BRANCH LINE COUPLER USING HYBRID T-MODEL STRUCTURE

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ABSTRACT: *A reduced size branch line coupler (BLC), which does not use bonding wires, lumped elements, or via holes, is reported in this article. The technique presented uses T-model approach, which is a combination of low-impedance and high-impedance quarter wave transmission lines for realizing the proposed structure. The coupler's operating frequency bandwidth is between 2.1 and 2.67 GHz, and its size has been reduced by almost 75.31% compared with the conventional BLC. The S-parameters and the phase difference between the output ports are simulated using CST microwave studio, and the simulation results have been compared with the measurements. The BLC has been designed to operate at 2.5 GHz and fabricated on flame resistance board (FR4 Board). The study shows that there is good agreement between the simulated and measured results. The proposed coupler has promising potentials for beam-forming network applications such as butler matrix due to its smaller size.* Microwave Opt Technol Lett 54:237–240, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26476

Key words: *coupler; miniaturization; hybrid; T-model*

1. INTRODUCTION

A branch line coupler (BLC) is an important component in microwave-integrated circuits. It can be used as a power divider and power combiner or apart of mixer. The normal BLC is formed by four quarter-wavelength ($\lambda/4$) transmission line at the design frequency, which results in a large occupied area at low frequency. To reduce the size of the BLC many methods have been proposed to reduce the circuit size as reported in Refs. 1, 2. The compact size is realized using lumped element with significant size reduction, but lumped inductor and capacitor with required values and high quality factor are not always available for the use in microwave integrated circuit [3]. Thereby, other method using only distributed element have been reported in Ref. 4, a microstrip BLC was designed by periodically loading open end stubs with the coupler, however, the size of this BLC is only 37% smaller compared to the normal design.

Uniplanar structure is another method of BLC which is realized through the combination of shorter high-impedance coplanar waveguide lines and shunt lumped capacitors [5]. The size of this coupler is reduced. However, metal insulator–metal capacitors are needed for the monolithic microwave integrated circuit. This technique requires a complex fabrication process and it will eventually increase the cost.

A BLC using eight stubs, the structure consisting of two section of high- and low-impedance transmission lines to make interconnection of a low-impedance stub to a signal line is presented [6]. In comparison to the conventional BLC, this proposed structure offers lower insertion loss. The size reduction is reported about 25% with the comparable performance.

Another method based on T-shaped structure is an attempt to reduce the size of the circuit by making use of the empty space inside the coupler. The size reduction of the BLC is realized using low-impedance transmission line without any implementation of lumped elements, bonding wires, and via holes has been proposed in Ref. 7. The size of the proposed coupler is reduced by 45% of the conventional BLC.

Additional method for designing a reduced size BLC with predetermined compact size and bandwidth was proposed in Ref. 8 using equivalent quarter-wavelength transmission line by combination of a high-impedance T-model quarter-wavelength transmission line with π-model high-impedance approach. The size of this BLC is 66.68% lesser at the bandwidth of 2.1–2.75 GHz compared with the conventional BLC.

A microstrip 90° coupler has also been reported by substituting the quarter wave transmission lines used in conventional 90° coupler with its equal circuits consisting of two oblique stubs and an inductor and capacitors [9]. The size of coupler is reduced by 27% compared to the conventional one. Furthermore, a compact BLC can be found in Ref. 10, 11. A BLC without the use of via-holes, multilayered technique, or air-bridged is reported in Ref. 10, using the concept of fractals to load a coupled transmission line to realize a compact quarter-wavelength transmission line, which form the couplers arms. The size reduction of this BLC has been reported about 27%. In Ref. 11, a compact BLC is designed by rejecting harmonic components in the BLC. After adding open stubs at the center of traditional branch lines, the size of this coupler is shrinking by 63%. In Ref. 12, miniaturized BLCs are designed. In this method, the high-impedance open stubs are used to miniaturize the conventional BLC using the combinational model (combinational of T- and π-model). The proposed design is reduced by more than 57.5% compared to the conventional BLC.

In this article, a novel reduced size BLC is presented, in which a low-impedance and high-impedance T-model quarter-wavelength transmission lines are combined. The proposed coupler is designed to operate at a frequency of 2.5 GHz and fabricated on FR4 board with dielectric constant of 4.5, thickness (h = 0.8 mm), dielectric copper = 0.35, and loss tangent = 0.017.

