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A Dual-Band Reflection Type Phase Shifter Using Active Loads

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Abstract

A dual-band reflection type phase shifter using active loads is presented for realizing a wide phase-shifting range and low insertion loss. The active load is based on a common-emitter configuration of SiGe HBTs employing stacked LC resonators in the load circuit for a wide shifting-range at multiple frequencies as well as RC series feedback circuits between emitter and ground for improving insertion losses. Since the parallel LC resonators with different resonant frequencies are stacked in configuration, the individual resonant frequency can be varied independently. The implemented dual-band reflection type phase shifter using 0.35 μm SiGe HBTs with an f_t of 25 GHz and Si varactor diodes with a capacitance ratio of 2.5:1 has achieved a maximal phase shift of 307° and an insertion loss of 1.17 dB at 0.4 GHz, a maximal phase shift of 307.7° and an insertion loss of 2.44 dB at 1 GHz, respectively.

Keywords: microwaves, reflection type phase shifter, stacked LC resonator, SiGe HBT, active load

1 Introduction

Recently, the active phased array antennas (APAAs) with digital beam-forming networks have been actively researched and developed for use in the next generation wireless radios, microwave sensors and radars [1]. Accurate phase steering of multiple beams is important for realizing high efficient power combining and tracking [2]. Thus variable gain amplifiers as well as phase shifters become a key device. Nowadays, a variety of reflection type phase shifters have been reported for use in the analog phase modulation and beam forming of the APAA because of bi-directional phase shifting, simple circuitry, zero DC power consumption and wide bandwidth [3]. Most of the reflection type phase shifters have focused on maximizing a phase-shifting range by using multiple varactor diodes or FETs as a load circuit. Multiple varactor diodes or FETs are combined in series or parallel [4], switched ON/OFF [5] or transformed by using lumped or distributed transformers [6]. However, little attentions are paid to minimizing insertion losses or insertion loss variations. The reflection type phase shifter in [7] has targeted minimal insertion loss variation by employing transformer-based quadrature couplers. Moreover, the authors have improved the insertion loss by employing the active load in place of the traditional reflective load using passive circuits with varactor diodes or FETs [8]. These reflection type phase shifters, however, are based on a single band operation.

In order to overcome this problem, a dual-band reflection type phase shifter with active loads is proposed in this paper. The active load is based on a common-emitter configuration of SiGe HBTs employing stacked LC resonators in the load circuit for a wide shifting-range at multiple frequencies as well as RC series feedback circuits between emitter and ground for improving insertion losses. The reflection type phase shifter proposed in this paper is considered to be one of the candidates for achieving a wide phase-shifting range and low insertion losses under multi-band operation.

2 Circuit Design

A schematic of the dual-band reflection type phase shifter using active loads is shown in Fig. 1. It is comprised of the 3-dB 90^o hybrid and the active load. To increase the maximal relative phase-shifting range for a given varactor diode with a limited capacitance ratio, increasing a bandwidth of 3-dB 90^o hybrid is crucial. Thus two pi-sections of 45^o LPFs are cascaded instead of the conventional 90^o LPFs. The active load is based on a common-emitter configuration of SiGe HBTs employing stacked LC resonators in the load circuit for a wide shifting-range at multiple frequencies as well as RC series feedback circuits between emitter and ground for improving insertion losses. Since the parallel LC resonators with different resonant frequencies are stacked, the individual resonant frequency can be varied independently.

