A Tunable Dual-Band DGS Stub Tapped Branch-Line Coupler

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Abstract — A tunable microstrip dual-band branch-line coupler using defected ground structure (DGS) stub tapped branch line is presented in this paper. Tuning the geometrical parameters of the DGS, both characteristic impedance and electrical length of an open stub can be controlled. To verify the frequency agility, a prototype dual-band coupler operated at 0.8 GHz and 1.9 GHz with 100 MHz frequency tuning range is fabricated and measured. In the frequency tuning range, the overall small phase and amplitude errors are also observed respectively.

Index Terms — Coupler, defected ground structure, frequency tuning, dual-band.

I. INTRODUCTION

The dual-band RF/MW passive component required in the modern wireless communications has been investigated for years. Amongst these components, the traditional single-band $\lambda/4$ branch-line coupler has been designed for dual-band operations by the centrally tapped stub [1,2]. The stub together with the signal line is formed in T-shaped line and was used to implement an equivalent dual-band 90° line. Furthermore, reconfigurable couplers that are capable of operating in different frequencies of multi-standard systems are highly desirable. Capacitive loading implemented by varactors is the traditional approach and used to vary the electrical length of transmission line so as to realize the reconfigurable operation [3,4].

Application of Electromagnetic Band Gap (EBG) to coupler research has been reported [5,6]. A notable class of EBG structures named Defected Ground Structure (DGS) is recently introduced and it has a controllable finite transmission zero characteristic. In a conventional rat-race hybrid coupler, it was reported that a dumbbell-shaped DGS was used to achieve a significant reduction of size and harmonic signal. Different types of compact rectangular patch hybrid couplers with different DGS were studied and size reduction up to 72.3% compared with the traditional ones without DGS was presented. As to the best of our knowledge, the usage of DGS in coupler tuning has not yet been addressed. To this end, we propose yet another technique that a T-shaped stub etched with U-shaped DGS is employed to implement the frequency agility of a microstrip dual-band stub tapped branch-line coupler. A prototype microstrip dual-band coupler designed at 0.8 GHz and 1.9 GHz with 100 MHz tuning range was experimentally characterized.

II. DUAL-BAND BRANCH-LINE COUPLER WITH U-SHAPED DEFECTED GROUND STRUCTURE STUB

The traditional $\lambda/4$ microstrip branch-line coupler with branch line impedances 50 $\Omega$ and $50/\sqrt{2}$ $\Omega$ operates at single frequency and it can be transformed to dual-band coupler by replacing $\lambda/4$ microstrip branch line by stub tapped branch line. For frequency tuning, the proposed reconfigurable coupler is a conventional branch-line coupler with shunt stub etched with a U-shaped DGS. Its structure is shown in Fig. 1. Each U-shaped pattern consists of three etched lines with equal width $W_1$, $W_2$ and length $L_1$. To study the frequency agility, the ABCD-matrix formulation is used. Assuming the input impedance looking into the DGS stub as $Z_{\text{DGS-Stub}}$, the ABCD-matrix of the DGS branch line is written as

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
= \begin{bmatrix}
\cos \theta_i & jZ_i \sin \theta_i \\
\frac{\sin \theta_i}{Z_i} & \cos \theta_i
\end{bmatrix}
\begin{bmatrix}
1 & 0 \\
\frac{1}{Z_{\text{DGS-Stub}}} & 1
\end{bmatrix}
\begin{bmatrix}
\cos \theta_i & jZ_i \sin \theta_i \\
\frac{\sin \theta_i}{Z_i} & \cos \theta_i
\end{bmatrix}
\]

where $Z_i$ and $\theta_i$ are the characteristic impedance and the electrical length of the branch line.
The element of ABCD-matrix is thus given by

\[ A = D = \cos^2 \theta_0 - \sin^2 \theta_0 + j \frac{Z_1}{Z_{DGS-Stub}} \sin \theta_0 \cos \theta_0 \]  
(2)

\[ B = - \frac{Z_1^2}{Z_{DGS-Stub}} \sin^2 \theta_0 + j 2 Z_1 \sin \theta_0 \cos \theta_0 \]  
(3)

\[ C = \frac{1}{Z_{DGS-Stub}} \cos^2 \theta_0 + j \frac{2}{Z_1} \sin \theta_0 \cos \theta_0 \]  
(4)

In addition to the equivalence of the dual-band quarter-wavelength transmission line like [1,2], it is observed that the control of input impedance \( Z_{DGS-Stub} \) may vary the characteristics of coupler due to the slow-wave-effect. In this context, \( Z_{DGS-Stub} \) can be simply modeled by

\[ Z_{DGS-Stub} = \frac{Z_{DGS-Stub}}{j \tan \theta_{DGS-Stub}} \]  
(5)

In fact, the U-shaped DGS control not only the electrical length but also the characteristic impedance of the stub. The change of slot length of U-shaped DGS against the characteristic impedance of stub is studied in Fig. 2. It is noticed that the characteristic impedance of DGS stub can be tuned from low impedance level of 40 \( \Omega \) to high impedance value of 90 \( \Omega \). Such slot length variation can be simply implemented by MEMS switch.