2. A DESIGN OF COMPACT SIZE BRANCH-LINE COUPLER

Figure 1 shows the equivalent T-shaped structure of quarter-wavelength transmission line. Generally, Z_1, Z_2, Z_3, θ_1, θ_2, and θ_3 represent the impedance characteristics and the electrical lengths of the reduced line in equivalent T-shape structure. These parameters are related to each other and can be estimated using ABCD matrices. The design equations for low impedance of T-model are [7]:

$$\tan\theta_1 \tan\theta_3 = \frac{N}{M^2} \quad (1)$$

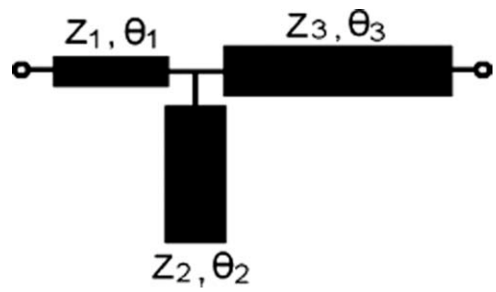

Figure 1 Equivalent T-shaped structure of quarter-wavelength transmission line

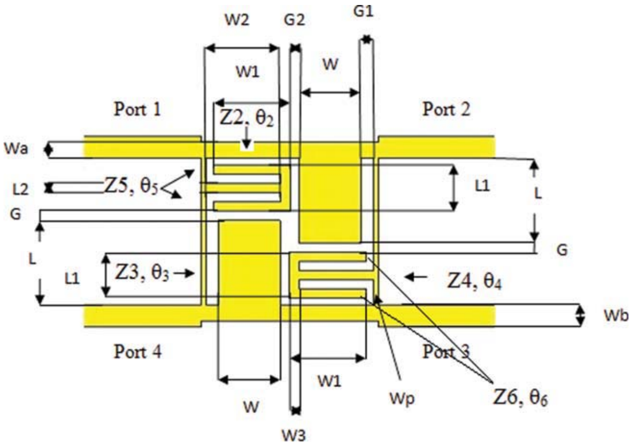

Figure 2 Simulated layout of the proposed branch line coupler. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

$$\tan\theta_2 = \frac{M^2 - N^2}{KN}\tan\theta_3 \tag{2}$$

$$K = \frac{Z_1}{Z_2},\ M = \frac{Z_1}{Z_0},\ N = \frac{Z_1}{Z_3}$$

The values of θ_1, θ_2, and θ_3 are obtained from the Eqs. (1) and (2), correspondingly by assuming that Z_1 is equal to Z_3 under the conditions of K, M, and N have been known. The electrical length of θ_1 is plotted against θ_3 for different values of M. It appears that the total electrical length ($\theta = \theta_1 + \theta_3$) of reduced line decreases as M increases [7]. The design equations for high impedance of T-model quarter wave transmission line are obtained as [8]:

$$\frac{Z_a\tan\theta - Z\tan\theta_a}{Z_a^2\tan\theta_a - Z\tan\theta + ZZ_a} = Y_1\tan\theta_1 + Y_2\tan\theta_2 + \ldots + Y_n\tan\theta_n \tag{3}$$

$$Z_a = Z_0\frac{\sqrt{\cos^2 2\theta + 4} - \cos 2\theta_a}{2\sin 2\theta_a} \tag{4}$$

$$Y_B\tan\theta_b = \frac{Z_a\sin 4\theta - Z_0}{(Z_a\sin 2\theta_a)^2} \tag{5}$$

$$Y_c\tan\theta_c = \frac{Z_0\cos 2\theta_a - Z_a}{Z_0 Z_a} \tag{6}$$

TABLE 1 Dimension of Proposed Branch Line Coupler

Parameter	Value (mm)
W	3.70
W_1	4.6
W_2	4.44
W_a	0.62
W_b	1.4
W_p	0.3
L	5.48
L_1	2.98
L_2	0.62
G	0.585
G_1	0.748
G_2	0.485

