Low-loss, Broadband MMIC Phase Adjustment

Many RF and microwave systems require the adjustment of signal phase. This paper describes an approach that allows the realisation of an MMIC-based phase shifter block with a broad operating band, low insertion loss and good RF return losses in all phase states. The approach is based on reflection phase shifters. Both analogue controlled and digitally controlled versions are presented. The design examples presented cover 6 to 14 GHz, with a maximum insertion loss ~1.6 dB and a phase control range of 80° to 100°. They can be realised as stand-alone components or as blocks within a multi-function MMIC. Higher phase shift ranges can be achieved by cascading multiple blocks or distributing the blocks within an MMIC.

Introduction

The reflection coefficient, Γc, of a one-port network terminated by a capacitor (see Figure 1) is given by Equation 1. The magnitude of Γc is always 1, so all incident power is reflected by the load, regardless of the value of C_v. The phase shift of the reflected wave varies from 0° to 180° (Figure 2 shows the effect of the capacitor on the phase shift). Assuming a voltage variable capacitor can be realised, all that is required to produce a voltage variable phase shifter is a means of separating the incident and reflected voltage waves, which can be achieved with a quadrature splitter.

$$\Gamma_c = \frac{-Z_0^* - \frac{j}{2\pi f C_v}}{Z_0 - \frac{j}{2\pi f C_v}} \qquad (1)$$

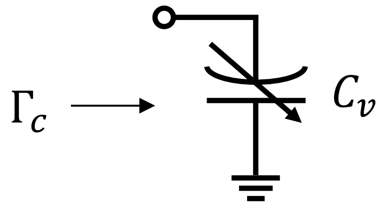

Figure 1: One-port variable capacitor network

Practical Implementation

A diagram of a typical reflection phase shifter is shown in Figure 3. The through and coupled ports of the hybrid are terminated with voltage variable capacitive loads. These loads should be as similar as possible, which is easy to achieve with integrated designs fabricated on the same die. Provided the Q of the loads is sufficiently high, most of the incident signal is reflected back into the coupler and, due to the quadrature splitter, the reflected signals sum constructively at the output and combine destructively at the input, which produces a good input match. Broadband performance can be achieved through the choice of quadrature hybrid topology, and the hybrid design.

The phase shifter can be implemented using analogue or digital control. The analogue version in this paper uses reverse-biased Schottky diodes as varactors, to replace the variable capacitors in Figure 3.

Digital architectures use switches to set which capacitors are connected to the hybrid ports. Figure 4 shows a block diagram of the digitally-controlled phase shifter. Both banks of capacitors are switched together, as with the analogue design. The designed phase shifter uses 4-bit control, with 16 total phase states.

