Design and Development of 2 Bit MEMS Phase Shifter for Satellite Communication

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Abstract— A 2 bit MEMS (Micro Electro Mechanical System) Phase shifter designed over a 4 to 7 GHz frequency applied for satellite communication. 4 to 7 GHz frequency phase shifter is implemented by using high pass and low pass filter topology. High pass and low pass filter topology consists of series and shunt inductors and capacitors either in T or π combinations. 2 bit phase shifter consists of 90° and 180° stage. As the first stage switches between +45° and -45° and second switch between +90° and -90° the resulting phase shift is in +135° to -135° in 45° steps. Every stage is controlled by pair of voltage source which is applied to MESFET pairs for switching ON and OFF arm. The Main advantage of high pass and low pass filter topology is, they are small in size, large bandwidth, and minimum phase variations. In this design, return loss (S_{21}) should be less than -10dB and insertion loss (S_{11}) should be less than 4dB. Also replacing MEMS switches with GaAs FET insertion loss minimizes.

Keywords — MEMS, Gallium Arsenide FET, High Pass and Low pass, MEMS Switch, phase shifter

1. INTRODUCTION

Phase shifters are the devices in which the phase of an electromagnetic wave of a given frequency shifted when propagating through transmission line [1]. Phase shifter have many applications such as phase discriminators, beam forming network, transmit and receive modules, phased array antenna, satellite communication etc. MMIC (monolithic microwave integrated circuit) technology based phase shifter suitable due to small in size, lightweight, reliability, low cost.

In general phase shifter is two port networks with phase difference between input and output signal controlled by DC bias. Basically there are two types of phase shifter analog and digital. In analog type of phase shifter phase varies continuously with variation of control signal where as in digital type of phase shifter phase variation in discrete steps. There are two major methods of creating digital phase shifter. The first method in which we use time delay phase shifter are either in switched line or reflection phase shifter and second method is true phase difference phase shifter are either in loaded line or high pass low pass phase shifter [4].

The main objective of 2 bit phase shifter is to designed over wide frequency range and implements using high pass low pass filter topology on gallium arsenide substrate which gives +135° to -135° phase shift. The advantages of using this topology is give minimum insertion loss, true phase shift, small in size, and low drive power.

Formula for designing of 90 & 180 deg Phase shifters at 2.45GHz

Lambda=c/f

where c=3x10^8m/s^2 & f=2.4x10^9

=125mm at 2.4Ghz

1) length of transmission line for 90 deg phase shifter l=lambda/4

i.e 30mm at 2.4Ghz.

2)feed line width calculate by using

$$Z=\frac{377}{\sqrt{er}(w/t+2)}$$

where,

er=dielectric const=4.4

w=width of feed line=?

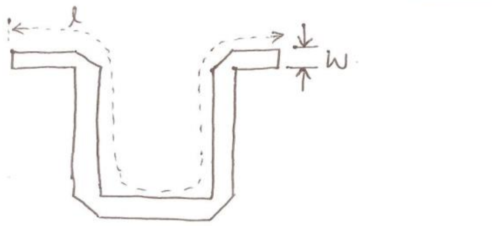
t=thickness of substrate=1.6mm

z=50 ohm

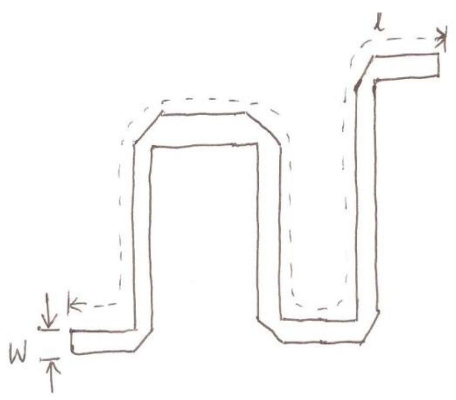
We get W=2.84mm

length of transmission line for 180 deg phase shifter Lambda/2=60mm

90° Phase Shifter (Fig 3)



2π ~~Lin~~ Transmission line lengths



2. SWITCHING ELEMENT

In electronic phase shifter pin diode and GaAs FET used as switching element to change the phase of RF signal. Phase shift is obtained by switching the control element ON and OFF, Such that RF signal is suitably routed to give desired phase shift [4]..

