An Improved Switched-line Phase Shifter Using Distributed MEMS Transmission Line

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ABSTRACT:
In this paper a new switched-line phase shifter is designed using Distributed MEMS Transmission Line (DMTL) instead of conventional transmission line. DMTL is transmission line with loaded MEMS bridges. At first using simplified model of DMTL the improved structure is analyzed. The design is explained by describing SIB frequency which minimizes return and insertion loss. The design procedure of improved structure is presented using closed-form equations. The Ansoft HFSS is used for simulation and a comparison is made between conventional and improved structures. The results show the feasibility of new design. Also it shows that the improved structure has low size and low loss compared with conventional switched-line. The simulation results show that the phase shifter creates180 degree with the average insertion loss and return loss of -1.1 dB and -38.2 dB at 2.45GHz respectively which demonstrate an improvement in loss and isolation of the new switched-line.

KEYWORDS: Phase shifter, Switched-line, DMTL, CPW

1. INTRODUCTION

Nowadays, the development of communication system using the smart antenna increases the demand for the phase shifter with better performance and minimum size. Microwave phase shifters are widely employed in many wireless communication and remote sensing systems, including radar sensors based on phased antenna arrays. Switched-line phase shifters are commonly used due to their simplicity [1-3]. They also can be designed as true time delay (TTD) phase shifter that is used for ultra wideband phased antenna arrays [4].

The Switched-line design uses the feature that the waves propagate on the transmission line has the phase which is proportional to the constant phase of the transmission line and the length of paths. In low frequency application the constant phase of the transmission line is reduced. Therefore they occupy very large space in low frequency applications [5].

In this paper a switched-line phase shifter is improved by DMTL. DMTL is transmission line with loaded MEMS bridges. Using DMTL instead of transmission line in switched-line phase shifter, the loss and size of structure is reduced. At first using simplified model of DMTL the improved structure is analyzed. The design is explained by describing SIB frequency which minimizes return and insertion loss. Then the improved structure is simulated and the result is compared with conventional switched-line which shows development in loss and size simultaneously.

2. DESIGN of NEW SWITCHED-LINE PHASE SHIFTER

Figure 1 shows the switched-line design which the phase shift is achieved by switching between two pathways as below:

$$\Delta\phi = \beta\,\Delta L \tag{1}$$

Where ΔL is the difference length between two pathways. In conventional switched-line the pathways are constructed of transmission line which β is the constant phase of them that is given below [6]:

$$\beta_{conv} = \frac{2\pi\sqrt{\varepsilon_{\text{eff}}}}{c} f \tag{2}$$

Where ε_{eff} is the effective permittivity of the unloaded line, f is the operating frequency, c is the light velocity in free space. But in improved switched-line the transmission line pathways are replaced by distributed MEMS transmission line (DMTL) which β is obtained using simplified model shown in Figure 2 as below [5,7]:

$$\beta_{imp} = \frac{2\pi\sqrt{\varepsilon_{\text{eff}}}\,Z_{\text{o}}}{cZ_{\text{ol}}} f \tag{3}$$

Where Z_o is the characteristic impedance of unloaded line and Z_{ol} is the equivalent characteristic impedance of DMTL which is given below:

$$Z_{ol} = \frac{Z_o}{\sqrt{1+\frac{C_b}{lC_t}}}\sqrt{1-\left(\frac{\omega}{\omega_B}\right)^2} \tag{4}$$

$$\omega_B = \frac{2}{\sqrt{lL_t\left(lC_t + C_b\right)}} \tag{5}$$

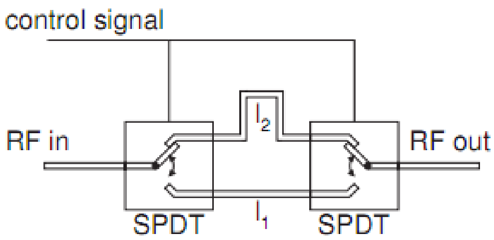
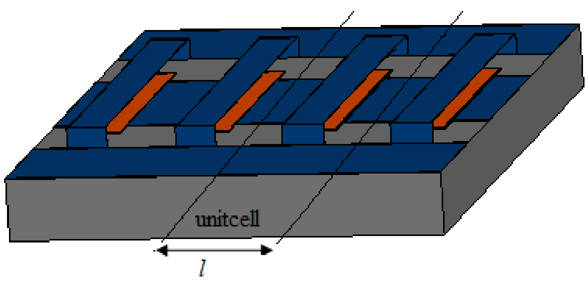