Multiple phase shifter blocks can be

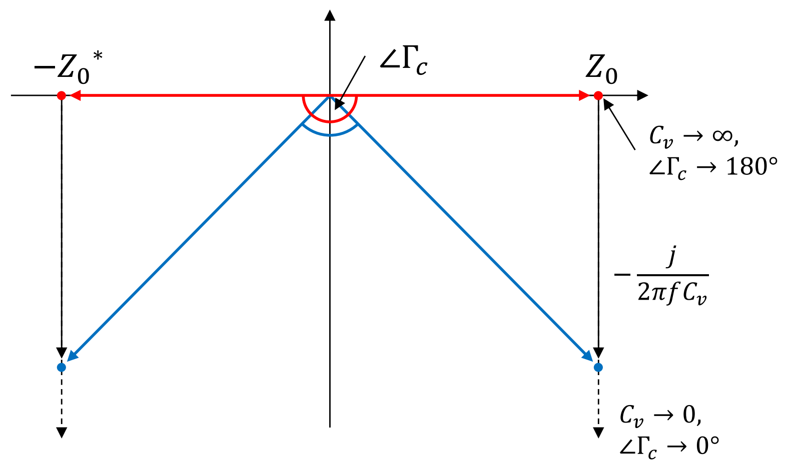

Figure 2: Phase of the reflection coefficient for the network in Figure 1

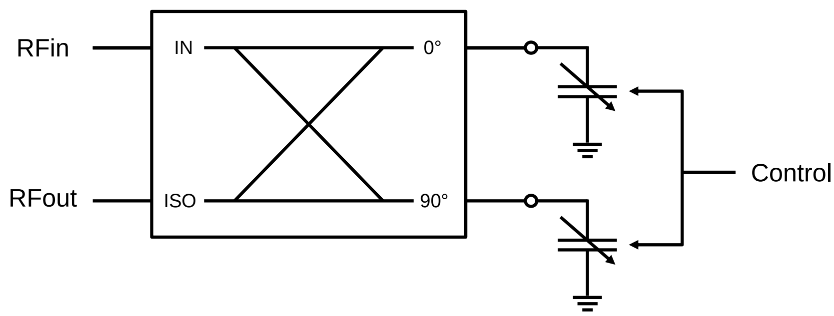

Figure 3: Generic reflection phase shifter

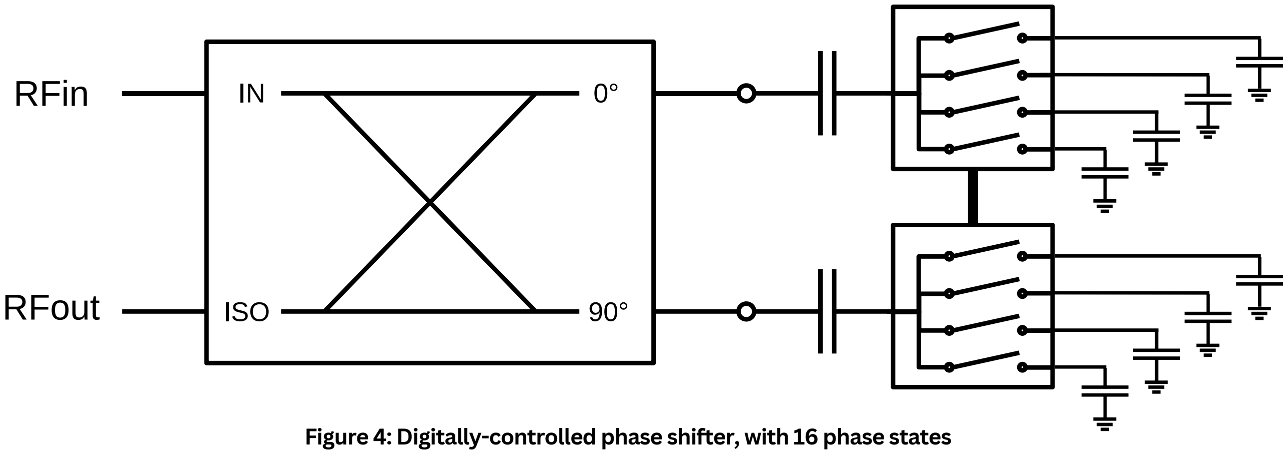

Figure 4: Digitally-controlled phase shifter, with 16 phase states

cascaded to increase the phase control range, provided the couplers are well balanced to reduce the interaction between the blocks.

Simulated Performance

The operating band of both example phase shifters presented here is 6 to 14 GHz. Figure 5 shows the simulated small signal performance of the analogue controlled design versus frequency across a range of phase states. A phase control range of ~100° is demonstrated. The insertion loss is low (<1.5 dB) and the change in insertion loss with phase state is modest. The input and output return losses are good in all phase states across the full band (>13.8 dB); this is a benefit of this topology over multi-bit low-pass/high-pass phase shifters, where the reflected waves from the different bits can add constructively to give a poorer worst case return loss.

A similar simulation plot for the digital version of the phase shifter block is shown in Figure 6. The maximum insertion loss is comparable (<1.7 dB) and a phase control range of ~80° is demonstrated. The input and output return losses are again good in all phase states across the full band, with the worst-case return loss over frequency and phase being >14.0 dB.

Summary

This paper has presented analogue and digital control approaches for MMIC-based phase shifter blocks. The blocks are broadband, operating from 6 to 14 GHz, and low-loss, with phase control ranges of ~80° to 100°. The phase shifters are designed on commercial processes and can be used as stand-alone blocks or incorporated into a larger multi-function MMIC design.

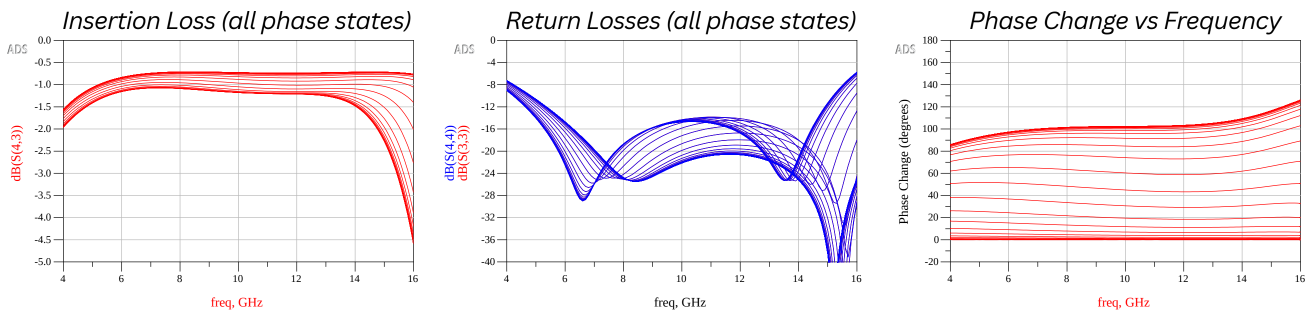

Figure 5: Phase shifter performance across frequency, using analogue control

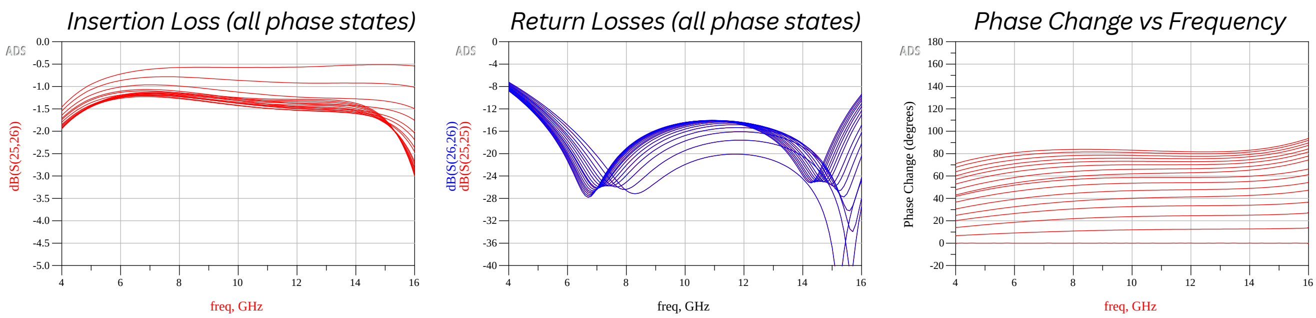

Figure 6: Phase shifter performance across frequency, using digital control

PRFI Ltd.
Abbey Barns, Suite 1, Building 3
Duxford Road, Ickleton, Cambridge, CB10 1SX, UK
www.prfi.com
T: +44 (0) 1799 796464
E: enquiries@prfi.com