CIRCUIT MODELING OF TRANSITION FROM STRIPLINE TO DUAL SLOTLINE FOR THE NOTCH ANTENNA

Joonho So,[1] Junyeon Kim,[1] Won Jang,[1] and Changyul Cheon[2]
[1]TRC 2nd Division, Agency for Defense Development, Yuseong P.O.Box 35-5,Taejon, 305-600, Korea
[2]Department of Electronics, University of Seoul 90 Jeonnong-dong, Dongdaemun-Ku, Seoul, 130-743, Korea
E-mail: joonhoso@hanmail.net

1. Introduction

Notch antenna has been used as a wideband radiator with a single element or array elements [1-2]. In order to reduce the radiation loss form the feeding line, the notch antenna can be designed using the the stripline-to-dual slotline transition. The dual slotline has relatively less dispersion and lower characteristic impedance than those of single-sided slotline for the same slot width, which gives an advantage for the fabrication of narrow slot [3], [4]. The equivalent circuit model for the microstrip-to-slotline transition is well known in [5] with analytical formulas, however not yet for the strip-to-dual slotline transition.

In this paper, a segmented analysis method of notch antenna and a circuit model for the transition of stripline to dual slotline are presented. In order to analyze the circuit model of the transition, the characteristic impedance, the dispersive characteristics and the shorted impedance of dual slotline are numerically calculated. Using these numerical results, the 4th order Marchand balun[6] are designed for the feeder of notch antenna. In order to verify the proposed circuit model, the notch antenna fed by the balun is designed, fabricated, and the calculated and measured results are compared.

2. Characterization of Transition

The notch antenna can be segmented into a balun and a tapered slot antenna fed dual slotline as shown in Fig.1 (a). The equivalent circuit for the segmented notch antenna is shown in Fig. 1(b). The 4th order Marchand balun circuit as a two-port circuit consists of two striplines with Z_1 and Z_2, an open-ended strip reactance X_2, and two dual slotlines with Z_3, Z_4, a shorted slotline impedance R_3 and X_3, turns-ratio of transformer n, and has an antenna input impedance Z_{ant} as a load. The dual slotline-fed notch antenna as one port circuit has the exponentially tapered slot shape. Here, R is the exponential opening rate, L_s is the length of the tapered slotline, and W_f and W_e are the widths of the dual slotline feeder and the antenna aperture as defined in [2].

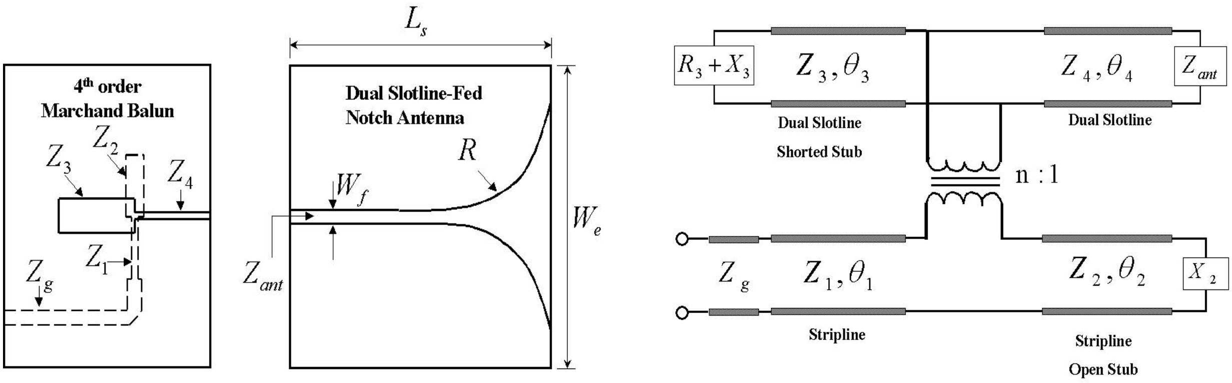

Fig. 1. (a) Segmented notch antenna and (b) its equivalent circuit model

ISBN: 89-86522-78-0 94460©KEES

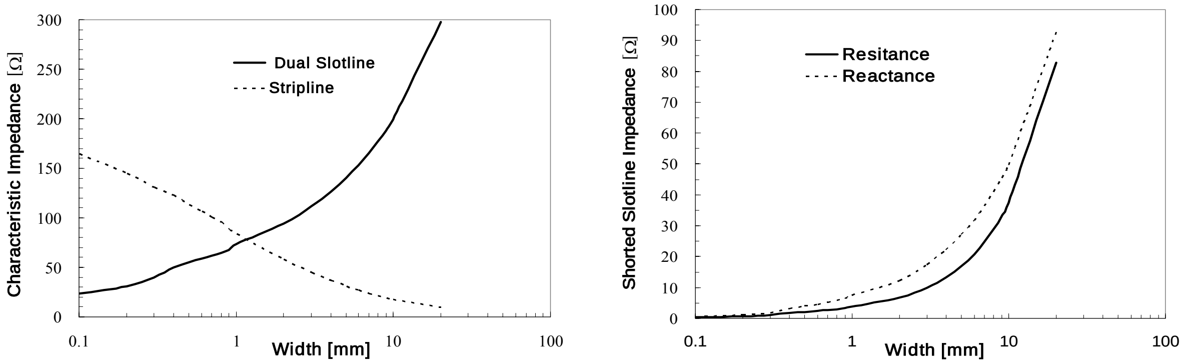

Fig. 2. (a) Characteristic impedance, and (b) resistance and reactance of shorted dual slotline.