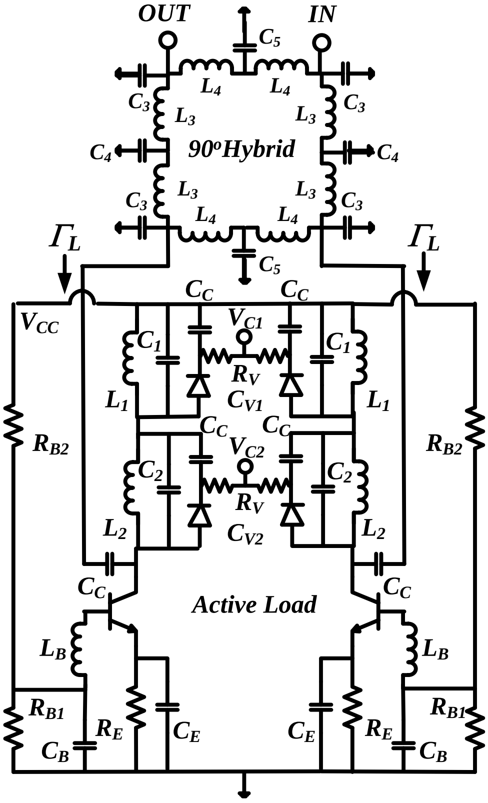

Fig.1 Schematic diagram of the dual-band reflection type phase shifter using active loads

Now it is assumed that the decoupling capacitor C_C is much larger than C_1, C_{V1}, C_2 and C_{V2}. Then the parallel resonant frequencies f_1, f_2 and the series resonant frequency f_3 can be given as follows:

$$f_1 = \frac{1}{2\pi\sqrt{L_1(C_1 + C_{V1})}} \tag{1}$$

$$f_2 = \frac{1}{2\pi\sqrt{L_2(C_2 + C_{V2})}} \tag{2}$$

$$f_3 = \frac{1}{2\pi}\sqrt{\frac{1/L_1 + 1/L_2}{C_1 + C_{V1} + C_2 + C_{V2}}} \tag{3}$$

Here L_1, C_1, L_2, C_2 are an element consisting of the parallel LC resonator as well as C_{V1}, C_{V2} are a variable capacitance of the varactor diode. It is clearly shown that f_1 and f_2 can be varied independently.

Next the RC series feedback circuit is employed between emitter and ground of the common-emitter transistor as shown in Fig. 1. The RC series feedback circuit comprised of R_E and C_E provides a positive feedback effect and therefore generates negative impedances, which greatly improve an insertion loss of the reflection type phase shifter. A supply voltage V_{CC} and C_E play a significant role in determining the positive feedback amount and thus the value of V_{CC} and C_E has to be carefully chosen in order to remove the unwanted oscillations. Here R_E keeps constant with 100 Ω for controlling a dc current. The reflection coefficient of the active load is calculated and plotted in Fig. 2 for a variable V_{CC} and a fixed C_E as well as Fig. 3 for a fixed V_{CC} and a variable C_E. V_{CC} =1.5 V and C_E =18 pF were finally chosen in consideration with the circuit stability.

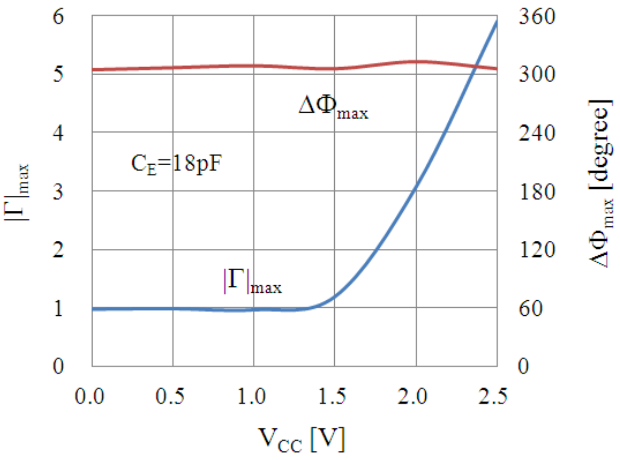

Fig.2 Calculated reflection coefficient of the active load for a variable V_{CC} and a fixed C_E

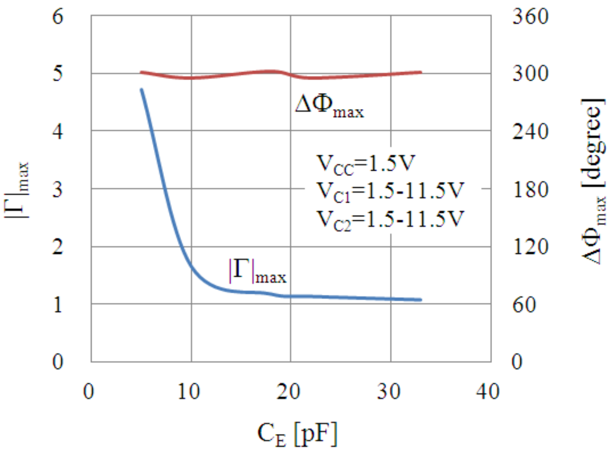

Fig.3 Calculated reflection coefficient of the active load for a fixed V_{CC} and a variable C_E