Fig. 1. Schematic of a conventional switched-line phase shifter



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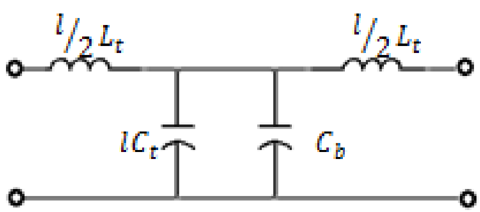

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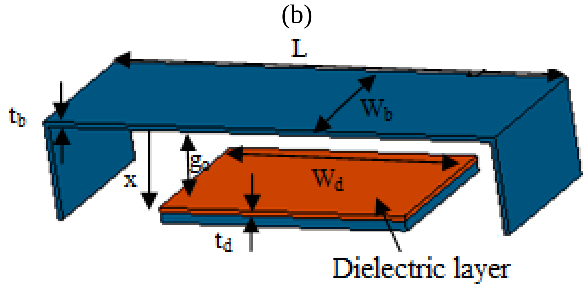


(c)

Fig. 2. a) Distributed MEMS transmission line (DMTL) b) simplified circuit model of unitcell c) MEMS bridge structure which modeled as capacitance of C_b

Where C_t and L_t are the capacitance and inductance per unit length of unloaded transmission line, respectively. ω_B is the Bragg angular frequency and C_b is the capacitance of MEMS bridge which can be achieved as below [8]:

$$C_b = \varepsilon_o W_d\left(\frac{W_b}{g_o + \frac{t_d}{\varepsilon_{rd}}} + \frac{1.06\, t_b^{0.5}}{\left(g_o + t_d\right)^{0.5}} + \frac{1.06 W_b^{0.25}}{\left(g_o + t_d\right)^{0.25}} + 0.77\right) \tag{6}$$

Where ε_{rd} is the relative permittivity of insulation layer and ε_o is the free space permittivity. Equation (3) shows large ratio of Z_o to Z_{ol} increases constant phase and therefore smaller pathways is needed for the same phase shift in improved switched-line compared with conventional one.

The phase of employed switches in switched-line phase shifter is not needed to consider for designing of phase shift but they effect on loss. Therefore it is sufficient to design pathways with minimum loss to decrease the loss effect of switches. Thus the concept of SIB frequency is described that is frequency in which the equivalent characteristic impedance reaches to 50 ohm as below [9]:

$$f_{SIB} = f_B\sqrt{1-\frac{2500}{lL_t}\left(lC_t + C_b\right)} \tag{7}$$

Therefore there are two frequencies, f_{SIB} and f_B, in improved switched-line that the loss is minimum or maximum in mentioned two frequencies, respectively. Parameters *a* and *b* are described to specify the distance of operational frequency, f_{opr}, respect to these frequencies:

$$\begin{cases} f_{SIB} = af_{opr} \\ f_B = bf_{SIB} \end{cases} \tag{8}$$

Consequently all design parameters are obtained as below:

$$l = \frac{C_{b,max} - C_b}{C_t} \tag{9}$$

$$C_{b,max} = \frac{\sqrt{b^2-1}}{50\,\pi a b^2 f_{opr}} \tag{10}$$

$$Z_o = \frac{50}{\sqrt{50\,\pi a f_{opr}\sqrt{b^2-1}\left(C_{b,max} - C_b\right)}} \tag{11}$$

$$n = \frac{\varphi\, c}{360\, l f_{opr}} \sqrt{\frac{1-\left(\frac{f}{f_{opr}}\right)^2}{\varepsilon_{eff}\left(1+\frac{C_b}{C_{b,max}-C_b}\right)}} \quad (12)$$

3. RESULTS AND DISCUSSION

One bit phase shifter is designed to study switched-line of conventional and new design. Both structures use CPW transmission line and ideal switches. Using above mentioned closed-form equations the improved switched-line is designed and the Ansoft HFSS is used for simulation that is a 3D full wave simulator to obtain its scattering parameters. The conventional switched-line also is designed using equations (1) and (2). The CPW dimensions are obtained using transmission line equations that are given as below [6]:

$$\varepsilon_{eff} = 1 + \frac{(\varepsilon_r - 1)}{2} \quad (13)$$

$$Z_o = \frac{30\pi}{\sqrt{\varepsilon_{eff}}} \frac{K(k_o{}')}{K(k_o)} \quad (14)$$

$$C_t = \frac{\sqrt{\varepsilon_{eff}}}{c Z_o} \quad (15)$$

$$L_t = C_t Z_o{}^2 \quad (16)$$

Where ε_r is the relative permeability of substrate and K is the complete elliptic integral of first kind and the argument k_o is given by:

$$k_o = \frac{w}{w+2g} \quad (17)$$

$$k_o{}' = \sqrt{1-k_o{}^2} \quad (18)$$

Where w and g are the signal and ground width of CPW, respectively. HRSS (high-resistivity silicon substrate) has been chosen as a substrate (ε_r=11.9) with 500µm thickness. Table 1 shows the design parameters of the circuit model. As shown in table 1, the new switched-line has smaller size than the conventional one. In other words, about 40% improvement has been achieved in new design.

