A STUDY ON THE PHASE SHIFT LAYER CONFIGURATION IN THE MULTI LAYERD PHASED ARRAY ANTENNA.

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1. Introduction

As a solution of the low cost phased array antenna, we are concerned with the multi-layer configuration with the micro electro mechanical systems (MEMS) as a RF switch for the phase shifter[1].

There are possible several multi-layer configurations, but it is well known that the ground plates sandwich configuration will suffer serious performance degradation due to the parallel plate mode between the ground plates. The short-bars or via-holes between the ground plates are effective to suppress the unwanted mode, but their manufacturing process is complex and will be expensive. Moreover, the available space for the phase shifter is not necessarily be extended.

Therefore, we chose the single ground plate configuration with phase shifter circuits and radiation elements on the single plane.

The purpose of this study is to arrange a 4 bit phase shifter, a patch radiator and a coupling slot in the area of a half wavelength square, which is the basic requirement to avoid the appearance of grating lobes. In our study, glasses with the dielectric constant(ε_r) of 6.0 is assumed for the substrate because of the availability in large size and the cost, in stead of GaAs or other materials. The study was performed by simulation using the Method of Moment.

2. Loaded-Line phase shifter for 22.5° bit and 45° bit elements

For the lower bits elements (45° and lower), Loaded-Line phase shifters are generally used because of its simplicity and low insertion loss. The circuit consists of two equal switchable reactance connected in shunt with a main line. The designs are categorized as three classes I, II(L/U type, Fig.2) and III(C/C type, Fig.1), defined by Opp and Hoffman[2] and analyzed by Atwater[3]. The C/C type are chosen in order to minimize phase shift deviation and insertion losses. In this paper, however, we chose the L/U type in order to minimize physical size. Fig.3 shows frequency characteristics of the 45° bit Loaded-Line phase shifter. The size of the L/U type is about 35% of the C/C type.

3. Switched-Line phase shifter for 90° element

Fig.4 shows a Switched-Line phase shifter. In the case of $S=0$, it has the most compact size as shown in Fig.5, and has an advantage of less (three) RF switches. In this case, however, the impedance matching is degraded. Therefore, the line width near RF switches was adjusted to improve the impedance matching. Fig.6 shows the calculated results.

4. Proposed Stub-Switched phase shifter for 180° bit element

In the Switched-Line phase shifter, the lengths L and S must be carefully selected in order to avoid large phase errors, high insertion losses and high return losses[4]. The large errors occur when the length of the isolated line is multiple of a half wavelength because of its resonance. Thus, both of the lengths (L and S) must not be multiple of a half wavelength. In the case of 180° bit, minimized Switched-Line phase shifter (Fig.7) has large errors shown as broken lines in Fig.9, because it has the resonance of the isolated delay line whose length $L=1/2\lambda_{g0}$. In order to avoid the resonance, we proposed Stub-Switched phase shifter[5] as shown in Fig.8 which does not have isolated line. It has only two RF switches, and has the same size with minimized Switched-Line phase shifter.

In the proposed Stub-Switched phase shifter, there are two states of switches. In state-A, delay stub L is connected as a transmission line in series to main circuit. In state-B, delay stub L is connected as a half wavelength open stub. Then, the difference of transmission path $(L=180°)$ makes phase shift $\Phi_0=180°$ by switching those two states. Besides the size, the 180° Stub-Switched phase shifter has another advantage as shown in Fig.9. It has about a half phase deviation compared with Switched-Line phase shifter. This is because of the reactance of the open stub compensates the phase deviation.

5. Proposed Dog-Bone shaped coupling slot

A coupling slot is generally used for inter-layer coupling. In this paper, the coupling slot is used to couple from the power divider layer to the phase shifter layer. We tried to arrange a coupling slot on the same layer with the phase shifters and the radiation element. However, it is difficult to arrange the coupling slot in a half wavelength square, because the slot is too long whose length is about $0.25\lambda_0$. However, the problem was solved by our newly proposed Dog-Bone shaped coupling slot[6] as shown in Fig.9. The characteristics of Dog-Bone shaped slot are shown in Fig.10. Dog-Bone type can be about 30% length of conventional slot, and has low radiation loss because of cancellation of the magnetic currents which are related to the radiation losses.

