# OPTICALLY CONTROLLED COUPLED LINE MICROSTRIP ATTENUATOR

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**An optically controlled coupled line microstrip attenuator on a high resistivity silicon substrate in the 3GHz -7GHz band has been investigated for 10 dB and 25dB attenuation control for one-port and two-port optical illumination respectively by 20mW, 650nm laser diodes. The attenuator has been modeled by the PUFF circuit simulator and the simulated results correspond to the experimental results.**

## 1 Introduction

An optically controlled microwave attenuator using a microstrip directional coupler on high resistivity silicon substrate has been experimentally demonstrated by Haider et al. [1]. They used two ports illumination by a high power argon laser (600mW, 514nm) to obtain 10dB attenuation control at 6GHz in the frequency band 3-8GHz. However, neither an analytical nor a simulated model has been presented by them.
In this paper we present investigations on one-port and two-port illuminated coupled microstrip attenuators on the high resistivity silicon substrate, in the frequency band 3-7GHz. Optical control of attenuation has been obtained with a low power laser diode (20mW, 650nm). To simulate the behavior, the popular microwave circuit simulator, PUFF [2], has been used to model the optically controlled microstrip attenuator, taking into account the SMA to microstrip transition. The simulated response shows good agreement with the experimental results.

## 2 The Operating Principle

Fig. 1 is the layout of the optically controlled coupled microstrip attenuator, on the high resistivity silicon substrate ($\varepsilon_r$=11.8, resistivity 3000Ω-cm, thickness 285 μm). The primary structure is a quarter wavelength 10dB directional coupler at the center frequency of 5GHz. The coupled port-2 and the through port-3 are left open for the optical illumination. Haider et al.[3] observed that a 514nm, 600mW argon laser creates a complex RC load at the optically illuminated open end of the microstrip line, whereas, we have observed that a 650nm laser diode at a relatively low power level of 20mW creates a predominantly resistive load [4].
The port-1 is the input port and the isolated port-4 is the output port of the attenuator. Due to mismatch at the coupled port-2, the microwave signal gets reflected and appears at the output port-4. This reflection is a maximum under dark condition. With optical illumination at port-2, the load resistance reduces at port-2, which in turn reduces the power at the output port-4. The minimum available output power at the port-4 is determined by the directivity of the mictrostrip coupler. A large reflection occurs on the main line resulting into poor return loss because port-3 is open. $S_{11}$ can be improved by optical illumination of port-3, as the illumination creates a better optically controlled matched load. At the center frequency of the coupler, we can estimate $S_{11}$ and $S_{14}$ for a coupling coefficient C by the following expressions:

$$S_{11} = \left(2C^2 - 1\right) \quad (1)$$

$$S_{14} = 2C\sqrt{1 - C^2} \quad (2)$$

**Thus, for a 10dB coupler $S_{11}$ is -1.94dB and $S_{14}$ is -4.4 dB, whereas, for a 6-dB coupler $S_{11}$ improves to -6.06 dB and $S_{14}$ is -12.35dB. Haider et al. [1] used a 6 dB coupling co-efficient for their design. However, for ease in fabrication we used a 10dB coupling co-efficient in our design of the optically controlled attenuator.**

## 3 Configuration of Attenuator

**We can obtain optical control of the attenuator either by one-port or by two-port illumination. In the case of one-port illumination either of the two ports, port-2 or port-3, can be illuminated while the other is open or terminated in a 50 Ω matched load. Our PUFF simulation results showed that illumination at port-2 with port-3 open provides better attenuation control (5.6dB) than when port-3 is illuminated and port-2 left open. The increasing optical illumination has been simulated by a decrease in load variation from 500Ω (dark condition) to 50 Ω. However, the return loss is not satisfactory. It can be improved upto 20dB for the case of illumination at port-2 by terminating port-3 in a 50Ω load with simultaneous improvement in attenuation control (11dB). The simulated results for the case of illuminated port-2 with port-3 open, show that the maximum coupling frequency shifts from 5GHz to 4GHz.**

**Fig. 2 shows, modeling of the SMA to microstrip line transition at both the input port-1 and at the output port-4 by the LC-network. Both open ends have been simulated by a parallel RC load with R changing according to illumination level at port-2. The value of C has been estimated by the open end discontinuity. The PUFF simulated response of the attenuator with these terminations (Fig. 3) show that under the dark condition maximum $S_{14}$ is -11.7dB at 3.8 GHz and comes down to -14.13dB, i.e., 2.43dB attenuation control for the load change from 500Ω to 50Ω. The attenuation control is 4.83dB when load comes down to 30Ω. Moreover, modeling of transition by LC network disturbs the smoothness of response for $S_{14}$. On illumination of both the through and coupled ports, attenuation control more than 20dB could be obtained. The simulation results are not shown due to shortage of space.**

