AN OPTICALLY COUPLED MICROWAVE SWITCH

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ABSTRACT

A new microwave switch that uses lightwaves to couple microwave energy between its ports is shown to offer outstanding performance in terms of on/off ratio and reverse isolation while exhibiting a state independent input impedance.

INTRODUCTION

Optoelectronic couplers have been used for some time in a variety of branches of electronics. For example, in digital systems such devices are commonly used to couple digital signals from one circuit to another while isolating the two circuits as far as dc potentials are concerned.

Direct modulation of laser diodes can now be done efficiently at rates on the order of 1 GHz, and the results of recent experiments in X-band suggest[1] that modulation at higher microwave frequencies will soon become practical. This development will allow the fabrication of new microwave devices that utilize an optical coupling of microwave energy.

In this paper, we report on the performance of a new microwave switching device that is based on such optical coupling. The use of light for microwave energy coupling rather than for microwave energy control distinguishes this device from other proposed "optoelectronic microwave switches,"[2-4] while the switching function provided by changing bias states sets this device apart from the conventional optoelectronic coupler.

CONFIGURATION

The basic configuration for the switch is shown in Fig. 1. As indicated in the diagram, the switch is composed of an input section containing an optical source (such as a laser diode) and an output section containing an optical detector (such as a PIN or avalanche photodiode). The two sections are isolated from each other at RF frequencies by proper shielding. In the input section, the RF signal modulates the intensity of the lightwave emitted by the optical source at the RF frequency. The modulated lightwave is then coupled to an optical detector where it is demodulated. The bias control signal determines the detector's sensitivity, thereby permitting continuously variable attenuation or on/off switching.

Three important features of this switching concept should be noted. First, the reverse isolation (the isolation of the input from signals present at the output) is virtually infinite provided that either photon emission by the detector or photon detection by the source is negligible. Second, the on/off ratio of this device can also be extremely high since this ratio is ultimately limited only by the degree to which the detector can be turned "off". And third, as a result of the virtually infinite reverse isolation, the input impedance of the switch is independent of its state and switching transients are prevented from reaching the input.

In the following, we present results on an experimental model of the switch, which was developed to demonstrate its performance at frequencies up to 1 GHz. This model was composed of an RCA C30130 double-heterostructure laser diode that was fiber-coupled to either an HP 5082-4203 PIN photodiode or a TIED 56 avalanche photodiode.

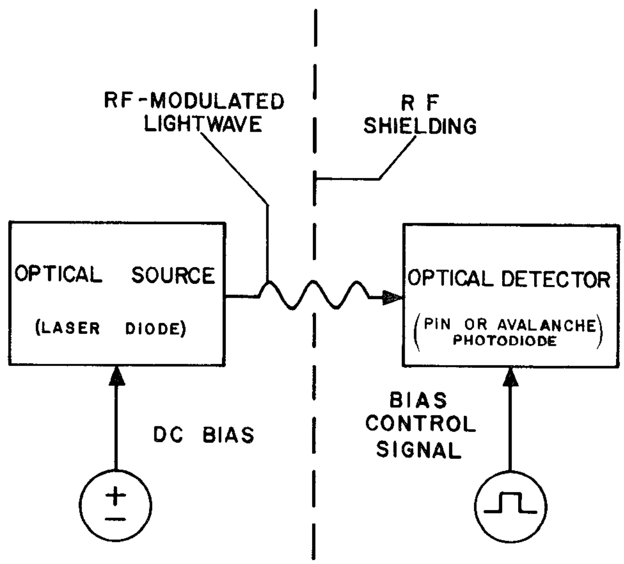

Fig. 1 Basic configuration of the optically coupled microwave switch.

