Optically Controlled Rat-race Coupler on Silicon Substrate

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ABSTRACT: **This paper presents an optically controlled microstrip rate race coupler fabricated on silicon substrate. Optically controlled can be realized by creating an optically induced load termination by a laser spot at the open end of controlling ports in rat-race coupler. To simulate the transmission behavior of proposed structure, the optically induced load at the open end of the port has been modeled as a resistive termination. The simulation and experimental results show that the phase and amplitude of the RF signal can be controlled by optical terminations at different intensities and can be used as an optically controlled reflection type RF phase shifter and attenuator.**

Index Terms **— Optical control, Phase-shifter, Rat-race coupler**

I. INTRODUCTION

In this paper, we have proposed and experimentally demonstrated an optically controlled rat-race coupler fabricated on silicon substrate shown in Figure 1.This technique offers high isolation between the controlling optical source and controlled microwave device, ultrafast response and high power handling capacity. Such optical control is based on the fact that when photons of energy greater than the band gap are incident on the surface; electron-hole pairs are created by light absorption.

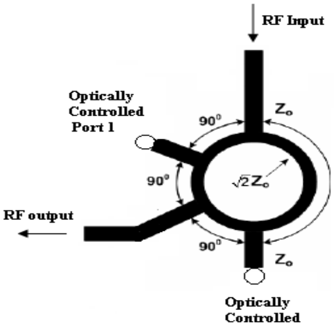


Figure 1: Optically controlled phase shifter using rat race coupler

The electron-holes generated at the end of an open port forms an optically controlled load as shown in Figure 2. The transmission parameter $|S_{21}|$ and phase shift between input and out ports depends on the reflection coefficient on controlling ports, which are linked to the load impedance created by optically induced resistive load as shown in Figure 2.

II. OPTICALLY CONTROLLED RAT-RACE COUPLER

When an open end of the microstrip line fabricated on semiconductor substrate is illuminated by a laser spot, electron-hole plasma is created by light due absorption and spreads into the substrate due to carrier diffusion.

The absorption or penetration depth of the illuminated radiation depends on the radiation wavelength and substrate parameters. Such electron- hole plasma created at the end of the open microstrip line due to illumination by a laser spot leads to change in conductivity within the illuminated region in semiconducting substrate. This conductivity profile leads to a load formation due to optical illumination at the open end [2].

The proposed optically controlled rat-race coupler is shown in Figure 1 and is based on the formation of such loads due to optical illumination as shown in Figure 2. It consists of input and output ports with two controlling ports and circular coupling ring. The phase shift between input port and out port depends on the reflection coefficient on controlling ports, which are linked to the optically induced load impedance.

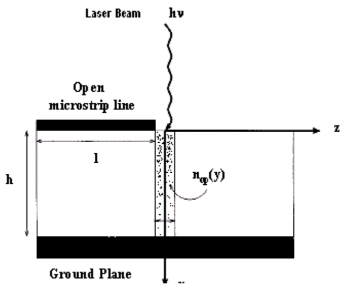


Figure 2: Formation of Optically induced load at the end of microstrip line

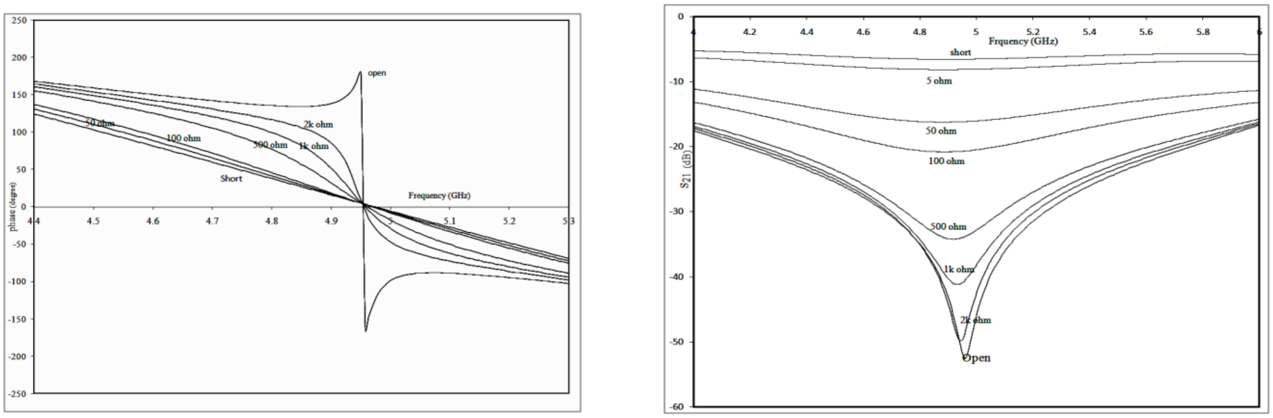


Figure 3: Simulated results for output phase and magnitude of S_{21} by terminating port 2 with different optically load