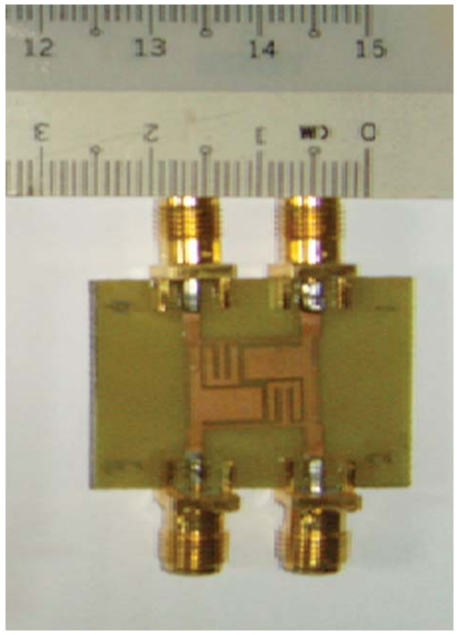

Figure 3 Photographs of the proposed reduced size branch line coupler. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Basically, a smaller and low-impedance BLC of T-model can be designed using Eqs. (1) and (2). The parameters to reduce the main line of BLC, are first selected as $M = 1.5$, $\theta_b = 16°$, then $\theta_{b3} = 58°$, substituting all these data in Eq. (2) and assuming $k = 3.3$, then $\theta_{b2} = 31°$ [7]. Meanwhile, the high impedance of T-model can be designed using Eqs. (3), (4), (5), and (6) by initially choosing the value of θ_2, θ_4, Z_4, and Z_6 to be 22.5°, 15°, 100 Ω, and 100 Ω, respectively.

Z_2, θ_5, and θ_6 can be obtained according to Eqs. (3), (4), and (6) as 83.38 Ω, 17.5°, and 14.11°, respectively [8]. By combining a low and high impedance of T-model quarter-wave transmission line, a reduced size branch line can be achieved. The optimized design of the reduced BLC is shown in Figure 2 together with completed dimensions using CST microwave studio software shown in Table 1. The proposed coupler is designed to operate at a frequency of 2.5 GHz and photograph of the implemented circuit of the proposed structure is shown in Figure 3, which occupies its substrate with a dimension of 10.6 × 9.48 mm^2. The fabricated proposed coupler will be measured in terms of S_{21}, S_{31}, and S_{41} using a network analyzer within frequency range from 2 to 3 GHz.

3. RESULTS AND DISCUSSION

The simulated and measured S-parameters of the reduced size BLC are shown in Figure 4(a). It is observed that the simulated and measured results have demonstrated a good response at the desired frequency of 2.5 GHz. The return loss (S_{11}) shows a value of −34.68 dB for simulation and −35.55 dB for the measurement. Moreover, the proposed coupler has successfully obtained a difference of only 0.34 dB between simulated and measured for S_{21} parameter which is −3.45 and −3.79 dB, respectively. A simulation of −3.64 and −3.8 dB of measurement has been revealed for the S_{31} parameter. Meanwhile, simulated of −23.1 and −27.05 dB of measurement are stated for the reflected coefficient and isolation (S_{41}).

The simulated and measured phase differences between the output ports show a value of 90.9° and 86.97°, respectively as

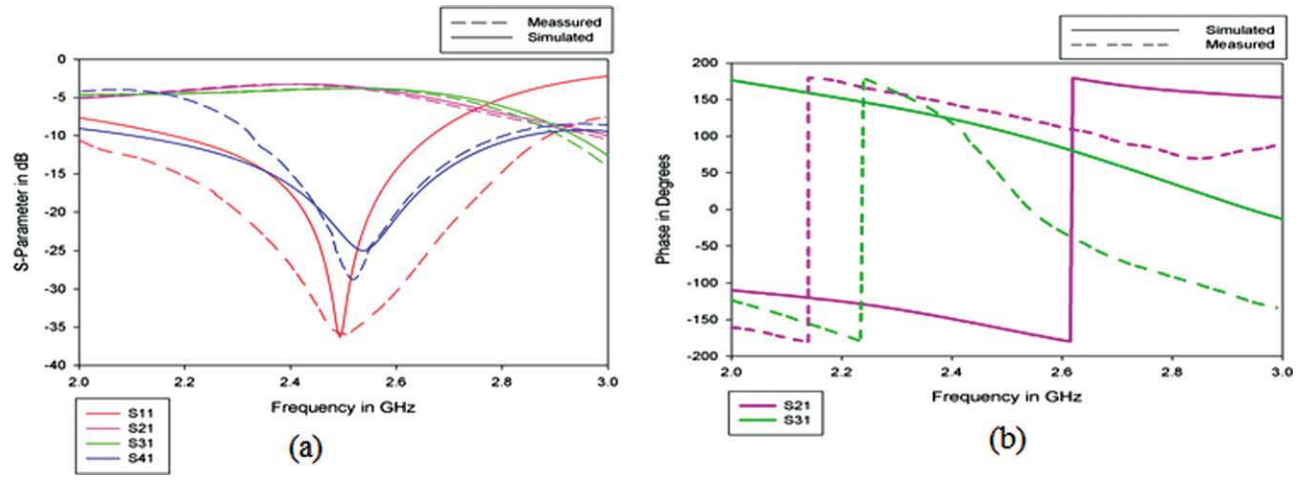

Figure 4 Measured and simulated of the proposed reduced size branch-line coupler (a) S-parameter (b) Phase difference between the output ports. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

