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AN IMPROVED PIN DIODE ATTENUATOR FOR HIGH RELIABILITY MIC APPLICATIONS

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ABSTRACT

Selection of either absorptive or reflective style PIN diode attenuators is based upon performance requirements such as bandwidth, dynamic range, VSWR, switching speed, and reliability. Unfortunately, all of the desirable features cannot be combined into a single design. A new concept in PIN diode attenuators is presented here in which inherent properties of a microstrip transmission line operating in a quasi-TEM mode is incorporated into a distributed-absorptive attenuator circuit. Numerous conflicting requirements are overcome thus providing the designer with new design trade-offs not previously available. Additionally, this new attenuator structure is inherently endowed with soft failure modes, thereby increasing reliability. The structure has been fabricated on hard substrate microstrip and is compatible with super-component fabrication techniques.

Introduction

Attenuators can be placed into one of two categories, either reflective or absorptive, depending on their respective mode of operation. The absorptive attenuators, most often configured as PI or TEE configurations, provide the best overall performance. These types usually are optimized for wide bandwidth, low VSWR, and low change in transmission phase shift with each change in insertion loss. Unfortunately, to achieve optimum performance, dual independent controls must be employed for the series and shunt paths. As a result, a complicated driver is required. Quite often a PROM look-up table is used to set the two control ports. As a result, switching speed is impaired. Reflective types are far simpler since only one bias port is required. This type of attenuator is usually narrowband, has poor VSWR at high insertion loss levels, and introduces large AM to PM conversion throughout its dynamnic range.

The PIN diode attenuator (Horkin attenuator) presented here is a new concept in which a simple TEM mode transmission line model can be used to develop a new attenuator design in which the best properties of both reflective and absorptive attenuators can be achieved in a single component. The Horkin attenuator features a single bias port, extremely fast switching, controllable VSWR, wide bandwidth, and high reliability due to its soft failure modes. It is most suitably fabricated on a hard substrate microstrip medium such as alumina and can be interfaced easily with other circuits fabricated using super-component techniques, or it can be packaged conventionally with coaxial interfaces.

Transmission Line Model

Electromagnetic wave propagation along a transmission line operating in a TEM mode can be analyzed using an incremental length of the line modeled with the circuit in Figure 1.

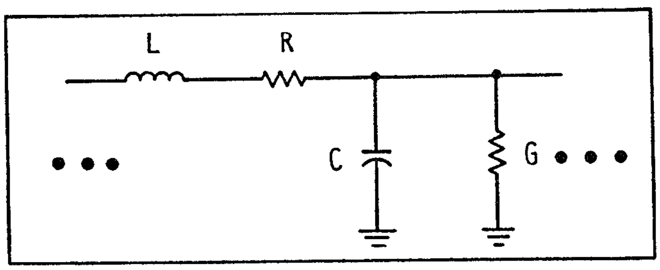

Figure 1. TEM Mode Model

Element values for the inductance (L), resistance (R), capacitance (C) and dielectric conductance (G) are given by the transmission line parameters on a per unit length basis. The characteristic impedance of such a line is given by:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{1}$$

In the lossless case, i.e., R = G = O, the characteristic impedance is frequency independent. Constraining the value of resistance per unit length and neglecting the dielectric loss establishes the maximum theoretical VSWR which varies with frequency as:

$$\text{VSWR} = \frac{|Z_0(F)|}{Z_0(o)_{\text{LOSSLESS}}} = \frac{\left|\sqrt{\frac{R + j\omega L}{j\omega C}}\right|}{\sqrt{L/C}}$$

If a transmission line is fabricated in which the series resistance per unit length can be varied, and in which the dielectric conductance can be approximated as zero, then the insertion loss can be varied and the maximum VSWR will be constrained. A microstrip transmission line operates in a quasi-TEM mode, and can be utilized to implement an attenuator based upon the lossy transmission line model described herein.

Circuit Configuration

Several circuit configurations can be realized, each optimized for particular performance characteristics. The simplest configuration is illustrated in Figure 2. This circuit

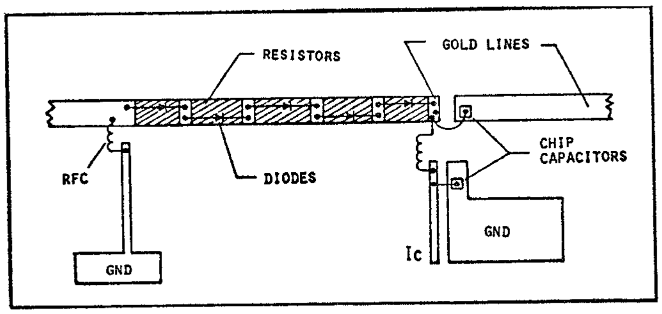

Figure 2. Series Current Configuration

uses beam lead PIN diodes bonded across thin film nichrome resistors whose line width is chosen for a desired Zo characteristic impedance in the lossless case. A single bias port provides the control current to affect a change in attenuator insertion loss. With zero current flowing into the bias port, the diode resistance (which is in parallel with R, the fixed resistance per unit length) is at a maximum, hence maximum insertion loss is achieved.

