DESIGN AND DEVELOPMENT OF RF VARIABLE PHASE SHIFTERS

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Abstract

This paper presents the design and development of a voltage controlled analog 0-90° and 0-360° variable phase shifter at 1.3 GHz using RF vector addition method. In this method the input RF signal is split into four signals in phase quadrature with two neighboring ones by using 3-dB rat-race coupler and 3-dB branch line couplers. Each of these signals is next passed through a voltage controlled FET based attenuator and the four signals are then combined in-phase using a 4 to 1 Wilkinson power combiner to get the phase shifted RF output signal. The control voltages to the four voltage controlled attenuators are applied in a proper method to get the full monotonic phase shift range of 0-360°. The circuit has been designed , simulated and optimized in Advanced Design System (ADS and Momentum software and finally fabricated on microstrip with soft substrate (εr=3.2). The design methodology, simulations and measured results are presented in this paper.

INTRODUCTION

Variable analog phase shifters are control devices used in a number of applications like heavy ion accelerators, phased array radars, adaptive antenna combining, microwave communication & measurements, feed-forward system and so on. Therefore the system performance greatly depends on the performance of these control elements. There are various methods reported in literature for developing phase shifters each having its own advantages and drawbacks. In this paper we shall present an analog variable phase shifter based on vector addition method which is capable of producing complete variable 0-360° phase shift. This phase shifter is realised by integrating various building blocks namely voltage controlled variable attenuators, 3 dB branch line coupler (3-dB hybrid), 3-dB rat race hybrid and 4-to-1 wilkinsons power combiner which are described in the subsequent sections. The schematic of the phase shifter using this method is shown in Fig. 1.

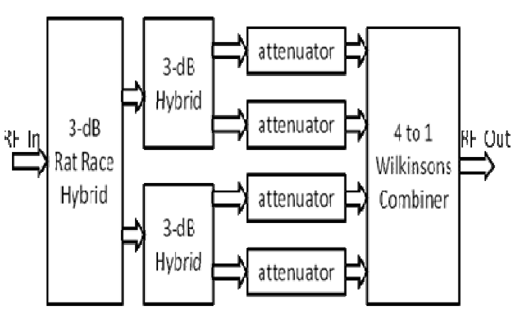

Figure 1: 0-360° variable phase shifter schematic

DESIGN OF BUILDING BLOCKS

Design of voltage controlled variable attenuator

The voltage controlled attenuator is used to control the RF level of the signal passing through it. The attenuator was designed based on a FET device by operating it in triode region. The variable control voltage 0-1 V (negative) is applied to the gate terminal of the FET. The two grounded inductors (L) on the Drain and Source terminals act as RF block to the RF signal while acting as DC ground for the Drain and Source terminals. The schematic of the attenuator is shown in Fig. 2

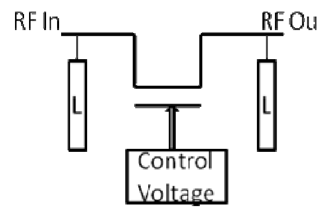

Figure 2: Variable attenuator schematic.

The above circuit was simulated in ADS and fabricated on microstrip with soft substrate (εr=3.2) and the measured results are in good agreement with the simulated results. The circuit gave measured voltage dependent variable attenuation from 1.8dB to about 19dB at desired frequency of 1.3GHz.

Design of 3-dB Branch Line Coupler

A 3-dB branch line coupler (3-dB hybrid) as shown in Fig. 3 is used to split the RF signal into two equal amplitude signals with 90° phase difference between them. For 3-dB coupling, the characteristic impedances of the shunt and series arms are Z_0 and $Z_0/\sqrt{2}$, respectively, with Z_0 being the characteristic impedance of the input and output ports. For most applications Z_0 =50Ω, thus shunt and series arms lines have characteristic impedances of 50Ω and 35.36Ω, respectively.

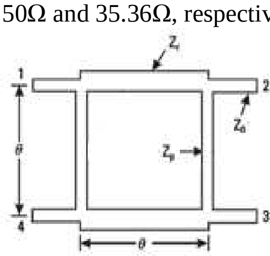

Figure 3: 3-dB Branch line coupler schematic.

The above circuit was simulated in ADS and optimized in Momentum and finally fabricated on microstrip with soft substrate (εr=3.2) and the measured results are in good agreement with the simulated results.

Design of 3-dB rat race coupler

A 3-dB rat race coupler as shown in Fig. 4 is used to split the RF signal into two equal amplitude signals with 180° phase difference between them. The input power fed at port 1 divides equally between ports 2 and 4 with 180° phase difference, and port 3 remains isolated.

