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

Kumari Khusboo¹, Raghuvir Tomar², and Prakash Bhartia³

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 \(Z_0=50 \, \Omega\). 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)](image)

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...
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

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.

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]:

$$\theta_1=\theta_2 \tag{1}$$

$$Z_1 = Z_0 /\sin \theta_1 \tag{2}$$

$$Z_2 = Z_0 \left( \sin \theta_1 + \frac{1.414 \tan \theta_1}{2 \tan^2 \theta_1 - \sin^2 \theta_1} \right) \tag{3}$$

The stub-susceptance was computed using the following equation:

$$B_s = \left( \frac{Z_1 + 2Z_2 - Z_1 \tan^2 \theta_1}{\tan \theta_1 \left( Z_1 + Z_2 \right) Z_2} \right) \tag{4}$$

The optimized physical dimensions of the design follow.

**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. 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.

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