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# Design for Harmonic Waves Suppression Based on 3 dB Branch Line Coupler

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**Abstract** : This paper presents a structure of the 3 dB Branch Line Coupler that can suppress the nth harmonic wave output. The 3 dB Branch Line Coupler consists of two pairs of λ/4n open stubs, which are located at the λ/4 series arms symmetrically. We established an optimal design method employing Powell's Least Square Method to design the circuit structure. Experimental results show that this 3 dB Branch Line Coupler suppresses the 2nd and 3rd order harmonic waves frequency components to less than -25 dB, while maintaining the characteristics of a conventional 3 dB Branch Line Coupler: featuring an equal power split, a simultaneous impedance matching at all ports and a good reflection and isolation. These results agree well with the simulation results.

**Key words** : Harmonic waves suppression; 3 dB Branch Line Coupler; λ/4; Powell's Least Square Method.

## Ⅰ. Introduction

As well known, the Branch Line Couplers are being used widely for RF circuits such as phasor shifter, Balanced Amplifier, Mixer, power divider, modulator, etc[1]. The harmonic waves exist in RF circuits widely, especially active circuit components because of the non-linearity. So if the harmonic waves can be suppressed in the Branch Line structure, we can eliminate the separate harmonic waves rejection filters from the RF circuits and design many area-effective RF components.

In this paper, we presented a modified 3 dB Branch Line Coupler that suppresses the nth harmonic wave component using λ/4n open stubs, where n is the harmonic component number that is to be suppressed. By placing a λ/4n open stub at each λ/4 series arms of the Branch Line Coupler, the nth harmonic component and its odd multiples are suppressed without sacrificing the characteristics of the conventional Branch Line Coupler at the operational frequency. In section Ⅱ, we proposed a structure of Branch Line Coupler for nth harmonic wave suppression, and we found the optimal parameters of the circuit by employing the Powell's Least Square Method. The simulation and experiment results of the 3 dB Branch Line Coupler for the 2nd and 3rd order

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harmonic waves suppression are given in Section III and a conclusion and plans in future are given in Section IV.

## II. 3 dB Branch Line Coupler for the nth Order Harmonic Wave uppression

### 2-1 Theoretical Analysis

A schematic diagram of the proposed 3 dB Branch Line Coupler, which suppresses the nth harmonic component using two pairs of λ/4n open stubs, is shown in Fig. 1. One pair of open stubs is used to suppress the 2nd harmonic component, and another pair of open stubs is used to suppress the 3rd order harmonic wave component. Each of the characteristic impedance is denoted by Z1, Z2, Z3, Z4, Z5, Z6, and each of series arms is divided into three sections by insertion of two open stubs, and the length of these three sections is λ/12-x, λ/12, and λ/12-y, relatively, where the x and y are used for compensating the phase shift resulting from the open stubs insertion. Here eight variables are imported, and we will find all the values by Powell's Least Square Method. Fig.1 shows that this circuit is symmetric, so we can analyze it by the even- and odd-mode analytical method.

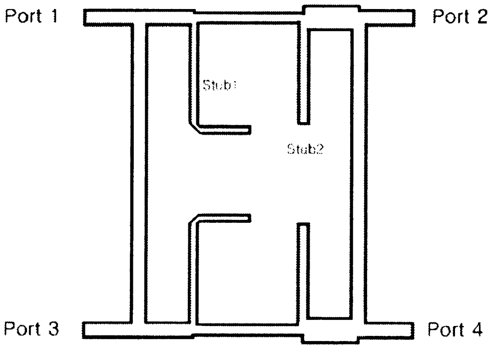


**Fig. 1 Schematic diagram of the 3 dB Branch Line Coupler for the nth harmonic wave suppression**

The even mode excitation is obtained by applying equal waves at ports 1 and 2 of the network, while the odd mode excitation is obtained by applying out-of-phase waves at ports 1 and 2. Equivalent circuits for the two modes are shown in Fig. 2 and Fig. 3[2].

#### 2-1-1 Even-Mode Analysis

From Fig. 2, this network can be considered as seven cascading components, including open stubs and transmission lines. Therefore, we can calculate the s-parameters from the cascading matrices[3]. The cascading matrices of the open stub and the transmission line can be calculated by Eq. (1) and Eq. (2), respectively.