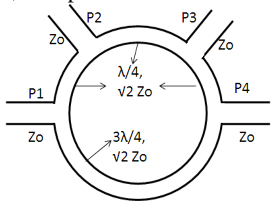

Figure 4: 3-dB rat race coupler schematic.

Design of 4-to-1 Wilkinson power combiner

A Wilkinson 2-to-1 power combiner/divider with schematic shown in Fig. 5 gives broad bandwidth and equal phase characteristics at each of its output ports. The isolation between the output ports is obtained by terminating the output ports by a series resistor.

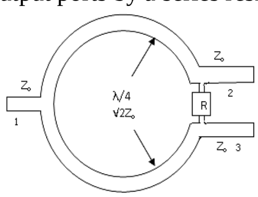

Figure 5: Power combiner/divider schematic.

The 4-to-1 wilkinsons power combiner is realised by combining the two outputs from two 2-to-1 combiner in a third 2-to-1 combiner .

0-90° RF VARIABLE PHASE SHIFTER

For 0-90° phase shifter the building blocks required are 3dB hybrid, two variable attenuators and a 2-to-1 wilkinson power combiner. Here the FET attenuators are fed in phase quadrature by means of the 3dB branch line coupler and then the outputs from the attenuators are combined by the power combiner. The circuit was simulated in ADS and Momentum and finally fabricated using photolithographic process on microstrip with soft substrate (εr=3.2).The fabricated circuit is shown in Fig.6

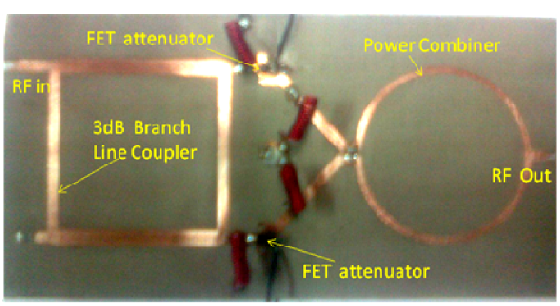

Figure 6: Fabricated 0-90° variable phase shifter.

The measured results were in good agreement with the simulation results. The measured phase shift range was about 70° (limited by the finite attenuation) with insertion loss about 6dB and input reflection coefficient less than 10 dB throughout the desired bandwidth (10%).

0-360° RF VARIABLE PHASE SHIFTER

The design of 0-360° RF variable phase shifter is just a logical extension of the design of 0-90° phase shifter. For 0-360° phase shifter the building blocks required are 3dB rat race coupler, two 3dB hybrid, four variable attenuators and a 4-to-1 wilkinson power combiner which are designed as described above and integrated as shown in schematic in Fig. 1 and was simulated in ADS.

Continuously variable phase shift over the complete range of 0- 360° is obtained by choosing a combination of two vectors for each of the four quadrants. The control voltage of the attenuators corresponding to the chosen vectors are varied appropriately while the other two attenuators are put in their max attenuation state.

The simulated average insertion loss was about 12dB with around 3dB variation around the average value. The insertion loss can be reduced by inserting an amplifier at the output. The simulated input reflection coefficient was less than 11dB throughout the desired band width of operation which is taken as 10% for this purpose. The bandwidth is mainly limited by the 3-dB hybrid couplers. The simulated results as shown in Fig. 7 show a complete 0-360° phase shift with voltage state (each state corresponds to a particular combination of voltages applied to the four variable attenuators).

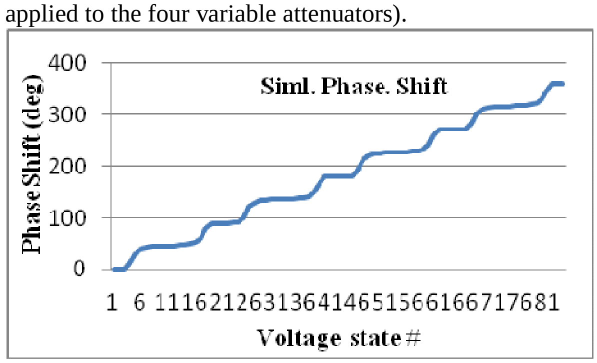

Figure 7: Simulated phase shift vs voltage state.

The circuit has been fabricated using photolithographic process on microstrip with soft substrate (εr=3.2) and shall be tested shortly

REFERENCES

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[2] S.J. Kim and N.H. Myung, "A New Active Phase Shifter Using Vector Sum Method", IEEE and microwave guided wave letters .,Vol 10,No 6, June 2000