## 4 Experimental Results

**Fig. 4a and Fig. 4b show the experimental results for attenuator with illumination at port-2 and port-3 open. A 20mW, 650nm-laser diode has been used for the optical illumination. The variable optical control has been obtained by using 0,1,2,3, and 4 attenuating film, where 0 film means 20 mW power and 4 film corresponds to the dark condition. The nature of $S_{14}$ and $S_{11}$ matches with the simulated results shown in Fig.3, showing the correctness of the circuit model.. The simulated results show two maxima, at 3.8GHz and 7GHz, with a dip at 5.6GHz. The experimental results show the maxima at 3.5GHz and 7.4GHz with a dip at 5.5GHz. At 5.5GHz the simulation results show attenuation control of 4dB from the dark condition load resistance 500Ω to the illuminated condition load resistance 30Ω. The experimental results in Fig. 4a also show the attenuation control 4dB. from dark condition to 20mW illuminated port condition. The linear change in the attenuation control shows that with higher power laser diode more attenuation control could be obtained as predicated by the PUFF simulation results. Fig. 4b shows that $S_{11}$ degrades with increase in illumination as predicted by the simulation results shown in Fig. 3.**

**Fig. 5a and Fig.5b show the experimental results on $S_{14}$ and $S_{11}$, when both port-2 and port-3 are illuminated simultaneously by two independent 20mW, 650nm laser diodes. The Fig. 5a shows attenuation control of 25dB and 12dB at 3.3GHz and at 7 GHz respectively. The return-loss improves with illumination. The non smoothness in response of $S_{14}$ is due to the transition from SMA to microstrip which has been modeled, by us with LC network. However, a properly designed transition can provide smoother response for $S_{14}$. An attenuator designed for 6 dB coupling coefficient will provide better return loss.**

## 5 Conclusion

**An optical control of 10dB and 25dB attenuation could be obtained by the one and two ports illumination respectively. In case of the one port illumination, the return loss could be improved by terminating the port-2 in the 50Ω matched load. In case of two ports illumination, return loss could be improved by designing the attenuator for 6dB coupling co-efficient. At 650nm illumination, optical load is modeled by a resistance. The transition from SMA to microstip is modeled by LC network and PUFF simulated results correctly predict behavior of the optically controlled attenuator.**


## Acknowledgment

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## References


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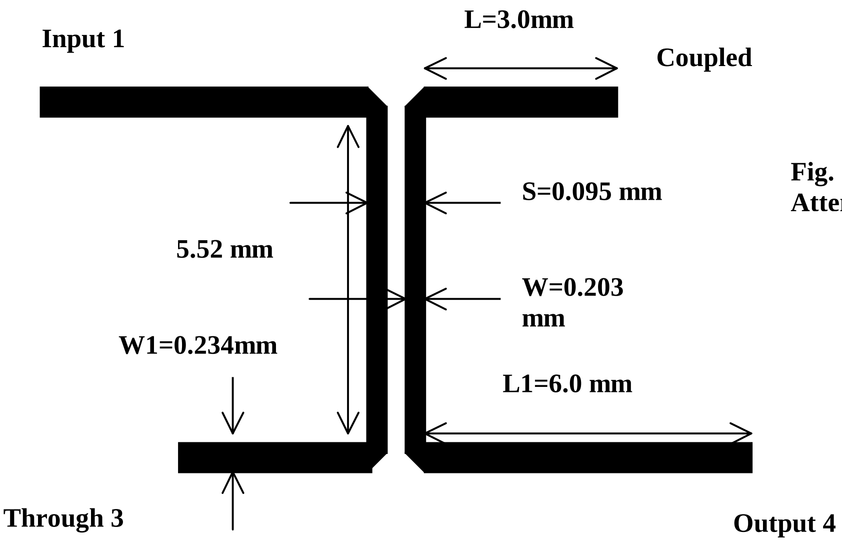
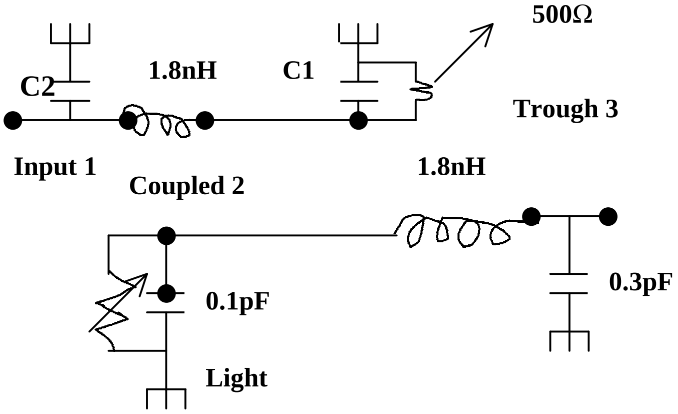