A rat-race coupler divides the input signal into two signals 180^o out of phase. These signals reflect from a pair of reflective loads, and combine in phase at the phase shifter output. The phase of the reflection-type phase shifter can be controlled by varying the impedance of the reflective load Z_l. The reflection coefficient can be expressed as Reflection coefficient can be expressed as

$$\Gamma = \frac{Z_l - Z_0}{Z_l + Z_0} \tag{7}$$

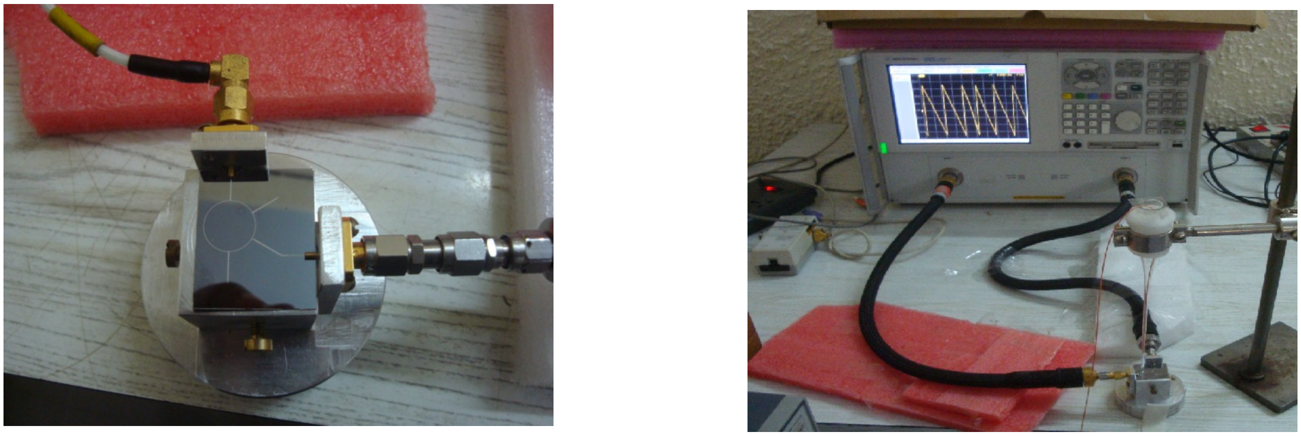
and, hence, the magnitude and phase of the output signal can be controlled by varying the illumination level. For the simulation a rate coupler has been designed at 5 GHz If Z_l varies from Z_{min} to Z_{max}, the phase shift achieved is given by

$$\Delta\varphi = 2\left[\arctan\left(\frac{Z_{max}}{Z_0}\right) - \arctan\left(\frac{Z_{min}}{Z_0}\right)\right] \tag{8}$$

frequency on silicon substrate of 300 micron thickness. The inner radius of coupler ring 5.3 mm, outer radius 5.4 mm and the width of circular ring 100 micron has been chosen. The 50 ohm input arm is 6.9 mm with the width of 0.239 mm while the length of output arm is chosen as 13.8 mm.

FABRICATION AND EXPERIMENTAL SETUP

The designed structure has been fabricated on 300 µm thick high resistivity substrate using Al sputtering of 1µm as shown in Figure 4(a). The Rf measurement have been carried out on Agilent *E8364B* PNA series *n*etwork Analyzer. The LASER Illumination have been facilitated by a fiber coupled with 980 nm wavelength laser to ceart an optically induced load at the controlling port. This arrangement is shown in Figure 4(b).The power is varied from no power to maximum power of 50 mW



(a) (b)