Table 1. Design parameters

parameters	Conventional	New design
f (GHz)	2.45	2.45
a	-	1
b	-	3
Z_0 (Ω)	50	90
ε_{eff}	6.35	6.45
C_b(fF)	-	533
$l(\mu m)$	-	3021
n	-	8 and 4 for each pathways
Length(mm)	38.8	24.1

Figure 3 shows the phase shift of two structures. The phase shift of them is linear with frequency which shows their TTD feature. Figure 4 shows the scattering parameters of structures. The simulation results show that the average insertion loss is -1.1 dB and -1.5 dB (see Fig. 4a), the average return loss is -38.2 dB and -34.9 dB (see Fig. 4b) at 2.45GHz for new design and conventional one, respectively which demonstrate an improvement in isolation and loss of the new switched-line.

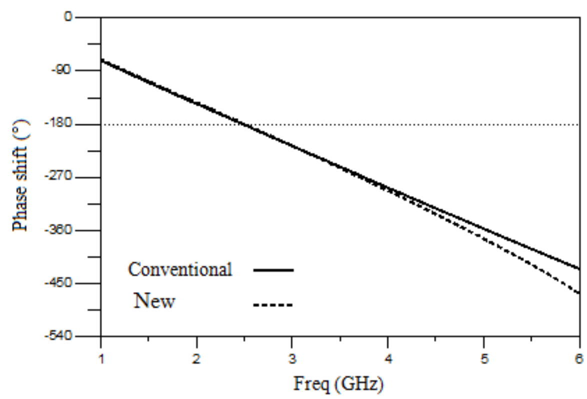
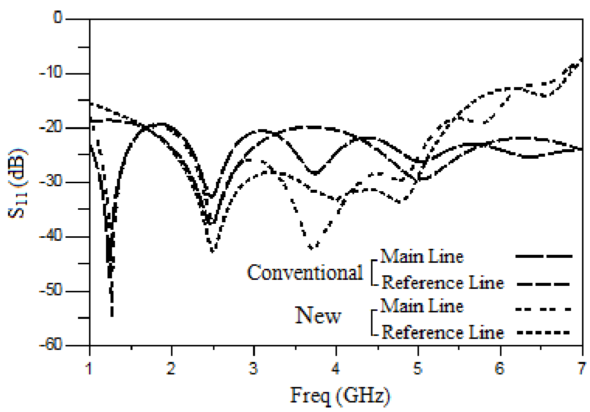


Fig. 3. phase shift of structures



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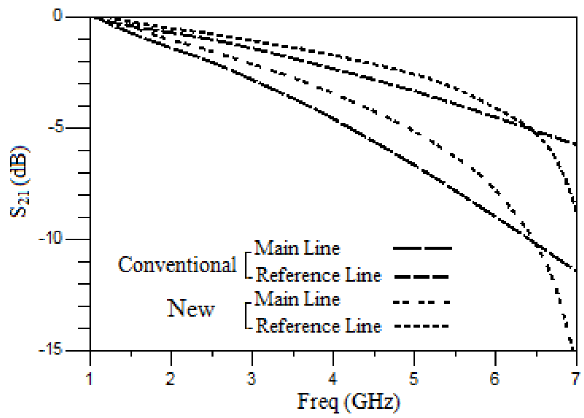

(b)

Fig.4. Scattering parameters of structures, (a) S_{11}, (b) S_{21}

4. CONCLUSION

In this paper a new switched-line phase shifter has been presented using DMTL. The new design improved constant phase of conventional switched-line design. The improved switched-line design doesn't suffer from occupying very large space in low frequency applications. The new switched-line has been designed using closed-form equations. A one bit conventional and new switched-line phase shifter has been analyzed and simulated using the High Frequency Structure Simulator (HFSS). The results show the improvement of 25% and 40% in loss and size of new switched-line compared with conventional one, respectively.

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