3 Circuit Fabrication and Performance

A photograph of the dual-band reflection type phase shifter using active loads is shown in Fig. 4. The phase shifter was fabricated on the FR-4 substrate with a dielectric constant of 4.5. 1005-type chip resistors, capacitors, and inductors are mounted on the substrate by soldering. A surface mount type of the 0.35 μm SiGe HBT with an f_t of around 25 GHz (Toshiba MT4S102T) and the Si varactor diode with a capacitance ratio of 2.5:1 (Toshiba 1SV279) are used. The circuit size is 16 x 16 x 1.2 mm^3.

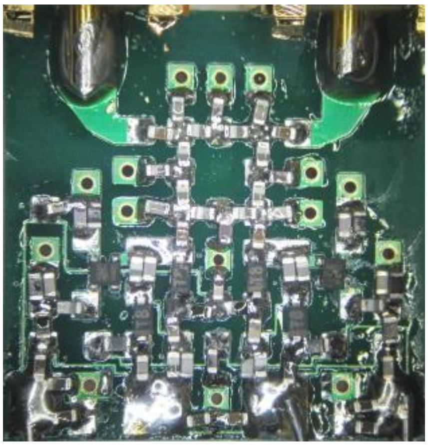

Fig. 4 Photograph of the dual-band reflection type phase shifter using active loads

Measured insertion losses of the dual-band reflection type phase shifter using active loads are plotted in Fig. 5 for a fixed f_1 and a variable f_2 as well as Fig. 6 for a variable f_1 and a fixed f_2. In Fig. 5, f_1 is fixed to 0.4 GHz and f_2 moves from 0.9 to 1.15 GHz. The minimal insertion loss and maximal insertion loss variation are 1.14 dB and 0.24 dB at f_1 =0.4 GHz as well as 2.44 dB and 3 dB at f_2=1 GHz. In Fig. 6, f_2 is fixed to 1 GHz and f_1 moves from 0.4 to 0.85 GHz. The minimal insertion loss and maximal insertion loss variation are 1.17 dB and 0.42 dB at f_1 =0.4 GHz as well as 2.18 dB and 1.84 dB at f_2=1 GHz. The bias conditions are shown in Figs. 5 and 6.