Using the commercial time domain solver, we have characterized the circuit parameters. The dispersion characteristics of dual slotline and stripline, and the end effect of a shorted slotline and an open-ended stripline are calculated. In this work, the parameters for the substrate are fixed with the thickness d = 3.2mm and the relative dielectric constant ε_r = 2.2.

Fig. 2(a) shows the characteristic impedance of dual slot increases with the slot width, but that of strip decreases with the strip width [3-4]. In Fig. 2(b), we can see the short end in a dual slot is not purely reactive, and the resistance R_3 and reactance X_3 are the same order as those of single-sided shorted slotline [5]. It was found that the resistance R_3 increases with the slot width, and has the linear frequency dependency. In this work, the resistance value R_3 is calculated at the design center frequency of 4GHz, and the frequency dependency is not considered. And we can also see that the effective dielectric constant decreases with the slot width, but the result is not shown here.

Since the stripline has a non-dispersive characteristic and the open-ended strip has a nearly non-radiative characteristic, the effective dielectric constant for the strip is fixed at ε_r = 2.2, and only the reactance of the open-ended strip is considered, but these numerical results are not shown here. The turns-ratio n of the transformer between stripline and slotline can be decided using the closed form equations in [7], which has a frequency dependency with the widths of strip and slot.

3. Analysis of Circuit Model

In order to design the 4th order Marchand balun in Fig. 1, the load impedance should be a real constant. In this work, we assumed that the antenna impedance is real and nearly constant with a small variation. And we can get the values Z_1, Z_2, Z_3, and Z_4 in the equivalent circuit which can be determined using the synthesis formula in [6]

Using the *ABCD* transmission parameter, the overall T_B matrix of the balun as a two-port circuit can be obtained by following expression:

$$T_B = T_1 \bullet T_2 \bullet T_n \bullet T_3 \bullet T_4, \quad (1)$$

where $T_{1,4} = \begin{bmatrix} \cos\theta_{1,4} & jZ_{1,4}\sin\theta_{1,4} \\ jY_{1,4}\sin\theta_{1,4} & \cos\theta_{1,4} \end{bmatrix}$, $T_n = \begin{bmatrix} n & 0 \\ 0 & n \end{bmatrix}$, $T_2 = \begin{bmatrix} 1 & Z_2^{in} \\ 0 & 1 \end{bmatrix}$, $T_3 = \begin{bmatrix} 1 & 0 \\ Y_3^{in} & 1 \end{bmatrix}$.

The series and shunt impedance Z_2^{in}, Y_3^{in} for the open end and shorted stubs are expressed as follows:

$$Z_2^{in} = Z_2 \frac{-jX_2 + jZ_2 \tan\theta_2}{Z_2 + X_2 \tan\theta_2}, \quad (2)$$

$$Y_3^{in} = Y_3 \frac{Z_3 + j(R_3 + jX_3)\tan\theta_3}{(R_3 + jX_3) + jZ_3 \tan\theta_3}. \quad (3)$$

Where θ_i is the electrical length of each element at the operating frequency and i = 1, 2, 3 and 4.

The overall scattering matrix S_B for the balun which has different two-port impedance is then readily obtained as follows:

$$S_B = \sqrt{Y_o}(Z_B - Z_o)(Z_B + Z_o)^{-1}\sqrt{Z_o}\,, \quad (4)$$

where $Z_B = \begin{bmatrix} A/C & (AD-BC)/C \\ 1/C & D/C \end{bmatrix}$, $Z_o = \begin{bmatrix} Z_g & 0 \\ 0 & Z_f \end{bmatrix}$, $Y_o = Z_o^{-1}$, Z_o and Z_f are the characteristic impedances of the generator and antenna feeder ports.

4. Performance Evaluation

The circuit model discussed in the previous section is applied to the design of a stripline-fed notch antenna with the 4th order Marchand balun that has the 4:1 bandwidth at the center frequency of 4GHz.

Firstly, to get the load impedance of the balun, the antenna input impedance Z_{ant} is obtained by the following equation:

$$Z_{ant} = Z_f \frac{1+\Gamma_{ant}}{1-\Gamma_{ant}}\,. \quad (5)$$

In order to design the balun as a feeder of notch antenna, the antenna impedance should be real and constant. Therefore, we tried to optimize the shape of the tapered slot antenna. In Fig. 3, the antenna resistance is nearly constant about 60 ± 20Ω and the reactance is about 0 ± 20Ω above 1.8GHz. Here, the antenna aperture W_e is 62mm, the taper length L_s is 72.6mm, the exponential opening rate R is 0.113 mm^{-1}, and the slot width W_f of the antenna feeder is 1.2mm.