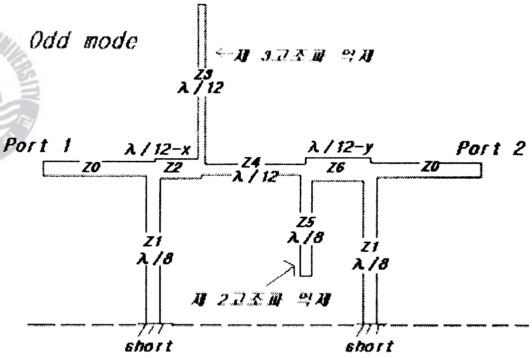


**Fig. 2 Even-mode equivalent circuit.**

$$[\,T^{e}_{os}] = \begin{bmatrix} 1 & 0 \\ Y_{IN} & 1 \end{bmatrix} \tag{1}$$

$$[\,T^{e}_{l}] = \begin{bmatrix} \cos\Theta & jZ_0\sin\Theta \\ jY_0\sin\Theta & \cos\Theta \end{bmatrix} \tag{2}$$

where $Y_{IN}$ is the input impedance of the open stub, and calculated by Eq. (3), and $\theta$ is the electrical length for the corresponding transmission line.

$$Y_{IN} = jY_0\tan\Theta \tag{3}$$

The total cascading matrix is calculated by Eq. (4)

$$[T_t] = [T_1]\cdot[T_2]\cdot[T_3]\cdot[T_4]\cdot[T_5]\cdot[T_6]\cdot[T_7] \qquad (4)$$

and then, the s-parameters of the even-mode can be worked out by the following Eq. (5).

$$\gamma_e = \frac{A+B-C-D}{A+B+C+D}$$

$$T_e = \frac{2}{A+B+C+D} \qquad (5)$$

### 2-1-2 Odd-Mode Analysis

All the parameters in the odd-mode equivalent circuit can be calculated in the same manner as the one used in the even-mode, and the reflection coefficient and the transmission coefficient are expressed by $\gamma_o$ and $T_o$, respectively. Thus we can calculate the s-parameters by Eq. (6).

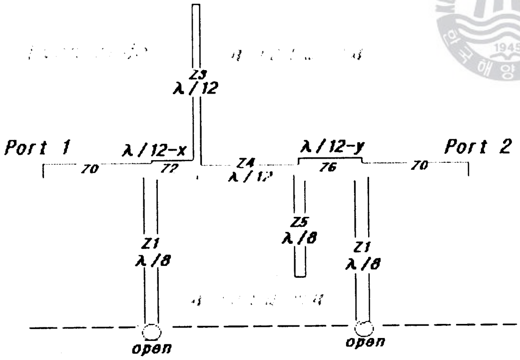


Fig. 3 Odd-mode equivalent circuit.

$$S_{11} = \frac{\gamma_e + \gamma_o}{2}$$

$$S_{21} = \frac{T_e + T_o}{2}$$

$$S_{31} = \frac{\gamma_e - \gamma_o}{2}$$

$$S_{41} = \frac{T_e - T_o}{2} \qquad (6)$$

### 2-2 Optimum Design and Calculation Results

In this paper, we find the optimum circuit parameters by Powell's Least Square Method.

Powell's Least Square Method is a powerful method for minimizing a sum of squares of non-linear parity functions without calculating derivatives[4].

At the center frequency, the ideal s-parameters of the 3 dB Branch Line Coupler $|S_{11}|, |S_{21}|, |S_{31}|, |S_{41}|$ will be 0, $\frac{\sqrt{2}}{2}$, 0, $\frac{\sqrt{2}}{2}$, relatively. So the parity function used in this paper is shown below:

$$F(Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, X, Y) =$$

$$|S_{11}|^2 + (|S_{21}| - \frac{\sqrt{2}}{2})^2 + |S_{31}|^2 + (|S_{41}| - \frac{\sqrt{2}}{2})^2 \qquad (7)$$

**Table 1 Circuit Parameters obtained by Powell's Least Square Method.**

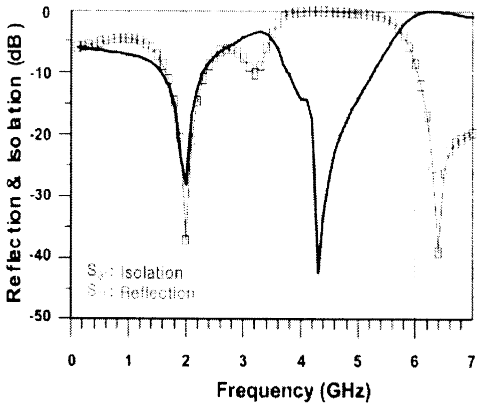
| | Normalized characteristic impedance (Ω) | Electrical Length (rad) |
|---|---|---|
| $Z_1$ | 1.0583 | $\pi/2$ |
| $Z_2$ | 0.9902 | $\pi/6$ - X |
| $Z_3$ | 1.4939 | $\pi/2n$ |
| $Z_4$ | 1.2427 | $\pi/6$ |
| $Z_5$ | 1.2942 | $\pi/2m$ |
| $Z_6$ | 0.7454 | $\pi/6$ - Y |