6. Layout

Based on the above study, the actual design was performed at 30GHz with the substrates $\varepsilon_r=6.0$. Fig.12(a) shows the results. All of the elements are arranged in a half wavelength square. It was difficult in the case of conventional design as shown in Fig.12(b). In the actual design, a slight design changes were performed by the Method of Moment in order to compensated the mutual coupling effect between each elements. In our design, phase shifter region occupies about 35% area (hatching area in Fig.12) of conventional design.

7. Conclusion

The arrangement of the phase shifters and the coupling slot in phased array antenna was studied. The L/U type of Loaded-Line phase shifters and the minimized Switched-Line phase shifter are chosen. Moreover, we proposed Stub-Switched phase shifter and Dog-Bone shaped coupling slot in order to reduce their size. As a results, all of the elements are arranged in a half wavelength square. The characteristics of each elements were confirmed by the Method of Moment.

References

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[2] F. L. Opp and W. F. Hoffman, “Design of digital loaded-line phase shift networks for microwave thin-film applications,” IEEE Trans., MTT, vol.MTT-16, No.12, pp.462-468, July 1968.

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[5] K. Nakada, et al., "Stub Switched Phase Shifter," IEEE Int'l Symposium AP-S, July 2000.
[6] K. Nakada, et al., "MSLs inter-layer coupling through Dog-Bone Shaped Slot," IEICE General Conference, March 2000.