Secondly, the characteristic impedances of the 4th order Marchand balun are obtained using the synthesis equations in [6]. Here, we assume that the load impedance of the balun is the averaged antenna impedance Z_{ant} of 60Ω and a generator impedance of 50Ω. The physical values of the balun such as each width W_i and quarterwave length L_i of stripline and dual slotline are obtained using the numerical results in Fig. 2 and are summarized in the table I.

And also, as shown in this table, we calculated the extended lengths due to the current flows around the shorted dual slotline and that due to the fringing field at the open-ended stripline stub. In order to compensate these end effects, the physical lengths in the table I are calculated as following equations:

$$L_{2,3} = \lambda_o / \sqrt{\varepsilon_{eff}^{w_{2,3}}} / 4 - \delta L_{2,3}\,, \quad (6)$$

where $\delta L_2 = \frac{1}{\beta_2 \tan^{-1}(X_2 Z_2)}$, $\delta L_3 = \frac{1}{\beta_3 \tan^{-1}(X_3 / Z_3)}$.

Finally, we can get the overall scattering parameter S^T_{11} for the notch antenna with the balun which can be obtained using the scattering parameters in (4) and the reflection coefficient of the antenna Γ_{ant} in (5).

$$S^T_{11} = S^B_{11} + \frac{S^B_{12} S^B_{21} \Gamma_{ant}}{1 - S^B_{22}\Gamma_{ant}}\,. \quad (7)$$

Fig. 4 shows the results obtained from the proposed circuit model, the fullwave analysis, and the measured for the physical parameters in the table I. The equivalent circuit model provides a reasonable result in return loss and bandwidth, but there are some disagreements in the passband. This is due to the tapered shape of the strip and slot stubs at the junction of the transition. From the compared results of the circuit model considering the shorted dual-slotline characteristics, we can find that the shorted resistance R_3 causes the null points at about 0.5GHz, and the bandwidth is very sensitive to the lengths of δL_2 and δL_3.

TABLE 1. The Characteristic Impedance and their Physical Values for the 4th Order Marchand Balun; BW=4:1, f_c= 4GHz, Z_{ant}= 60 Ω, and Z_g= 50 Ω

i	1	2	3	4
Z_i [Ω]	52.6	16.2	184.9	56.9
W_i [mm]	2.39	11.47	9.01	0.58
L_i [mm]	12.64	11.87	14.42	15.58
δL_i[mm]	-	0.77	2.49	-

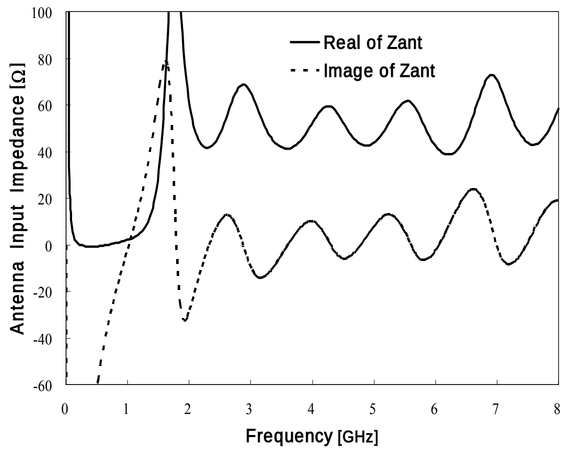

Fig. 3. Antenna input impedance

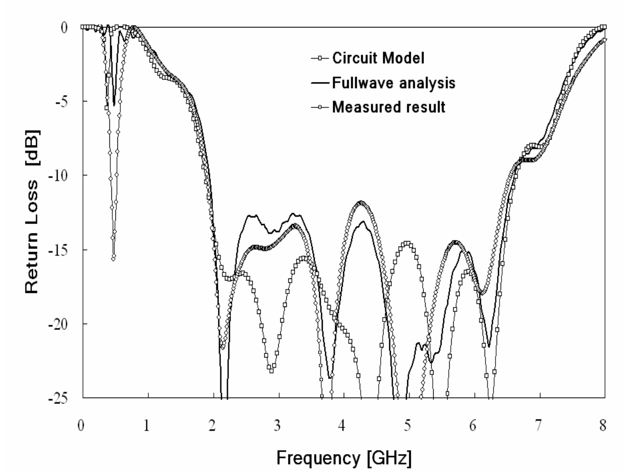

Fig.4. Return loss of the notch antenna with balun

5. Conclusion

A segmented method has been presented to analyze the stripline-fed notch antenna and an equivalent circuit model was developed to design the balun for the transition from stripline to dual slotline. A notch antenna with the 4th order Marchand balun was designed and fabricated with the requirement of 4:1 bandwidth. The result of circuit model shows the good agreement with the measured results. Using the proposed circuit model, we can systematically design the notch antenna without a cut-and-trial method, and also apply the segment method to analyze the notch array antenna.

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