Broadband 180° Bit Phase Shifter Using a New Switched Network

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ABSTRACT — **In this paper, a broadband 180° bit phase shifter using a new switched network was presented. A new network is composed of coupled lines(section) and 45° open and short stubs, which are shunted at the edge points of the main line, respectively. The design graphs provide the required Z_m, Z_s values, and I/O match and phase bandwidths. Four different 180° bit phase shifters, operated at 3 GHz, were designed and fabricated using the design graphs, and were experimented. The measured performances of each phase shifter were well in agreement with the corresponding the simulation ones over the operating bands, and showed broadband phase characteristics.**

I. INTRODUCTION

Phase shifters are important components that are used extensively in electronic beam scanning phased arrays and phase modulators[1]. The ideal phase shifter is a two-port unit designed to change the phase of the input signal without insertion loss and has a flat phase characteristic in the operating frequency band. The phase shifter with a broadband and large phase shift proposed is a switched network type. The phase shift is achieved by switching between two different networks. Phase shifters that are similar in purpose and type have been reported[2–5]. In contrast to the above structures, the proposed broadband phase shifter is suitable for large phase shifts such as 90°and 180°.

II. STRUCTURE AND THEORY

The proposed structure makes use of a switching network as shown in Fig.1. The structure is composed of two paths, path 1 and path 2, and a path is chosen by the toggle switching operation of each diode pair of D1, D2 and D3, D4. The path 1 network is a variable standard transmission line that has characteristic impedance Z_o and a length fixed at half the wavelength at the centre frequency, $0.5\lambda_o$, plus an additional length that is required to obtain the desired phase shift. On the other hand, the path 2 network is composed of coupled line and 45° open

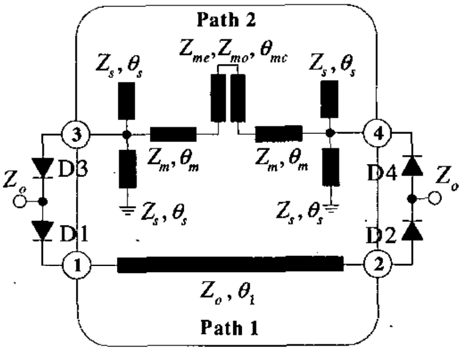

Fig. 1. Proposed phase shifter structure

and short stubs, which are shunted at the edge points of the main line, respectively. The path 2 networks have a more dispersive phase property than the standard line of the path 1, and the phase slope can be controlled by the specific ratio of main and stub impedances, and by an impedance ratio R of a coupled line according to the desired phase shift. Applying the even and odd mode analysis and the superposition principle, the S-parameters to the path 2 of Fig. 1 are given by

$$S_{11}=S_{22}=0 \tag{1}$$

$$S_{33}=S_{44}=\frac{1}{2}\left(\frac{1-jT_e(f)}{1+jT_e(f)}+\frac{1+jT_o(f)}{1-jT_o(f)}\right) \tag{2}$$

$$\begin{aligned}\Delta\phi_T(f)&=\arg(S_{21})-\arg(S_{43})\\&=-\theta_1(f)+\pi-\tan^{-1}\left(\frac{1+T_eT_o}{T_e-T_o}\right)\end{aligned} \tag{3}$$

where,

$$T_e(f)=\frac{\bar{Y}_m(\bar{Y}_{me}\tan\theta_c+\bar{Y}_m\tan\theta_m)}{\bar{Y}_m-\bar{Y}_{me}\tan\theta_c\tan\theta_m}-2\bar{Y}_s\cot2\theta_s \tag{4}$$

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$$T_o(f)=\frac{\bar{Y}_m\left(\bar{Y}_{mo}\cot\theta_c-\bar{Y}_m\tan\theta_m\right)}{\bar{Y}_m+\bar{Y}_{mo}\cot\theta_c\tan\theta_m}+2\bar{Y}_s\cot 2\theta_s \qquad (5)$$

$$Z_{me}=\sqrt{R}Z_m \qquad (6)$$

$$Z_{mo}={Z_m}\Big/{\sqrt{R}} \qquad (7)$$

$$\theta_c=\tan^{-1}\left(\sqrt{R\left\{\frac{1-\cos(180^\circ-2\theta_m)}{1+\cos(180^\circ-2\theta_m)}\right\}}\right) \qquad (8)$$

with $\theta_s=0.25\pi\bar{f}$, $\theta_1=[\pi+\Delta\phi_T(f_o)]\bar{f}$. $\bar{Y}_m, \bar{Y}_{me}, \bar{Y}_{mo}, \bar{Y}_s$ are the normalized characteristic admittances.