**Fig. 1 Optically Control Attenuator**




**C1 = 0.1pF, C2 = 0.3pF**

**Fig. 2 Equivalent Circuit**

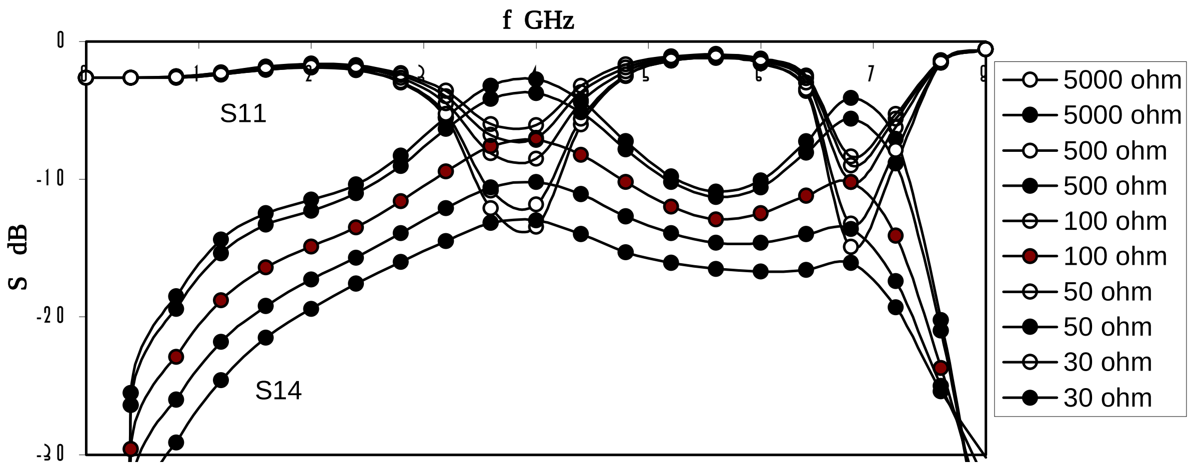



Fig. 3 PUFF Simulation for Port-2 illumination

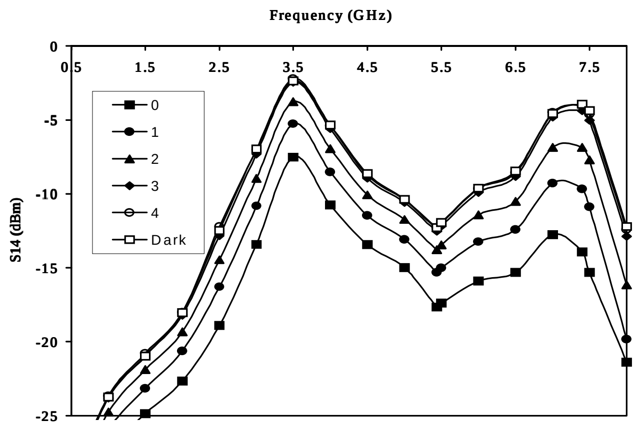



Fig. 4a Expt. Results for Port-2 Illumination

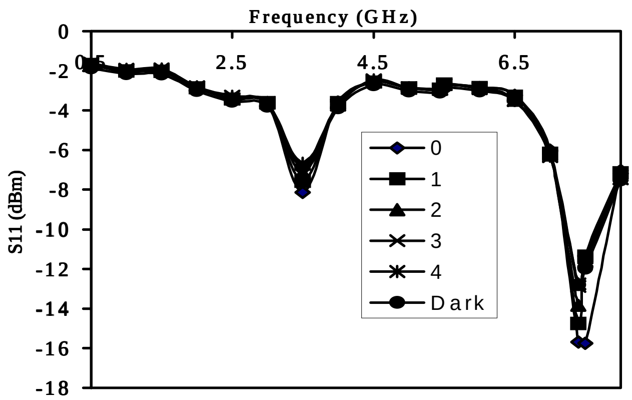



Fig. 4b Expt. Results for Port-2 Illumination

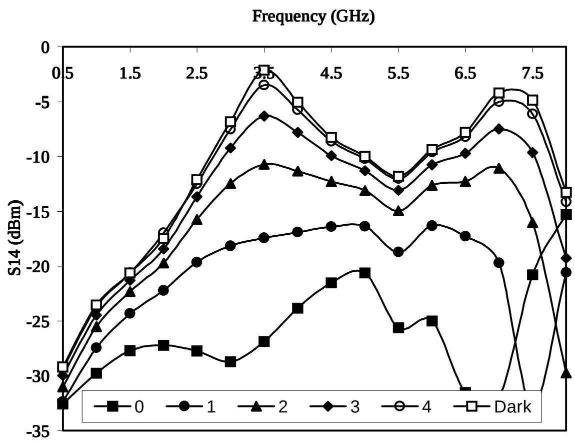
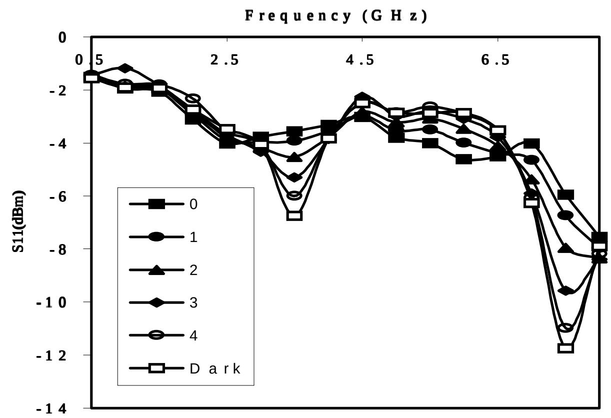



Fig. 5a Expt. Results for Two ports Illumination




Fif. 5b Expt. Results for Two Ports Illumination