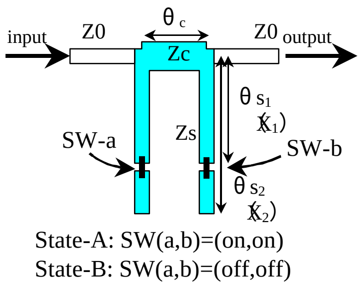


Fig.1 C/C type loaded-line phase shifter

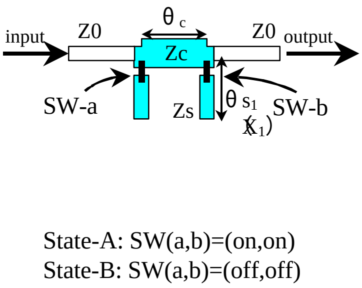


Fig.2 L/U type loaded-line phase shifter

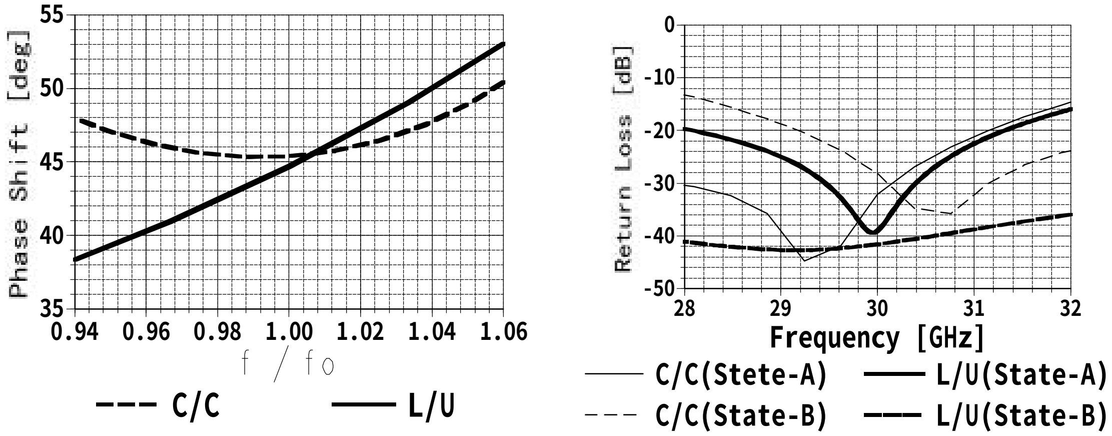


Fig.3 Frequency characteristics of 45° bit phase shifter

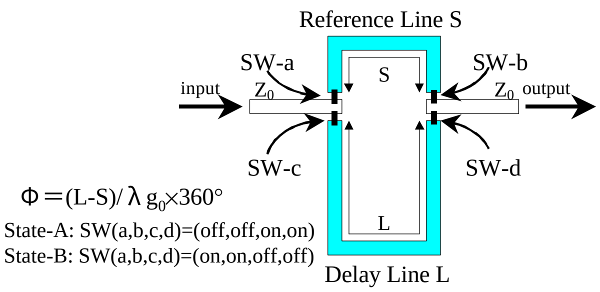


Fig.4 Switched-line Phase Shifter

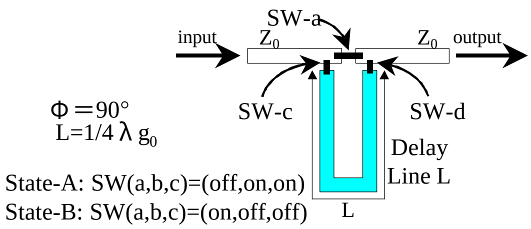


Fig.5 90°bit element

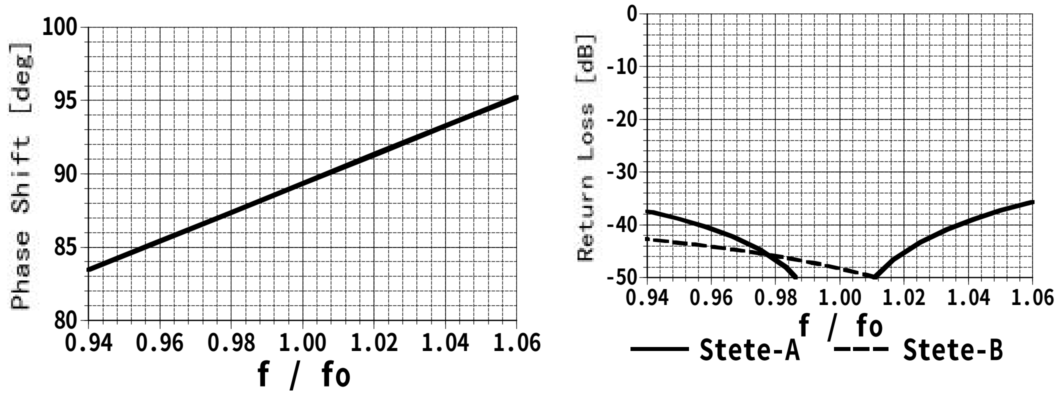


Fig.6 Frequency characteristics of 90° bit phase shifter

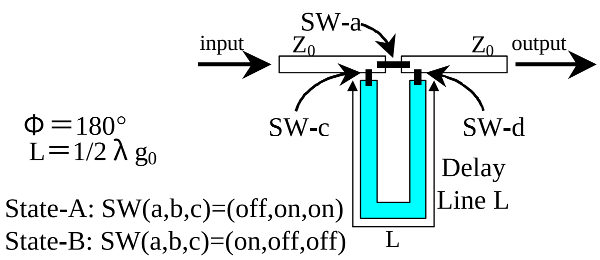


Fig.7 Switched-line phase shifter (SL)

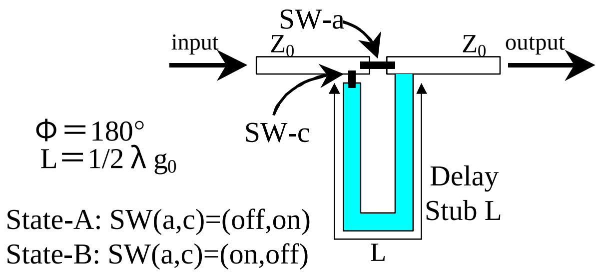


Fig.8 Stub-Switched phase shifter (SS)