![Characteristic impedance variation against slot length of DGS stub.](image)

Fig. 2. Characteristic impedance variation against slot length of DGS stub.

Followed the basic coupler design as in [1], using the full-wave electromagnetic solver – IE3D, the simulation results of a dual-band coupler at \( f_1 = 0.8 \) GHz and \( f_2 = 2 \) GHz on a Rogers RO4003 substrate with dielectric constant of 3.38 and a thickness of 0.81 mm are shown in Fig. 3. The proposed coupler are symmetric in XX’ and YY’, the basic geometrical parameters are \( L = 71.1 \) mm, \( W = 72.2 \) mm, \( L_1 = 25 \) mm, \( L_2 = 66.4 \) mm, \( L_3 = 65 \) mm, \( W_1 = 65 \) mm, \( W_2 = 1 \) mm, \( W_3 = 5.3 \) mm, \( W_4 = 3.3 \) mm, \( W_5 = 0.8 \) mm and \( W_6 = 0.4 \) mm. According to Fig. 3(a), the return/insertion losses at these two operating frequencies are as good as 18.1 dB/2.53 dB at 0.8 GHz and 16.7 dB/3 dB at 2 GHz respectively. The phase difference between port#2 and port#3 is kept around 90° as illustrated in Fig. 3(b).

![Simulation results of the dual-band coupler](image)

Fig. 3. Simulation results of the dual-band coupler (a) the return loss and insertion loss, (b) the responses of \( \angle S_{21} \) and \( \angle S_{31} \).

![Simulated operating frequencies of the dual-band coupler](image)

Fig. 4. Simulated operating frequencies of the dual-band branchline coupler, the length of DGS etched in four stubs of branch
lines is varied from 5 mm to 50 mm. Its effect on the matching frequencies is studied in Fig. 4. Both operating frequencies $f_1$ and $f_2$ can be lowered for a longer DGS length. The characteristic impedance of DGS stub is indeed increased to high impedance value, for example, 82 Ω at $L_1 = 40$ mm referenced to Fig. 2. This high impedance stub does benefit to the design of dual-band coupler as addressed in [2]. Increasing 25 mm of the length of DSG stub of the nominal coupler of Fig. 3, the matching characteristic of the dual-band coupler is plotted in Fig. 5. The responses of two operating bands are similar in addition to the frequency tuning of $f_1$ varied from 0.8 GHz to 0.7 GHz and $f_2$ tuned from 2 GHz to 1.9 GHz. In dual-band tuning, the overall performance of the coupler is kept as good as the nominal ones.

III. MEASUREMENT RESULTS

To demonstrate the tuning of the proposed DGS coupler, a 0.8 GHz/2 GHz branch line coupler is prototyped on a Rogers RO4003 substrate with dielectric constant of 3.38 and a thickness of 0.81 mm. The dimensions of the designed coupler are similar to those presented in last section. The length variation of DGS can be implemented by MEMS switches.

Fig. 6 plots the measurement results of the coupler tuned for $L_1 = 25$ mm and 50 mm. The performance clearly shows two passbands at 0.8 GHz and 1.9 GHz respectively. Fig. 6(a) shows that the first passband is tuned from 0.7 GHz to 0.8 GHz whilst the second passband is varied from 1.89 GHz to 1.91 GHz. The measured return losses as recorded in Fig. 6(a) are better than 10 dB in the first passband and 17 dB in the second passband. From Fig. 6(b), the insertion loss at port#2 of the first passband varies from 2.45 dB to 3.08 dB whilst 4.02 dB to 3.3 dB for the second passband. At port#3, Fig. 6(c) records a insertion loss variation from 4.4 dB to 7 dB in the first passband whilst 3.97 dB to 4.4 dB in the second passband.

Fig. 5. Comparison of simulated return losses of the dual-band coupler for $L_1 = 25$ mm and 50 mm.

Fig. 6. Measured S-parameters of the dual-band coupler for $L_1 = 25$ mm and 50 mm. (a)$|S_{11}|$ (b)$|S_{21}|$ (c)$|S_{31}|$
In addition, the phase difference between the coupled and through outputs of the two passbands is plotted in Fig. 7. An average variation of \(90^\circ \pm 11^\circ\) is observed between these two ports in tuning.

Fig. 7. Measured phase response of \(S_{21}\) and \(S_{31}\) of the dual-band coupler for \(L_1 = 25\) mm and 50 mm. (a) Phase of \(S_{21}\) (b) Phase of \(S_{31}\)

IV. CONCLUSION

This paper presents a tunable dual-band branch-line coupler using DGS stub. Due to the slow-wave effect of the DGS, the electrical length and characteristic impedance of the stub can be tuned by the length of the U-Shaped defective ground structure alone in order to extend the usage of the conventional dual-band stub tapped branch-line coupler with a novel reconfigurable function. An experimental tunable dual-band branch-line coupler at 0.8/1.9 GHz is demonstrated with overall good coupler’s performance and frequency tuning.

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