# A Scalable Reflection Type Phase Shifter With Large Phase Variation

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***Abstract*—We describe a reflection type phase shifter which exhibits a large phase shift range. We characterized its response between 1.95 GHz and 2.15 GHz and achieved over 400° phase shift with less than 4 dB insertion loss. The transition time from 0° to 180° is < 20 nS. Our design is scalable to mm-wave operation because it uses no inductors.**

***Index Terms*—Air-bridge processes, hybrid coupler, mm-wave operation, phase shift range, reflection type phase shifter.**

## I. Introduction

Reflection type phase shifters have several advantages, such as simple control, low reflection, and low insertion loss in spite of their large size. But even when resonant loads are used, it is difficult to get a large phase shift range [1], [2]. In order to get 360° phase shift, they are commonly cascaded or shunt connected for vector summation. These methods increase insertion loss [1], complexity, and size [3], [4]. Furthermore, reflection type phase shifters usually employ inductors to increase the phase variation range, require air-bridge processes for IC fabrication, and are more sensitive to process variation due to resonance frequency tuning.

We have developed a phase shifter that has ladder-type reflection loads, and have thus achieved a large phase variation without inductors.

## II. Circuit Design

As shown in Fig. 1, the circuit is composed of a 3-dB hybrid coupler and reflection loads. Due to the characteristic of a 3 dB hybrid coupler, most of the reflected power should be transferred to port 2 when the reflection loads are made identical. Each reflection load of the phase shifter consists of 50-Ω quarter-wave-length transmission lines with a varactor diode at every node. The total reflection Γ of a reflection load is the same as the sum of partial reflection at each varactor diode. By changing the capacitance of the varactors, we can control the reflection angle at each node. The relationship between the capacitance and the phase of a reflection load can be calculated by using even-odd mode analysis [5].

Fig. 2 shows the relation between phase $\theta$ of a reflection coefficient Γ of a reflection load and the admittance of a varactor diode. If we assume that all varactor diodes in the phase

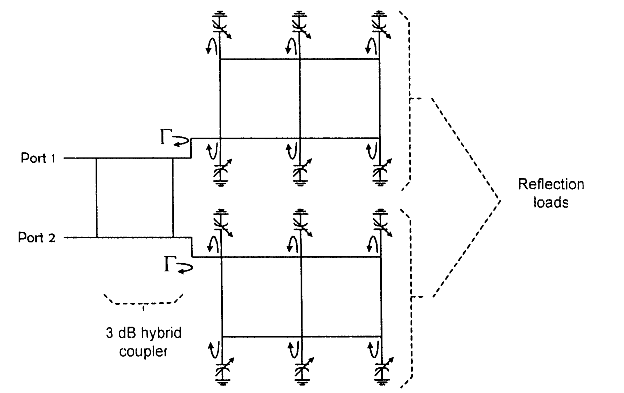


Fig. 1. Schematic diagram of reflection type phase shifter.

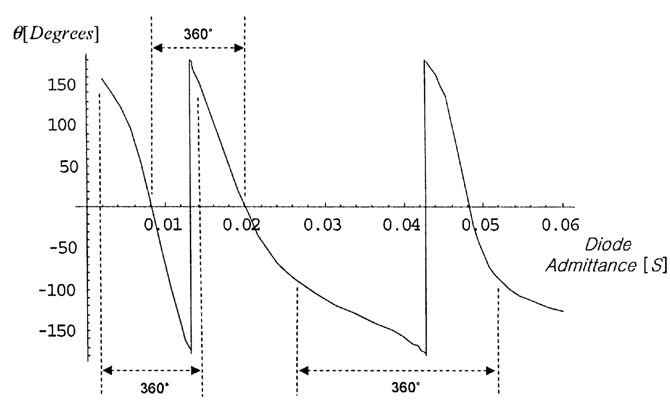


Fig. 2. Phase of reflection coefficient versus admittance of the varactor diode.

shifter are the same, the phase of Γ in Fig. 1 is determined by the admittance of each varactor diode at a given control voltage, plotted from 0.002 to 0.06 S (see Fig. 2). When the operating frequency is specified, any range of admittance can be chosen depending on the available capacitance values at that frequency using Fig. 2. For example, an admittance ranging from 0.002–0.0135 S can give a 360° phase shift, as can 0.008–0.02 S. So, one can select a varactor diode whose capacitance varies either from 0.16 to 1.07 pF or from 0.64 to 1.59 pF to get 360° phase shift at 2 GHz.

## III. Measurement Results

Fig. 3 shows the reflection measurement $S_{11}$ and insertion loss $S_{21}$ between 1.95 and 2.15 GHz. The relative phase shift with various control voltage is given in Fig. 4. We used MA-COM MA46H120 flip-chip varactor diodes, whose capacitance range is 0.2 pF to 1.1 pF. The circuit was made on *Rogers*™ RO4003 high frequency board material ($\varepsilon_r = 3.38$, dielectric thickness = 0.015 in). Insertion loss is less than