We use GaAs FET as switching element. FET Switch is a three terminal device in which gate bias voltage V_{gs} control the switching. When $v_{gs} = 0$ switch is ON and when $|v_{gs}| > |v_p|$ is in OFF stage as shown in Figure1 [4].

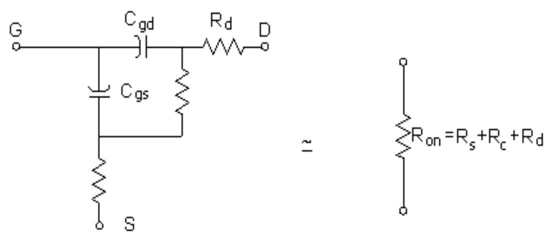


Figure1.a: The MESFET in ON State and its equivalent circuit

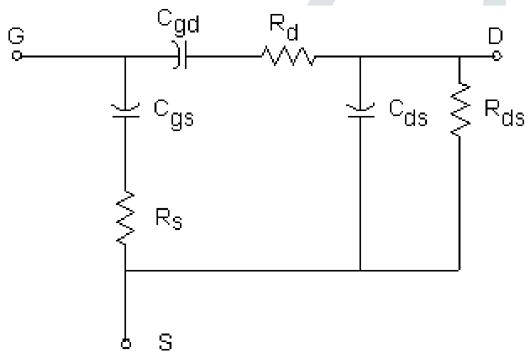


Figure1.b: The MESFET in ON State and its equivalent circuit

MEMS switch gives excellent performances at microwave to mm-wave frequencies in comparison with other types of switches such as, GaAs-based FET, PIN-diode switches. Recent development in MEMS provides the design and fabrication of control devices suitable for switching microwave signal. Active element in MEMS switches is a thin metallic membrane that moves with the application of DC electrostatic field. Figure 2. Show the schematic diagram of switch [5]. A thin dielectric layer, typically 1,000 A° of silicon Nitride is deposited on bottom electrode to reduce stiction and provide isolation between metal bridge and electrode

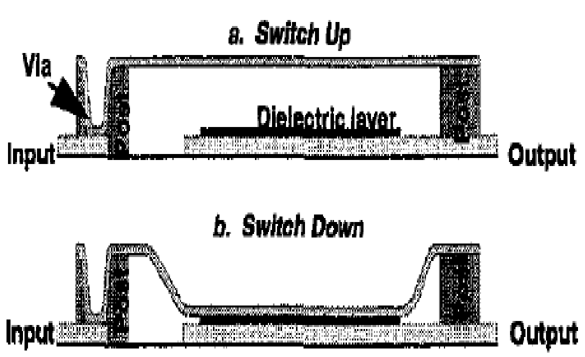


Figure 2. Schematic diagram of switch in the (a) up state and (b) down state

A MEMS switches offer lower insertion loss and higher isolation, zero power consumption, small size and weight as show in TABLE 1.

TABLE I: Comparison of RF MEMS with Pin diode and GaAs FET

Parameter	RF MEMS	GaAs FETs	PIN Diode
Isolation	High	Medium	Medium
Insertion loss	High	Medium	Medium
Power Handling	Medium	Low	Medium
Power Consumption	Low	Medium	High
Switching Speed	Low	High	Medium

3. CIRCUIT DESIGN

Design of digital phase shifter we use switched network configuration as shown in fiure2. Input signal originally passing through network 1 has switched to pass to network 2 with differential phase shift of $(\emptyset_2 - \emptyset_1)$ [6].

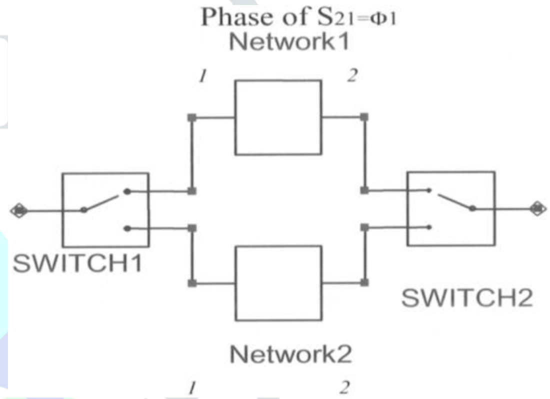


Figure 3: Switched network topology

Here we use High pass and Low pass filter topology in π combination as shown in figure 3. In low pass filter, phase delay increases with increase in frequency, while in high pass filter phase advances resulting $\Delta\emptyset = |\emptyset_1| + |\emptyset_2|$; were $\Delta\emptyset$ is phase shift over wide frequency range.