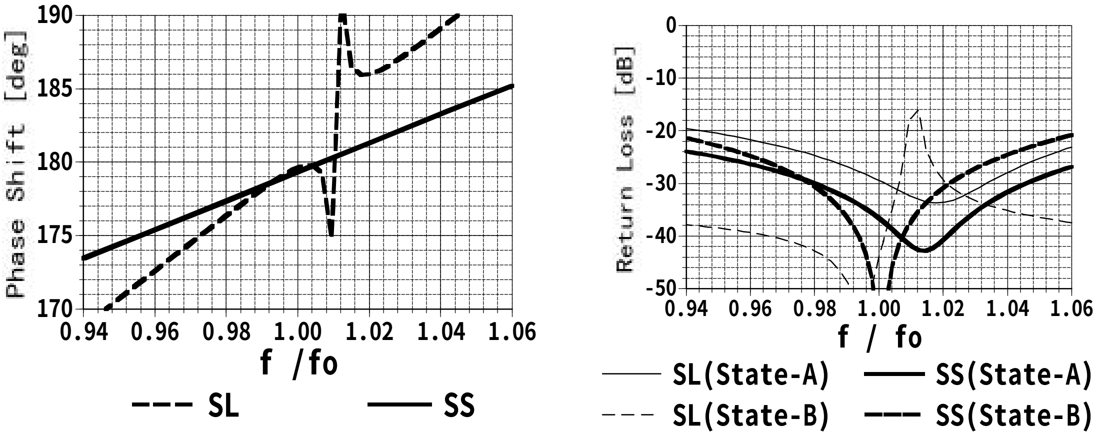


Fig.9 Frequency characteristics of 180° bit phase shifter

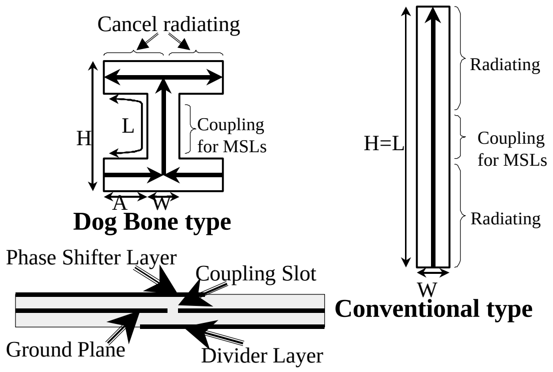


Fig.10 Dog-bone shaped coupling slot

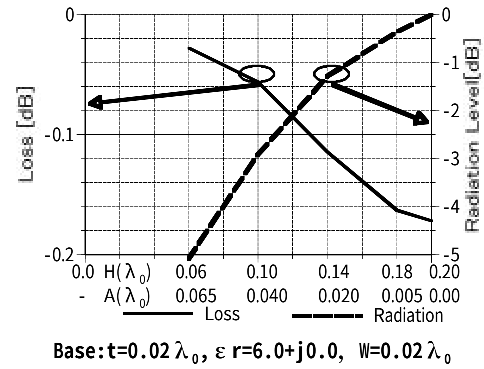
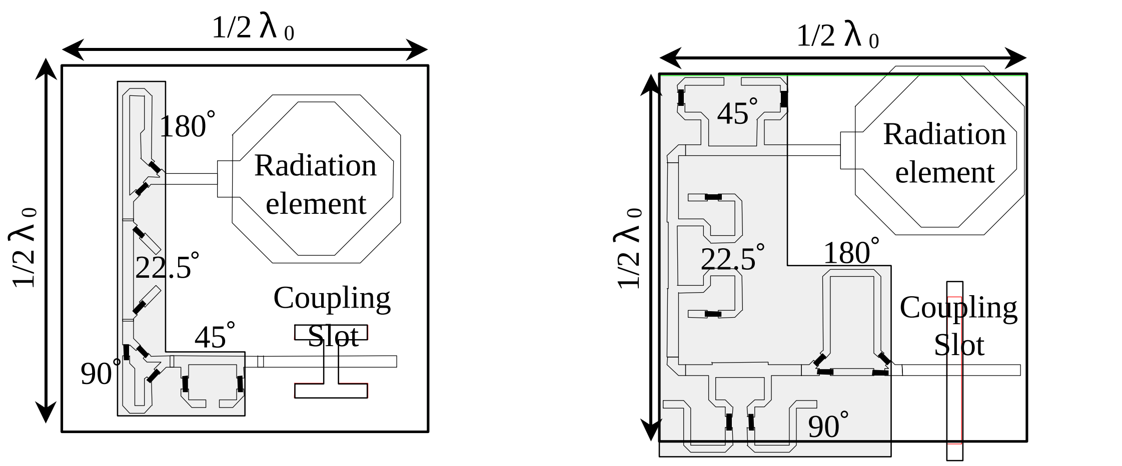


Fig.11 characteristics of coupling slot



(a) Our Design (b) Conventional Design

Fig.12 An element of planer phased array antenna