microwave Theory Tech.*, vol. 58, pp. 1213-1221, May 2010. http://dx.doi.org/10.1109/TMTT.2010.2046064

[6] K. Rawat, M.S. Hashmi, and F.M. Ghannouchi, "Dual the band and optimize," *IEEE Microwave Magazine*, vol. 13, pp. 69-82, April 2012. http://dx.doi.org/10.1109/MMM.2011.2181449

[7] K. Rawat, M.S. Hashmi, and F.M. Ghannouchi, "Dual-band RF circuits and components for multi-standard software defined radios," *IEEE Circuits and Systems Magazine*, vol. 12, pp. 12-32, March 2012. http://dx.doi.org/10.1109/MCAS.2011.2181074

[8] S. Taravati and M. Khalaj-Amirhosseini,"Compact dual-band stubless branch-line coupler," *Journal of Electromagnetic Waves and Applications*, vol. 26, July 2012. http://dx.doi.org/10.1080/09205071.2012.699393

[9] K. Rawat and F.M. Ghannouchi, "A novel dual-band matching technique based on dual-characteristic impedance transformer for dual-band power amplifier design," *IET Microwavs Antennas and Propagation*, vol. 5, pp. 1720-1729.

[10] Jin Shao et al, "Designs of dual-band microwave components and their applications," in *14th Annual IEEE Wireless and Microwave Technology Conference*, pp. 1-6, 2013. http://dx.doi.org/10.1109/wamicon.2013.6572730

[11] Q. Liu et al, "Generalized impedance-transforming dual-band branch-line couplers for arbitrary coupling levels," *Progress in Electromagnetics Research B (PIER B)*, vol. 13, pp. 399-415, 2013. http://dx.doi.org/10.2528/PIERB13061717

[12] Ye Yan, "Independently-tuned concurrent branch-line coupler using varactor," *Journal of Electronics (China).*, vol. 31, pp. 348-353, 8th August 2014. http://dx.doi.org/10.1007/s11767-014-4047-0

[13] Pragya Singh and Raghuvir Tomar, "The use of defected ground structures in designing microstrip filters with enhanced performance characteristics," *Procedia Technology (Elsevier)*, vol. 17, pp. 58-64, November 2014. http://dx.doi.org/10.1016/j.protcy.2014.10.216

[14] Kumari Khusboo and Raghuvir Tomar, "Compact, fractal-shaped, unequal length branch-line couplers for dual-band applications ,"in *IEEE National Conference on Communications (IEEE NCC)*, Kanpur, 2014.

[15] N. Gupta, R.Tomar, and P. Bhartia, "A low-loss voltage-controlled analog phase-shifter using branchline coupler and varactor diodes," in *IEEE International Conf. on Microwave and Millimeter Wave Technology (IEEE ICMMT)*, Guilin, 2007. http://dx.doi.org/10.1109/icmmt.2007.381435

[16] A. Bouzakis and L. Overmeyer, "RFID tag positioning with the aid of an active electronically-steered array, "in *IEEE International Symposium on Personal Indoor and Mobile Radio Communications (IEEE PIMRC), 2012*. http://dx.doi.org/10.1109/pimrc.2012.6362774

[17] Y.K. Jung and B. Lee, "Dual-band circularly polarized microstrip RFID reader antenna using metamaterial branchline coupler," *IEEE Trans. Ant. Prop.*, vol. 60, pp. 786-791, February 2012. http://dx.doi.org/10.1109/TAP.2011.2167943

[18] D. Draskovic, H. Koulouzis, and D. Budimir, "A reduced size branch-line coupler for improved LDMOS balanced power amplifiers," *Microwave and Optical Technology Letters.*, vol. 51, pp. 445-447, February 2009. http://dx.doi.org/10.1002/mop.24058

[19] K. Rawat and F.M. Ghannouchi, "Design methodology for dual-band Doherty power amplifier with performance enhancement using dual-band offset lines," *IEEE Trans. Industrial Electronicss.*, vol. 59, pp. 4831-4842, December 2012. http://dx.doi.org/10.1109/TIE.2011.2176695

[20] Dong-Hyun Kim and Jae-Sung Rieh, "CMOS 138 GHz low-power active mixer with branch-line coupler," *Electronics Letters*, vol. 48, pp. 554-555. May 2012. http://dx.doi.org/10.1049/el.2012.0402

[21] http://www.amitecltd.com/

[22] D.M. Pozar,"Microwave Engineering," 3rd Edition, New Delhi: Wiley (India), 2010.

[23] M. Dydyk, "Master T-junction and sharpen your MIC designs," *Microwaves*, vol. 16, pp. 184-186. May 1977.