II. DESIGN GRAPHS FOR 180° BIT PHASE SHIFTER

The I/O match and relative phase shift response versus frequency of the path 2 network with respect to the desired phase shift can be optimized by the proper determination of the Z_m, Z_s, R, θ_m values. For 180° phase shift with design conditions of R=1.7, VSWR=1.15:1 and 2° maximum phase deviation, an unique set of the optimum Z_m, Z_s and θ_m values from the equations (1) ~ (8) can be achieved with respect to the non-coupling length as shown in Fig. 2 by the computer simulation. Also, in the same design conditions, the responses of I/O match and phase bandwidths by θ_m variations can be plotted as shown in Fig. 3. The structure can obtain maximum I/O match and phase bandwidth when a non-coupling length is zero. Under given design conditions, Z_m, Z_s impedances and fractional bandwidths by variations of a coupling impedance ratio R are shown in Fig. 4 and Fig. 5, respectively.

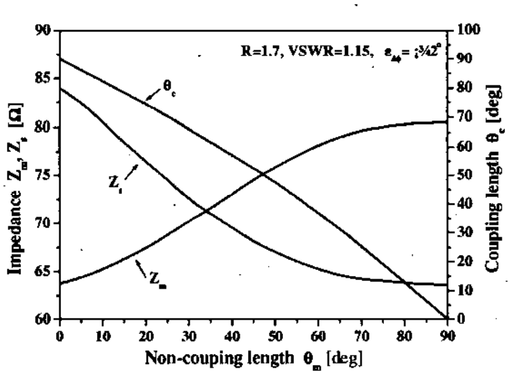


Fig. 2. Optimal values of Z_m and Z_s by θ_m variations

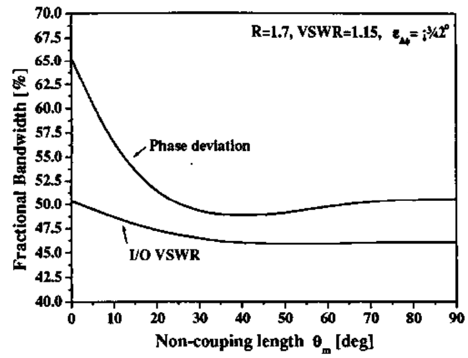


Fig. 3. I/O match and phase bandwidths by θ_m variations

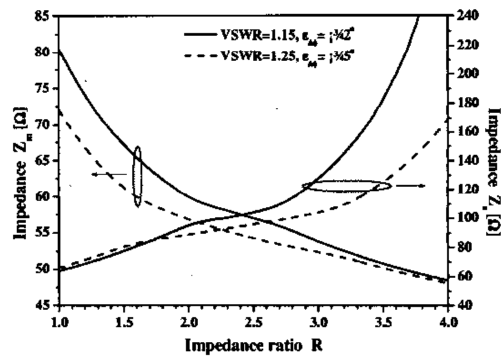


Fig. 4. Optimal values of Z_m and Z_s by R variations

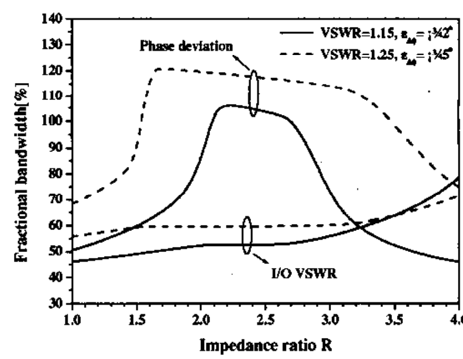


Fig. 5. I/O VSWR and phase bandwidths by R variations

IV. EXPERIMENTAL RESULTS AND DISCUSSION

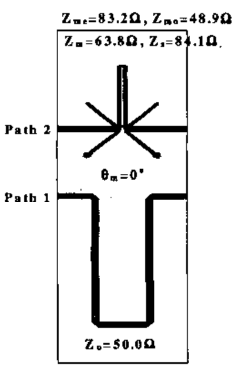
Four different kinds of 180° phase shifter operated at 3 GHz were fabricated using a soft teflon substrate whose parameters are ε_r=2.17, H=20 mils, T=0.5 oz., and tanδ= 0.0009(@10 GHz). One of them was fabricated with a standard Schiffman structure relatively to compare with the phase characteristics. Design values were obtained from Fig. 2, and a coupling impedance ratio R was chosen as 1.7 considering MIC technology. The design parameter values was summarized in Table 1.