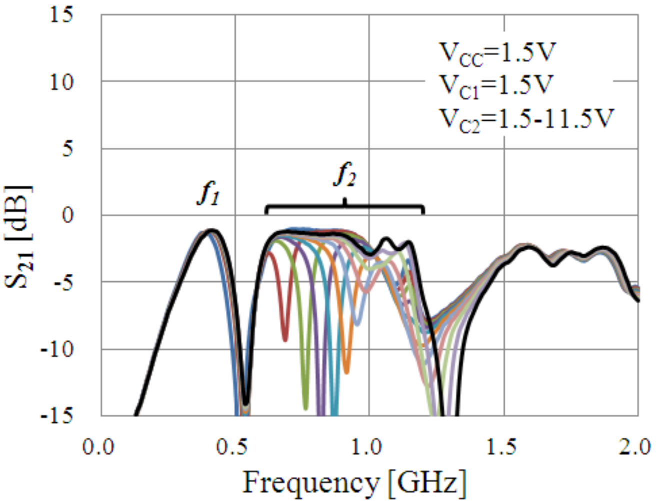

Fig. 5 Measured insertion losses for a fixed f_1 and a variable f_2

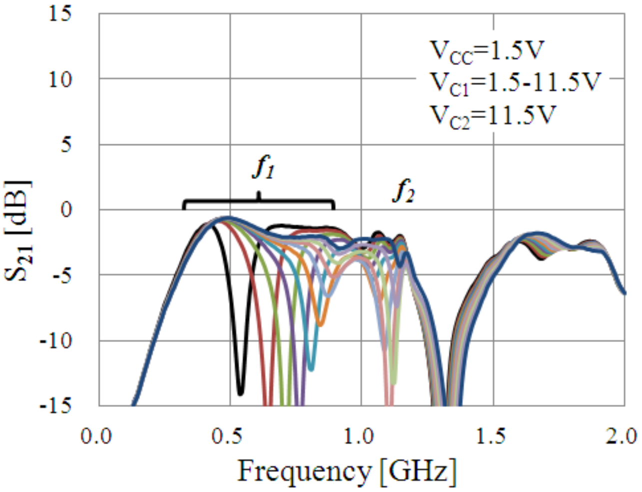

Fig. 6 Measured insertion losses for a fixed f_2 and a variable f_1

Measured phase shift $\Delta\Phi$ of the dual-band reflection type phase shifter using active loads are plotted in Fig. 7 for a fixed f_1 and a variable f_2 as well as Fig. 8 for a variable f_1 and a fixed f_2. In Fig. 7, the maximal phase shift $\Delta\Phi$ of 307° has been achieved at 1 GHz for keeping $\Delta\Phi$ less than 15.8° at 0.4 GHz. In Fig. 8, the maximal phase shift $\Delta\Phi$ of 307.7° has been achieved at 0.4 GHz for keeping $\Delta\Phi$ less than 8.78° at 1 GHz.

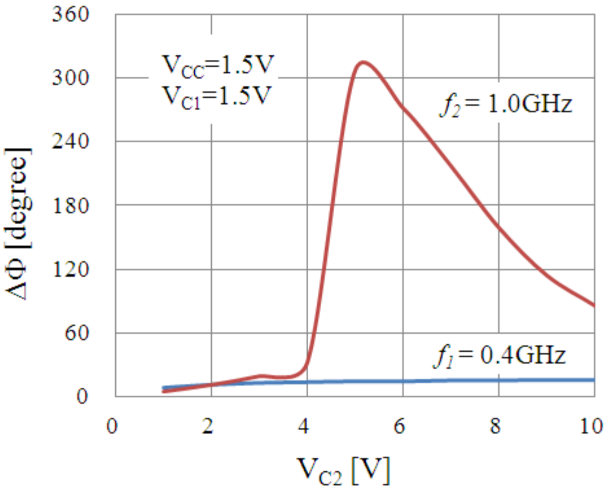

Fig. 7 Measured phase shift ΔΦ for a fixed f_1 and a variable f_2

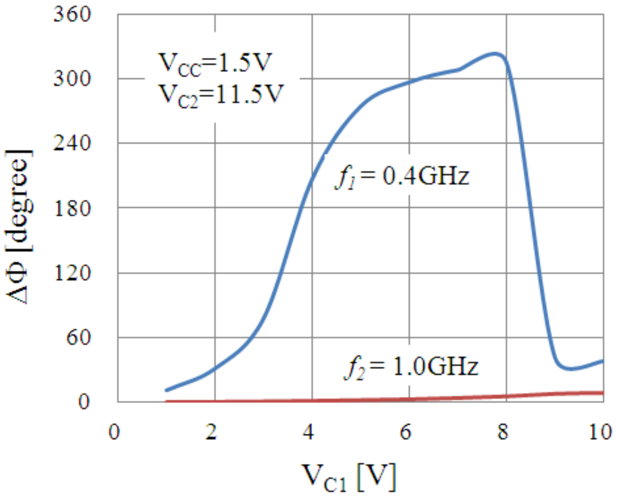

Fig. 8 Measured phase shift ΔΦ for a fixed f_2 and a variable f_1

6 Conclusions

Design, fabrication and performance of the dual-band reflection type phase shifter using active loads have been presented. The implemented dual-band reflection type phase shifter has achieved a wide phase-shifting range and a low insertion loss under dual-band operation. These results clearly demonstrate that the reflection type phase shifter presented in this paper would be useful for the next generation adaptive and/or reconfigurable wireless transceivers using the active phased array antennas with beam-forming networks.

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