RF POWER TRANSFER CHARACTERISTICS

The ratio of RF output power to the available RF input power P_o/P_i was measured over the range of 0.01 to 1.25 GHz and is shown in Fig. 2 for both the PIN and

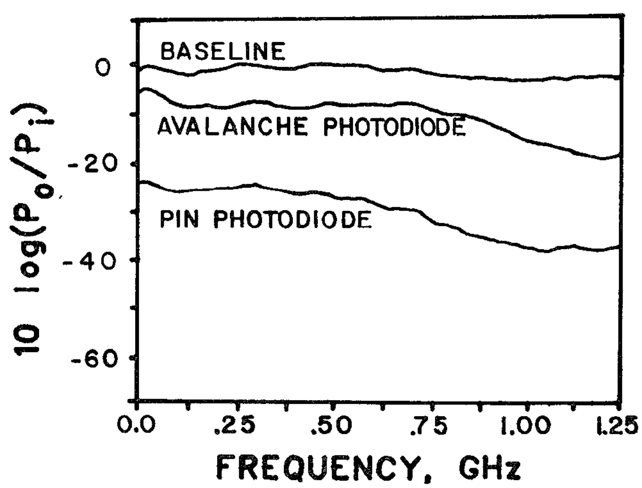

Fig. 2 Power transfer ratio as a function of frequency for both a PIN and an avalanche photodiode. (Input power = -2 dBm).

avalanche photodiode detectors under optimal bias conditions. It can be seen that the power transfer ratio in the case of the PIN photodiode is about -25 dB at the lower frequencies and drops to -35 dB near 1 GHz. The power transfer is greatly improved with the avalanche photodiode due to carrier multiplication, which in fact can result in a net RF gain through the device. As shown, in the present experiment a transfer ratio of about -8 dB was achieved at the lower frequencies while a ratio of -12 dB was realized at 1 GHz.

Reverse-isolation measurements were also made across the same frequency range by reversing the input and output ports. The RF power input was 10 dBm. An isolation of at least 114 dB, the measurement system limit, was found to occur across the entire frequency range.

The saturation of the RF output power at high input levels is illustrated in Fig. 3 for both detectors. The RF frequency for this measurement was 0.5 GHz. Examination of the figure reveals that the 1 dB

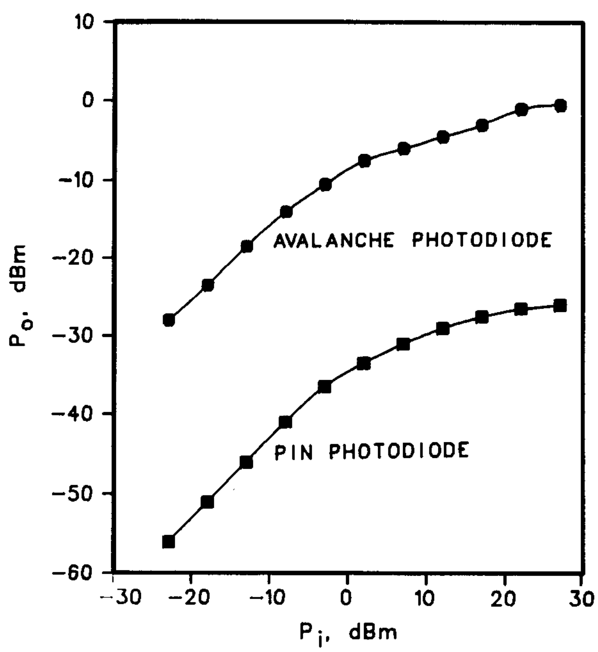

Fig. 3 RF output power as a function in input power. (RF frequency = 0.5 GHz.)

compression point occurs at $P_i \simeq 1$ mW in both cases. This point corresponds to the input signal level at which the laser current is driven below the lasing threshold.

SWITCHING PERFORMANCE

To examine the switching performance in terms of on/off ratio, the effect of bias on the power transfer ratio was measured at various RF frequencies. Results for the PIN photodiode are shown in Fig. 4. It can be seen that under reverse bias the power transfer ratio is relatively insensitive to bias, especially at low frequencies. However, in all cases the power transfer ratio drops below -100 dB (the lower limit of the measurement apparatus) at slight forward bias. Consequently, on/off ratios of at least 65 dB are achievable throughout the entire measurement range with the PIN photodiode.