Figure: 4 (a) Device under test and (b) Experimental setup

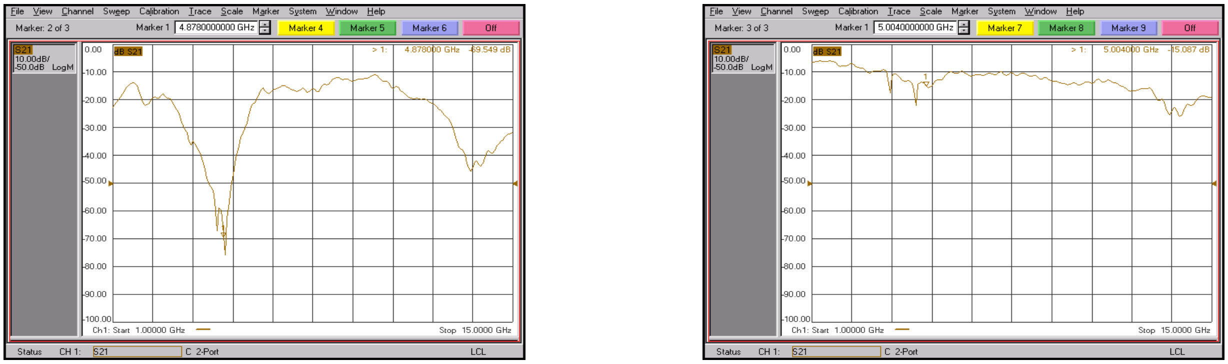
RESULTS AND DISCUSSION

An optically control optically have been simulated on IE3D software assuming that optically induced loads is resistive. The simulation results have been shown in Figure 3 at different values of load termination [2]. Similarly the measured results have been shown in Figure 5 and 6. It can be seen that by increasing optical intensity from dark state to 50 mW the modeled resistance decreases from several mega-ohms to almost short circuit. The simulation and experimental results show that in absence of illumination (dark condition), when the port is open, the phase at the output port 180 degree out from the input port. As we start to increase the incident optical power the equivalent resistance keep decreasing at open port. This leads to change in output phase and at a very high illumination level (~50 mW) the resulting resistive load attains the value of few ohms and gets almost short circuited, and leads to a maximum phase change of 180 degree as shown in Figure 3 and 6.

The results also show that at very high optical illumination (correspond to a short circuit or zero resistance) at the port 2, the magnitude of transmission parameter at the output port remains constant but a large shift in phase can be seen(~180 degree change in phase) at the frequency of interest.

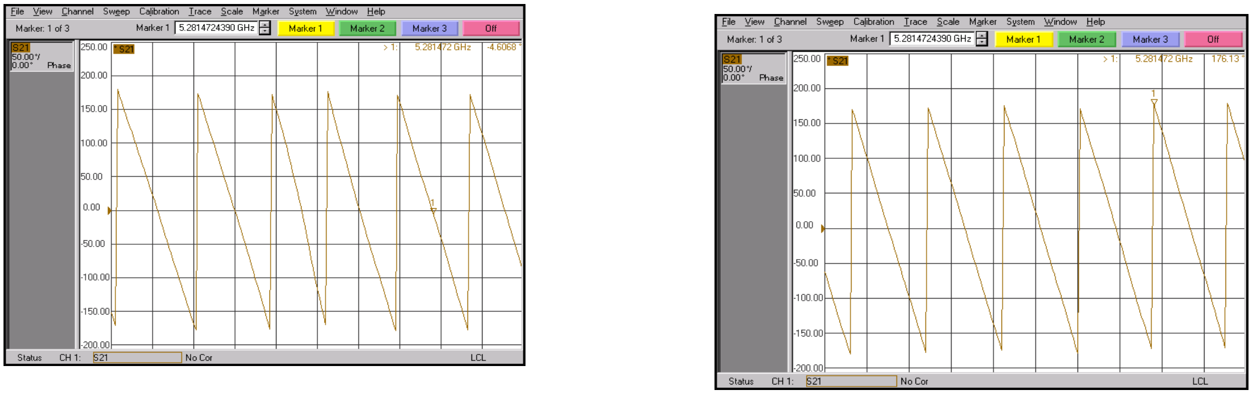
CONCLUSION

We have proposed a new type of phase shifter based on race coupler with optical control. Due to its ultrafast response and high isolation between controlling optical signal and controlled RF signal, the device can be use for ultrafast microwave signal processing. Further, It can also be as an Optically controlled reflection at type variable attenuator using different level of illumination. This type of phase shifter has the advantage of being easy to realize in planar technologies with a ultrafast response



(a) (b)

Figure 5: $|S_{21}|$ at (a) no illumination and (b) at 50 mW illumination



(a) (b)

Figure 6: Phase of S_{21} at (a) no illumination and (b) at 50 mW illumination

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