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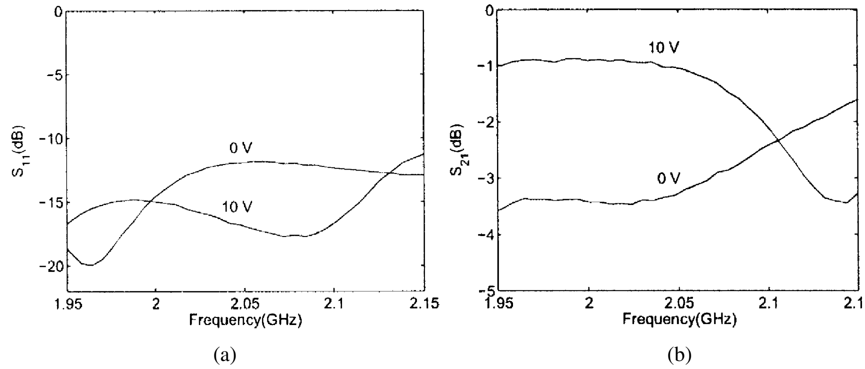


Fig. 3. (a) Measured reflection $S_{11}$ and (b) the insertion loss $S_{21}$.

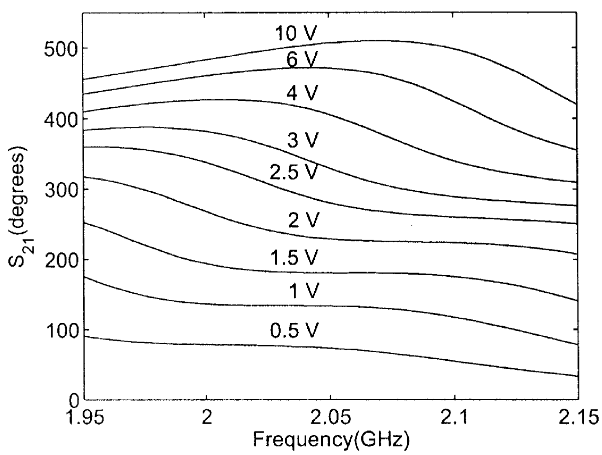


Fig. 4. Measured relative phase shift.

4 dB for $> 400^\circ$ phase shift. The insertion loss in this structure mainly arises from the series resistance of the varactors and the resistance of the silver epoxy which was used for convenience—higher performance could be achieved with better assembly technique. The admittance range of the selected varactor diode is from 0.0025 to 0.0138 S at 2 GHz. These values give approximately 360° phase shift in Fig. 2. However, parasitic parallel capacitance between a device and the ground plane should be added to the varactor capacitance range. This moves the admittance range to the right in Fig. 2 and increases the measured phase shift range over the calculated one. However, parasitic capacitance doesn't always increase the phase shift range. Whether it increases or decreases the phase shift range depends on the slope of the curve at the selected admittance in Fig. 2.

We also measured the transition time between 0° and 180° (see Fig. 5). In Fig. 5(a), a 2-GHz input signal was divided into two branches like a Mach–Zender interferometer. One of the branches was controlled by the phase shifter and added to the other using a power combiner. The phase shifter was switched between 0° and 180° by a 1-MHz square wave control signal, thus, the waves at points 1 and 2 in Fig. 5(a) are in-phase for a half cycle and out of phase by 180° for the other half cycle of the control signal. With this setup, the shape of the output signal becomes an amplitude modulated square wave and the rise/fall time is the same as the transition time of the phase shifter. The plots in Fig. 5(b) show the control and the output signals. Here, 10%–90% rise times and fall times are about 20 nS.

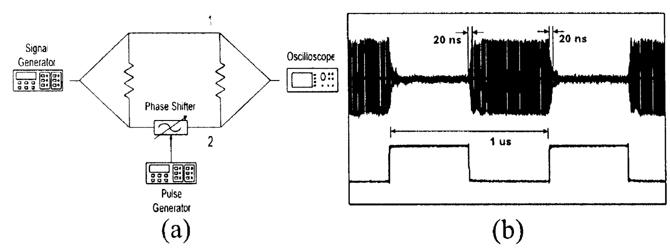


Fig. 5. Transient time measurement setup and measured data.

## IV. Conclusion

We have developed a reflection type phase shifter exhibiting large range. Without using inductors, we can realize $> 400^\circ$ phase shift with $<$ 4-dB insertion loss from 1.95 to 2.15 GHz. The input and the output match was excellent due to the use of a 3-dB hybrid coupler, and the transition time between 0° and 180° was measured $<$ 20 nS. This new structure is appropriate for use at mm-wave frequencies because it is scalable.

## References


[1] J. I. Upshur and B. D. Geller, "Low-loss 360° X-band analog phase shifter," in *IEEE MTT-S Int. Dig.*, vol. 1, May 1990, pp. 487–490.

[2] F. Ellinger, R. Vogt, and W. Bächtold, "Compact reflective-type phase-shifter MMIC for C-band using a lumped-element coupler," *IEEE Trans. Microw. Theory Tech.*, vol. 49, no. 5, pp. 913–917, May 2001.

[3] M. Kumar, R. J. Menna, and H.-C. Huang, "Broad-band active phase shifter using dual-gate MESFET," *IEEE Trans. Microw. Theory Tech.*, vol. 29, no. 10, pp. 1098–1102, Oct. 1981.

[4] S. J. Kim and N. H. Myung, "A new active phase shifter using a vector sum method," *IEEE Microw. Guided Wave Lett.*, vol. 10, no. 6, pp. 233–235, Jun. 2000.

[5] D. M. Pozar, *Microwave Engineering*. New York: Wiley, 1998, ch. 8, pp. 380–382.