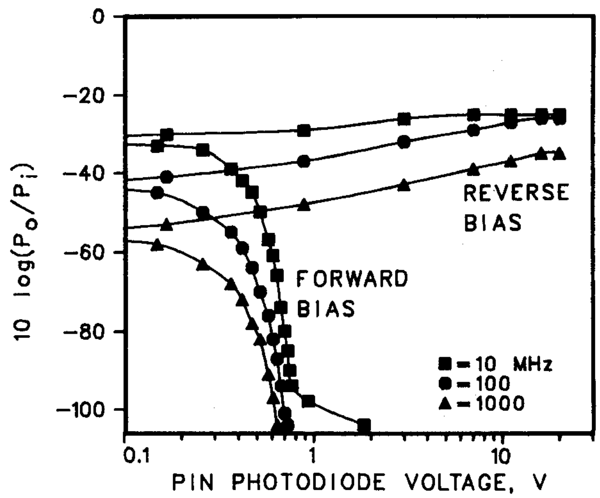

Fig. 4 Power transfer ratio as a function of bias voltage for a PIN photodiode at various RF frequencies. The lower limit of the data represents the system noise level.

Results for the avalanche photodiode are shown in Fig. 5. Due to the enhanced response with this device,

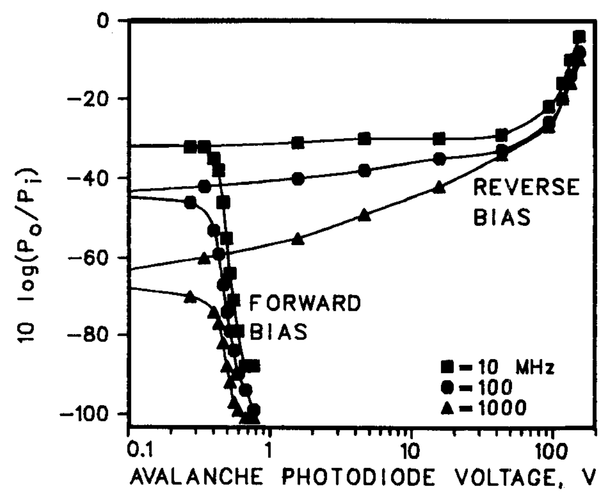

Fig. 5 Power transfer ratio as a function of bias voltage for an avalanche photodiode at various RF frequencies. The lower limit of the data represents the system noise level.

an on/off ratio of nearly 50 dB can be achieved by operating between reverse- and zero-bias states, while a ratio of at least 90 dB can be achieved between reverse- and forward-bias states.

In order to investigate the switching dynamics of the device, the detector was driven with narrow pulses, while the input was driven by a CW RF source. After high-pass filtering to remove the pulse waveform, the output signal was displayed on an oscilloscope. Results for the avalanche photodiode detector are shown in Fig. 6 and illustrate that clean, rapid transitions are possible between switching states.

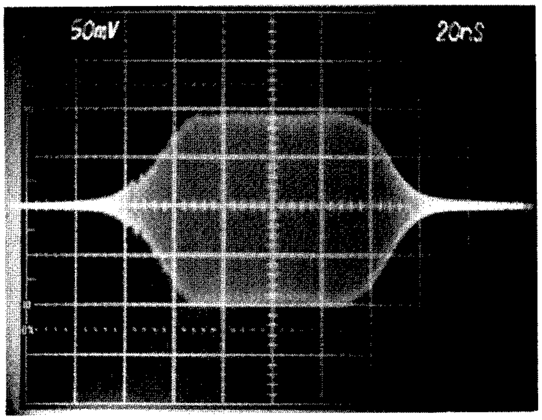

Fig. 6 Output of switch under pulsed conditions illustrating the gating of a 0.5 GHz RF source.

CONCLUSIONS

A new optically coupled microwave switch has been described, and it has been shown that this device is capable of remarkably outstanding performance with regard to on/off ratio and reverse isolation. The best results to date for these parameters are 91 dB and 114 dB, respectively, at 1 GHz and have been limited only by the measurement system. An insertion loss as low as 5 dB at 1 GHz and a saturated output power of up to 1 mW have been achieved. It has also been demonstrated that the switching dynamics of this device are suitable for short pulse generation. Considerable improvement in all performance parameters is expected for optimized devices.

The demonstrated characteristics of this device make it particularly attractive for a variety of radar applications, where high on/off ratio and high reverse isolation improve sensitivity and jamming immunity. In addition, the fact that the input impedance of this switch is independent of the switching state makes this device attractive for applications where oscillator "pulling" must be avoided.

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