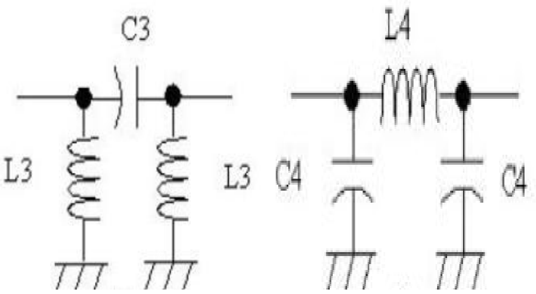


Figure 4.Schematic of high pass and low pass filter topology in π configuration.

Following formula used for calculating Inductor and capacitor value.

$$X_n = \sin(\tfrac{\Delta\emptyset}{2}) \quad ; \quad B_n = \tan(\tfrac{\Delta\emptyset}{4})$$

Ideal component for high pass and low pass network were calculated, including renormalisation 50Ω

Low Pass Filter

$$C_L = \frac{B_n}{2\pi f Z_o} \quad ; \quad L_L = \frac{X_n Z_o}{2\pi f}$$

High Pass Filter

$$C_H = \frac{1}{2\pi f Z_o X_n} \quad ; \quad L_H = \frac{Z_o}{2\pi f B_n}$$

Our analysis area encompasses the high frequencies, therefore we use Microstrip inductor and Microstrip Interdigital Capacitor implemented on chip.

4. SOFTWARE DESIGN

Parallel combination of high pass and low pass filter in series with second parallel combination of high pass and low pass filter is designed. One filter from each filter combinations is selected using GaAs FET switches. First parallel combination is of filter +45 and -45 and second parallel combination is of filter +90 and – 90.

First Filter	Second Filter	Absolute Phase
+45	+90	+135
+45	-90	-45
-45	+90	+45
-45	-90	-135

Get the relevant curve for each filter we simulated them using ADS software in an ideal element mode.

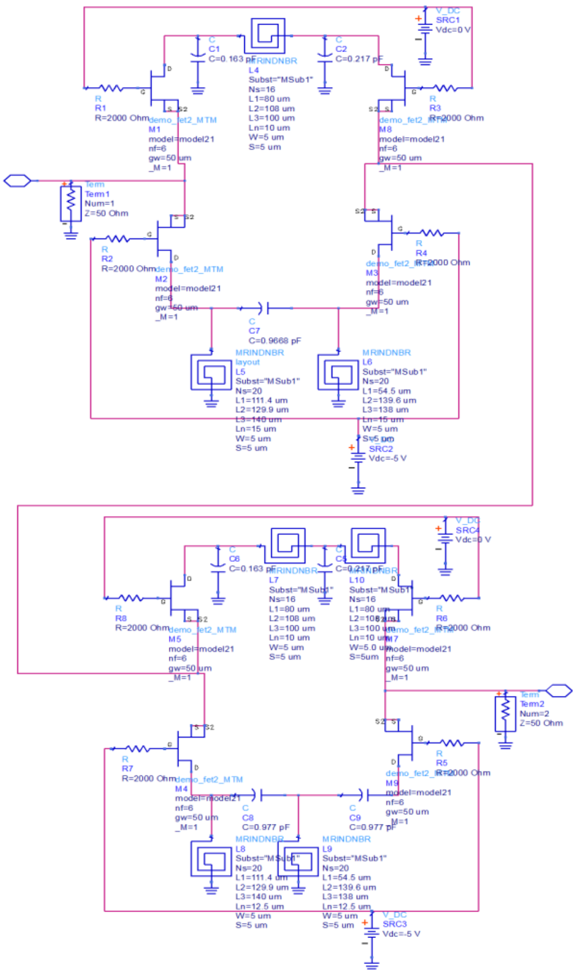
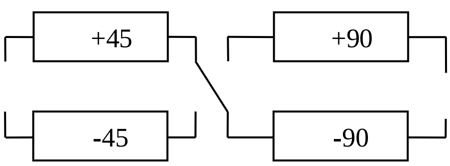
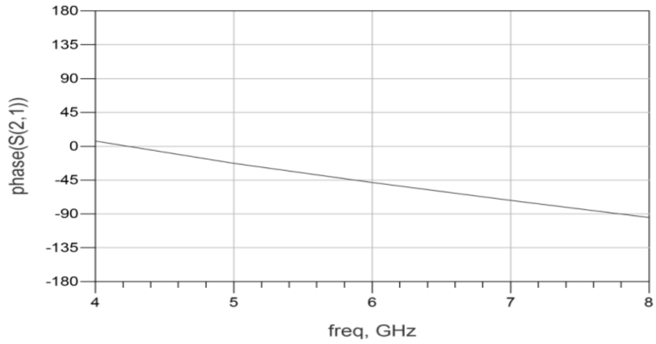