Table 1. Design parameter values

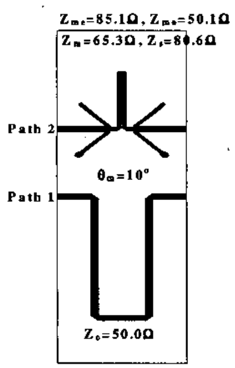
Item		θ_m			S.S.*
		0°	10°	90°	
Main Line & Stubs	Z_m	63.8Ω	65.3Ω	80.5Ω	50.0Ω
	Z_s	84.1Ω	80.6Ω	63.7Ω	-
	θ_s	45.0°	45.0°	45.0°	-
Coupled line (R=1.7)	Z_{me}	83.2Ω	85.1Ω	-	65.2Ω
	Z_{mo}	48.9Ω	50.1Ω	-	38.3Ω
	θ_c	90.0°	82.3°	-	90.0°
Band-width	I/O	50.4%	48.7%	46.1%	∞ (정합)
	Phase	65.4%	56.3%	50.6%	3.2%

(*) S.S.: Standard Schiffman

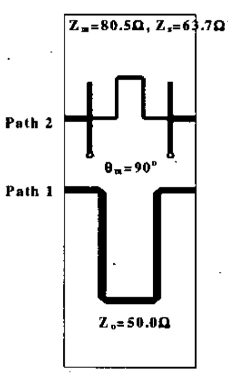
The photos of the fabricated phase shifters are shown in Fig. 6. The electrical performance of each phase shifter was measured using HP8510C, and their return loss and phase shift responses are shown in Fig. 7 and Fig. 8, respectively, together with simulation ones.



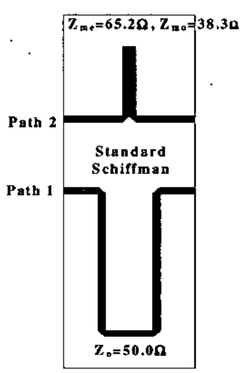
(a) θ_m=0°



(b) θ_m=10°

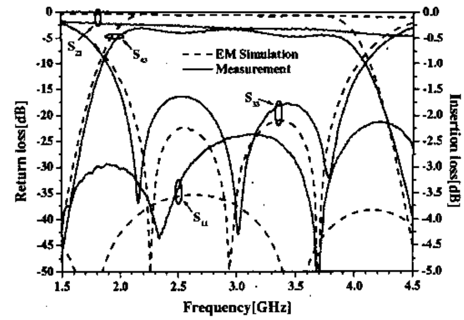


(c) θ_m=90°

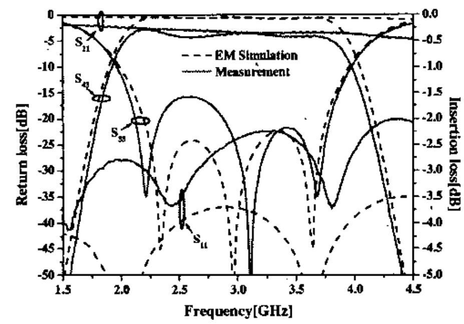


(d) Standard Schiffman

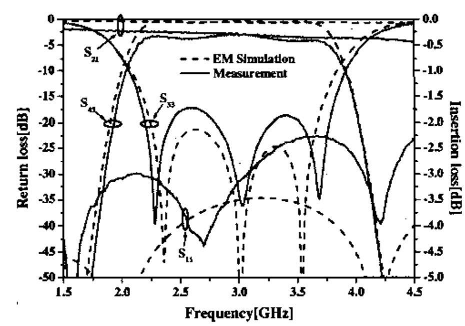
Fig. 6. Photos of fabricated 180° bit phase shifters