Where n=2, m=3 and X=0.2587, Y=0.2387. $Z_0$ = 50 Ω

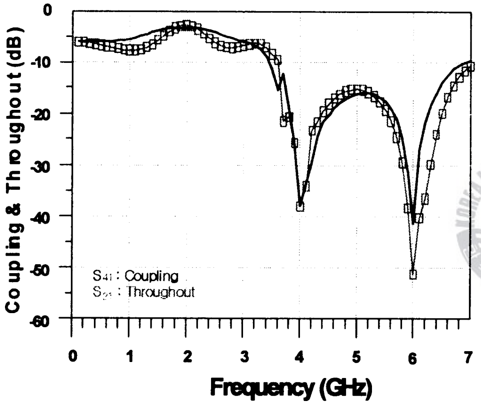
A search cycle of this method starts with the characteristic impedance Zo and X=Y=0. The optimum results obtained when the parity function converged on 0.011 are shown in Table 1.

## Ⅲ. Simulation and Experiment

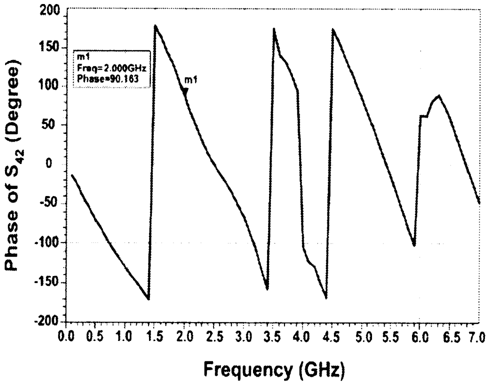
A 3 dB Branch Line Coupler for fo = 2 GHz and Zo = 50Ω is fabricated on a 0.5 mm-thick substrate, which has a relative permittivity of 3.5 and a conductor thickness of 35μm. The simulation results by ADS(Advanced Design System) are shown in Fig.4. In Fig.4(a), the reflection coefficient $S_{11}$ and the isolation



(a)



(b)



(c)

**Fig. 4 Simulated S-parameters of the 2 GHz 3 dB Branch Line Coupler for the 2nd and 3rd harmonic waves suppression: (a) S11 and S31. (b) S21 and S41. (c) Phase of S42.**

coefficient $S_{31}$ are -37 dB and -28 dB at 2 GHz. Fig.4(b) shows that the 3 dB Branch Line Coupler passes the 2 GHz fundamental signal, and equally divided the input power at port 1 into the output ports 2 and 4, but reflects the 4 GHz 2nd-order and the 6 GHz 3rd-order harmonic waves components. Simultaneously, the phase-difference between two output ports 2 and 4 is 90.163°.

A photograph of the proposed 3 dB Branch Line Coupler in this paper is shown in Fig.5. This circuit has an area of 2.4 x 1.7 $cm^2$. The s-parameters are measured using an Wiltron Model 360B network analyzer, and shown in Fig.6.