TABLE 2 Performance of the Reduced Size Branch Line Coupler at 2.5 GHz

S-parameter	Simulation	Measurement
S_{11}	−34.68 dB	−35.55 dB
S_{21}	−3.45 dB	−3.64 dB
S_{31}	−3.79 dB	−3.8 dB
S_{41}	−23.1 dB	−27.05 dB
Phase difference	90.9°	86.97°

shown in Figure 4(b). Any increment of L parameter especially from 5.48 to 5.98 mm will influence the return loss S_{11} and insertion loss S_{21} to shift to the lower frequency as depicted in Figure 4(a). In Figure 4(b), the opposite situation is experienced when the L parameter is declining from 5.48 to 4.98 mm. When the phase shift between the output ports is 100° at 2.4 GHz, the return and insertion losses are −22.6 and −2.83 dB, respectively. Whereas when the phase shift is 75° at 2.6 GHz, the return and insertion losses are −32.5 and −5.2 dB, respectively. The performances of the reduced size BLC are summarized in Table 2.

One of the most important challenges in the coupler design is equal power dividing and accurate phase difference. In this article, the measurement in Figure 4(a) shows insertion losses, S_{21} and coupling, S_{31} magnitude of -3 ± 1 dB at 2.5 GHz which indicate the BLC successfully provides an equal 3 dB split at the resonant frequencies at the output power. Thus, it has clearly indicates that equal power are split at the output port, and hence, this design is suitable to be applied as power divider or power combiner. In addition, the phase differ measurement of the proposed coupler displays value of 86.97° at 2.5 GHz which comply the theoretical value of 90°.

4. CONCLUSION

A reduced size BLC operating at 2.5 GHz is presented in this article. The proposed coupler is accomplished using T-model approach by integrating a low-impedance T-model quarter-wavelength transmission line with high-impedance T-model quarter-wavelength transmission line. As a result, the size of the proposed coupler has been successfully reduced by 75.31% compared to the conventional coupler with comparable performance. There are good matches between simulations and measurements. An enormous return loss (S_{11}), reflected coefficient (S_{41} = −35.55 dB) and isolation (−27.05 dB) are promising features that will support the coupler to efficiently work at an operating frequency of 2.5 GHz at the bandwidth between 2.1 and 2.6 GHz. Moreover, the low value of insertion loss which is −3.8 dB has contributed to the less of the coupler total loss. The design also reduced the electrical length of transmission line. Other than compact in size, the novel coupler is cheaper as it is manufactured on flame Resistant 4 (FR4) Board. The proposed coupler is comfortable for the butler matrix applications especially in smart antenna system.

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NOVEL CPW-FED PRINTED MONOPOLE ANTENNA WITH AN n-SHAPED SLOT FOR DUAL-BAND OPERATIONS

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ABSTRACT: *A novel coplanar waveguide (CPW)-fed printed monopole antenna with an n-shaped slot for dual-band operations is proposed. By etching an n-shaped slot on the radiating element, two tunable operating bands can be obtained. The measured results indicate that the impedance bandwidths of the proposed antenna, defined by 10-dB return loss, are 13.6% (1.85–2.12 GHz) and 5.7% (2.39–2.53 GHz), covering the required bandwidths for PCS (1850.5–1989.5 MHz), CDMA2000 (1850–1990 MHz), TD-SCDMA (1880–2025 MHz), and 2.4 GHz WLAN (2400–2484 MHz). In addition, good omnidirectional radiation characteristics have been obtained over the entire frequency range of interest.* © 2011 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:240–242, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26475

Key words: *coplanar waveguide fed; n-shaped slot; dual-band antenna; printed monopole*

1. INTRODUCTION

Recently, printed monopole antennas have found widespread applications in wireless mobile communication systems due to their attractive features of low profile, light weight, and easy fabrication. The increasing use of mobile communication systems has stimulated the interest in the dual-band design of monopole antennas for application in two different mobile communication standards. Numerous designs of dual-band monopole antennas have been presented, including the P-shaped monopole [1], G-shaped monopole [2], double-T monopole [3], disc-slit monopole [4], U-slot monopole [5], and multiple slots monopole [6]. However, most of them have either a large size or a complicated structure.