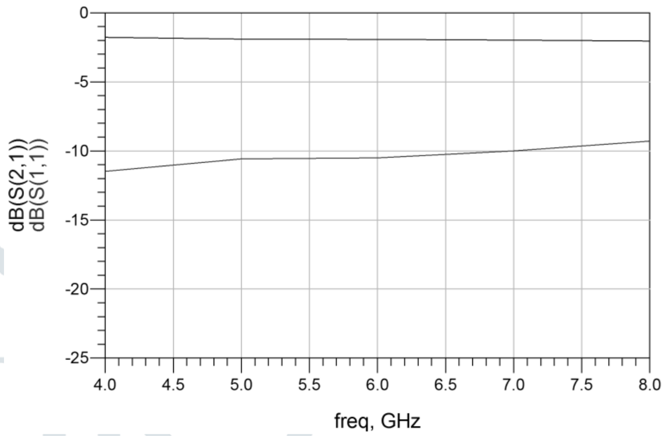
Figure 5. 2 bit phase shifter

5. SOFTWARE SIMULATION RESULT

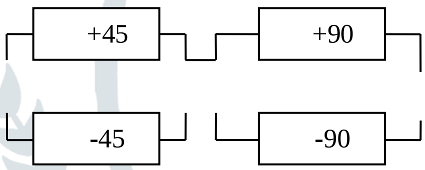
First Stage: -45° Phase shift

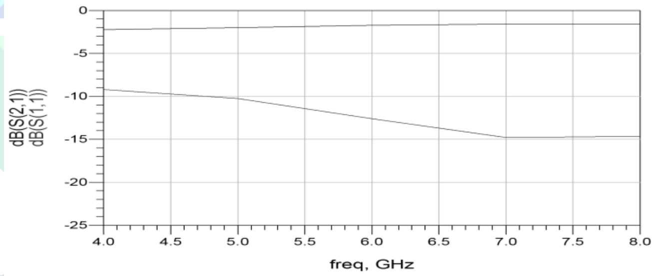


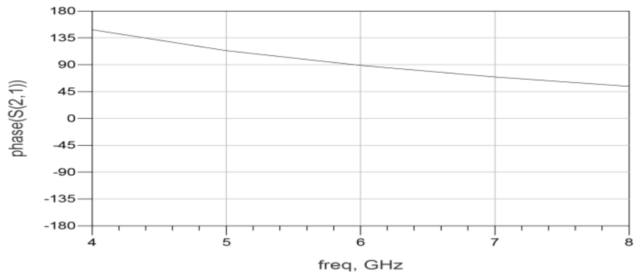




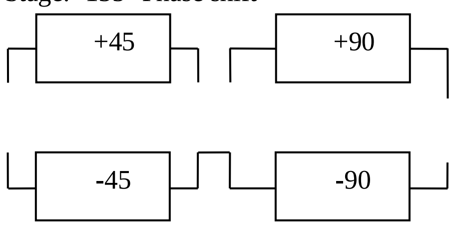
Second stage : +135° Phase shift

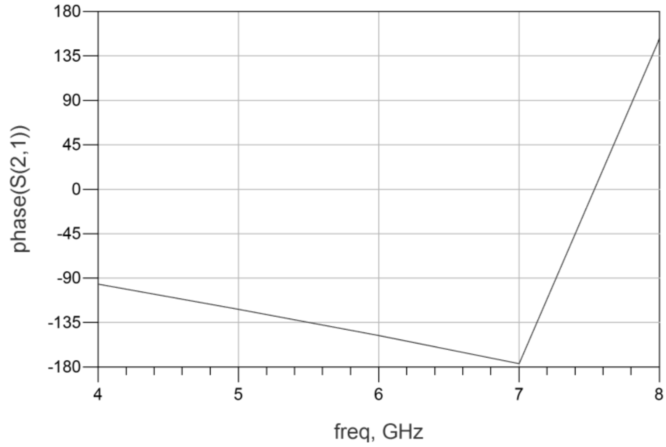


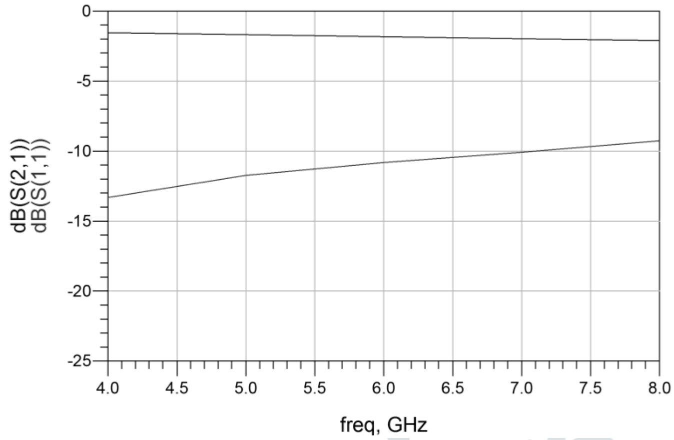




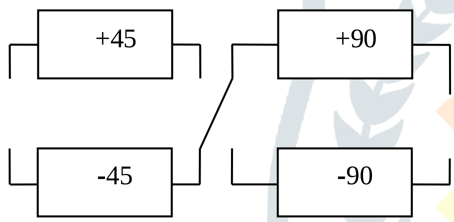
Third Stage: -135° Phase shift

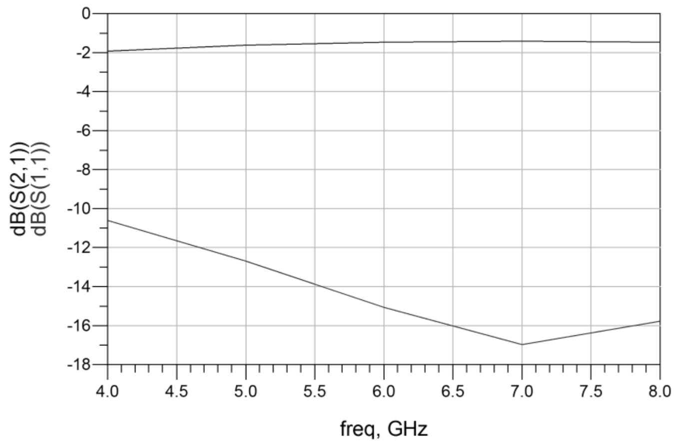


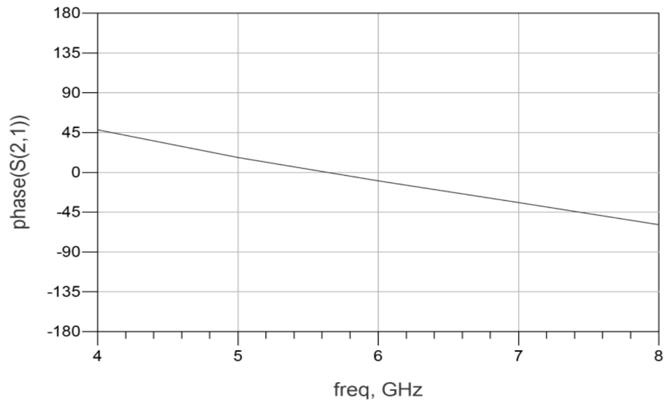




Fourth Stage: 45° Phase shift







6. CONCLUSION

A 2 bit MEMS Phase Shifter for Satellite Communication design using high pass low pass filter topology. Using High pass and Low pass filter topology obtained phase shift from +135° to -135° in 45° steps. Design phase shifter used over a wide frequency range results in low loss, small in size and Phase shift over a wide frequency range. Replacing GaAs FET switches with MEMS switches gives significant advantage as compared to their insertion loss, isolation and DC power consumption.

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