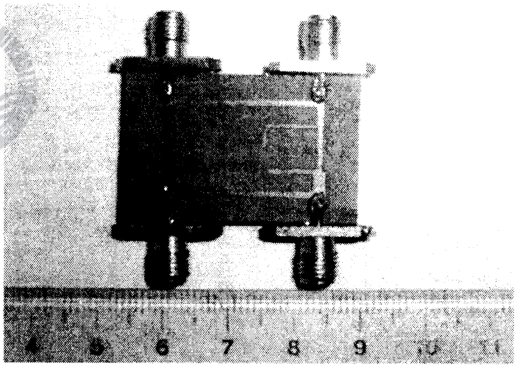
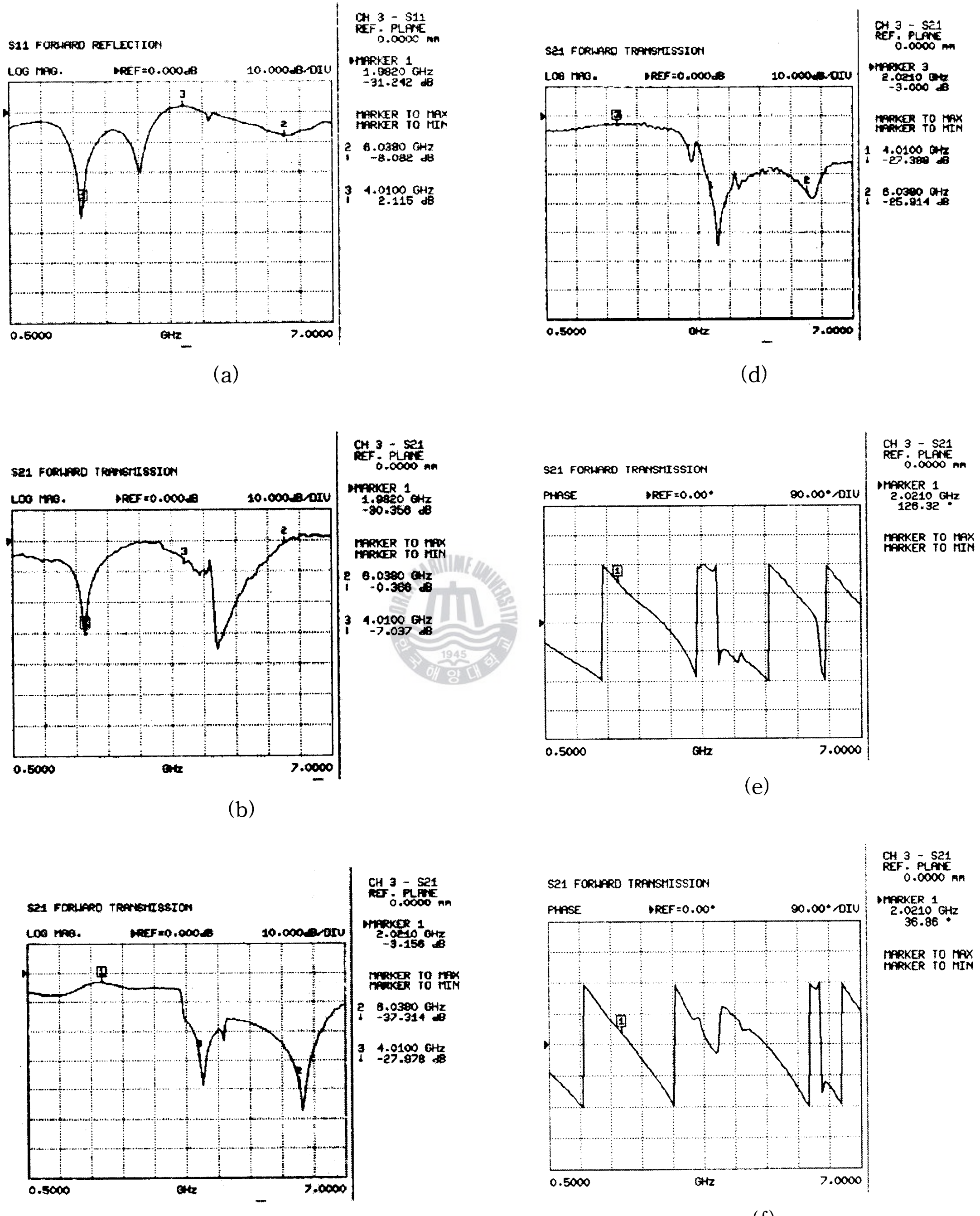


**Fig. 5 Photograph of fabricated 2 GHz 3 dB Branch Line Coupler for the 2nd and 3rd order harmonic waves suppression.**

The measured $S_{11}$ and $S_{31}$ are -31.24 dB and -30.36 dB at 2 GHz, the measured S21 and S41 are the -3.15 dB and -3.00 dB at 2 GHz, and at 4 GHz and 6 GHz, the $S_{21}$ and $S_{41}$ are less than -25 dB. The phase of $S_{42}$, namely the difference between S21 and S41 is 89.46°. These results showed that the proposed 3 dB Branch Line Coupler operates well as a conventional one at the operating frequency, while suppressing the 2nd and 3rd order harmonic waves components.



(a) (d)

(b) (e)

(c) (f)

**Fig. 6 Measured S-parameters of the 3 dB Branch Line Coupler for the 2nd and 3rd order harmonic waves suppression: (a) S11. (b) S31. (c) S21. (d) S41. (e) Phase of S21. (f) Phase of S41.**

## Ⅳ. Conclusion

A structure of the 3 dB Branch Line Coupler, which can suppress the nth harmonic output, is proposed and has been fabricated for 2 GHz operation. At 2 GHz, the measured $S_{11}$, $S_{21}$, $S_{31}$, $S_{41}$ are -31.24 dB, -3.15 dB, -30.36 dB, -3.00 dB, respectively. At the 2nd order harmonic wave frequency of 4 GHz and the 3rd order harmonic wave frequency of 6 GHz, the measured $S_{21}$, $S_{41}$ are 37.31 dB, -27.39 dB and -27.98 dB, -25.91 dB, respectively. The results at 2 GHz show that the 3 dB Branch Line Coupler has an equal power split to the two output ports, and simultaneously maintains 90° phase-difference between ports 2 and 4 and a good isolation between ports 1 and 3. These results indicate that the proposed 3 dB Branch Line Coupler operates well as a conventional one at the operating frequency of 2 GHz, while suppressing the 2nd and 3rd order harmonic waves components.

## Acknowledgements

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