In this article, a coplanar waveguide (CPW)-fed printed monopole antenna with an n-shaped slot for dual-band operation is proposed. By etching a narrow n-shaped slot on the radiating element and properly adjusting the lengths of the element and slot, a good dual-band characteristic can be achieved. The measured results show good agreement with the simulated ones. Details of the antenna design and parameter study are presented and discussed as follows.

2. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Figure 1(a). The antenna is designed and fabricated on one side of the FR4 substrate with dielectric constant of 4.4, thickness of 1.6 mm, and overall size of 50 × 25 mm^2. A 50-Ω CPW transmission line, with the width of 3.5 mm and gap of 0.5 mm, is adopted to excite the radiation element that is etched by an

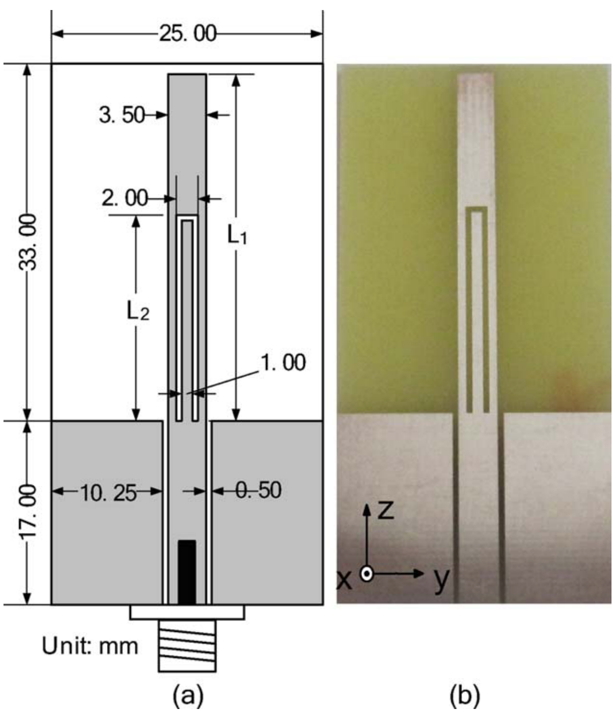

Figure 1 Geometry (a) and prototype (b) of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

n-shaped slot. The lengths of the radiation element and the vertical slots are L_1 and L_2, and the separation between the two vertical slots is 2 mm. By varying the value of L_1 and L_2, appropriate impedance bandwidths for the PCS/CDMA2000/TD-SCDMA and WLAN applications can be obtained. The required numerical analysis and proper geometrical parameters of the proposed antenna are studied with the aid of Ansoft's high-frequency structure simulator (HFSS) software, and the final optimum design parameters are as follows: $L_1 = 32$ mm and $L_2 = 18.5$ mm. A prototype is fabricated according to the aforementioned design results, as shown in Figure 1(b).

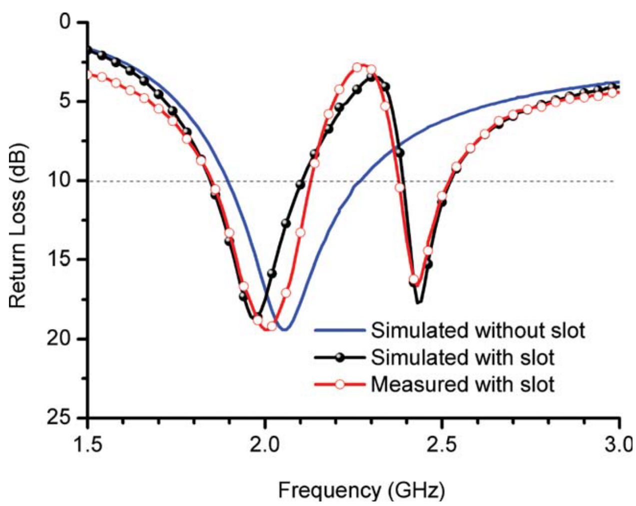

Figure 2 Comparison of the return losses between the antennas with/without an n-shaped slot. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]