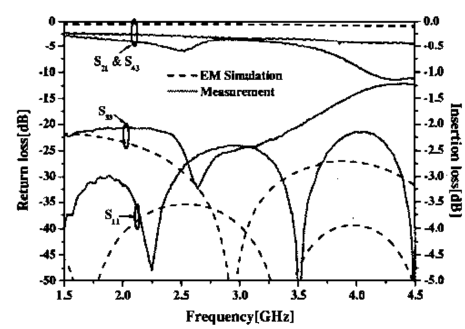
(a) θ_m=0°



(b) θ_m=10°

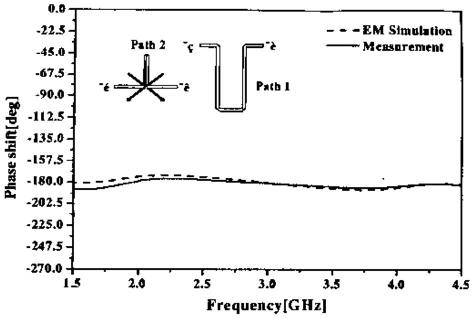


(c) θ_m=90°

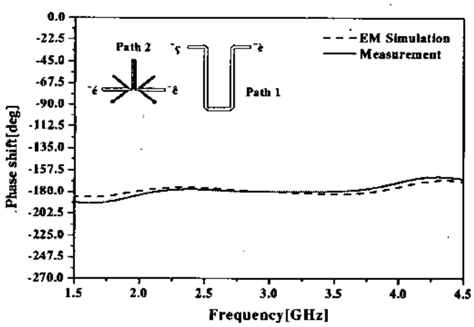


(d) Standard Schiffman

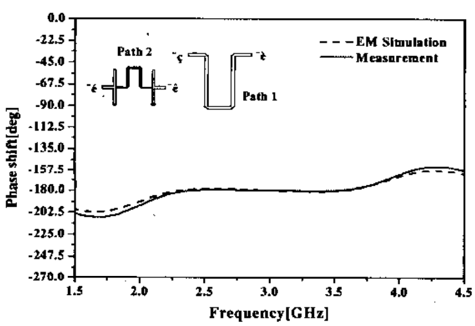
Fig. 7. Measured return loss responses



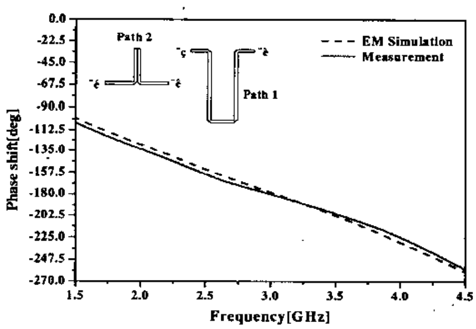
(a) θ_m=0°



(b) θ_m=10°



(c) θ_m=90°



(d) Standard Schiffman

Fig. 8. Measured phase shift responses

It showed that the measured performances of each phase shifter were well in agreement with the corresponding simulation results over the operating bands. The bandwidths defined by the return loss 14 dB and the phase error ±5° were summarized in Table 2.

Table 2. Measured I/O match and phase bandwidths

Bandwidth	θ_m=0°	θ_m=10°	θ_m=90°	Schiffman
I/O match	66.8 %	61.3 %	57.1 %	∞(match*)
Phase(±5°)	94.8 %	62.5 %	55.8 %	8.7 %

(*) the return loss of 12 dB is considered.

The measured data of Table 2 verified that I/O match and phase bandwidths are largest at θ_m=0° according to Fig. 3. And also, the phase characteristic of the proposed structure showed wider than one of a standard Schiffman structure.

V. CONCLUSION

The broadband phase shifter using the new switched network with a coupled line and two double-stubs was presented. As the new network can provide a controllable strong phase dispersive characteristic by the proper determination of the Z_m, Z_s, R, θ_m values, it is appropriate for broadband application of large phase shifts such as 90° and 180°. With the impedance ratio R=1.7, VSWR = 1.15:1 and 2° maximum phase deviation, the design graphs was obtained as the function of the non-coupling length θ_m through the computer simulation. Using the design graphs, four kinds of 180° phase shifter were fabricated, and they showed broadband phase characteristics. In the near future, the proposed structure will be widely used in the MIC applications to require a broadband phase shifter.

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