Increasing the control current will gradually forward bias the diodes, thereby decreasing their RF resistance. Since the diodes are in parallel with the thin film resistors, the net effect is to control the resistance per unit length of the transmission line in a distributed-lumped fashion. A photograph of a typical Horkin attenuator configured in this manner is shown in Figure 3.

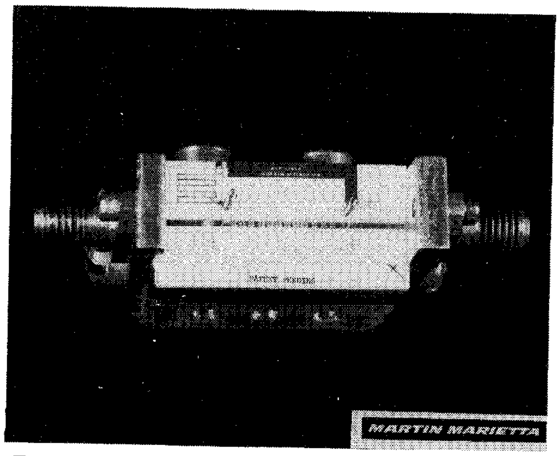

Figure 3. Horkin Attenuator—Series Version

Speed is often a requirement for attenuator applications. The Horkin attenuator is inherently fast in switching from low insertion loss to high insertion loss independent of driver characteristics since a built-in discharge path exists for each diode. To achieve minimum risetime a current driver is essential. An alternate circuit configuration is better suited for fast switching applications. This configuration contains the identical microwave circuit but modifies the driver interface such that the driver current splits equally and drives each diode in parallel. The result is faster switching speed without increasing total driver power. A simple current switch provides very fast turn-on since it will provide a momentary voltage spike prior to turn-on of the diodes. The photo in Figure 4 illustrates the voltage spike in the driver waveform and the detected attenuator output. The voltage spike is produced because all of the driver current flows through the resistors initially, but splits between the resistors and diodes in the steady state condition. Typically the steady state resistor current is 25 to 50 per cent of the total driver current. The voltage waveform is directly proportional to the resistor current.

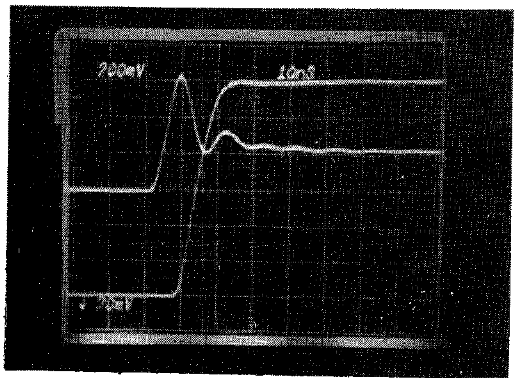

Figure 4. Switching Speed

Reliability

Reliability of the Horkin attenuator compared to the PI or TEE configuration (best choice for electrical performance comparison) is enhanced due to its soft failure modes. Each section contributes dB/N of the dynamic range (for N sections). Diodes failing in any mode, i.e., short, open, or fixed resistance, will reduce the total dynamic range without grossly affecting the performance of the attenuator. A typical attenuator may lose 3 to 6 dB out of 60 due to a single open or shorted diode. Multiple failures will continue to cause graceful degradation of the performance.

Measurement and Analysis Results

The attenuator was analyzed using the Super-Compact program with the microstrip transmission line model for a device with ten sections. The metalization chosen for analysis was nickel, and its thickness was varied to control the total resistance of each section. Computations on insertion loss show a slight frequency dependence with the loss increasing with increasing frequency, and the slope increasing for higher attenuation values. Figure 5 illustrates a composite output of several analyses for differing insertion loss values. Measured data show similar results with somewhat more pronounced slope, especially at high insertion loss levels.

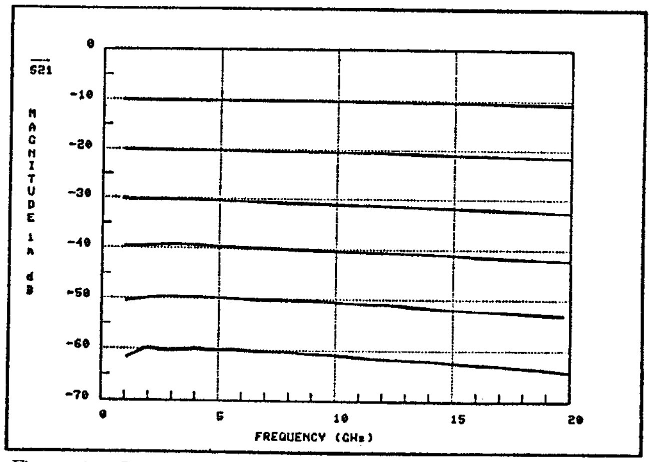

Figure 5. Predicted Insertion Loss

Figure 6 illustrates the typical return loss versus frequency characteristics at three insertion loss levels. As can be seen the return loss decreases with increasing attenuation as the lossy transmission model would suggest. Figure 7 shows the effect of attenuation on return loss at two frequencies. Once again, the return loss decreases with increasing insertion loss.

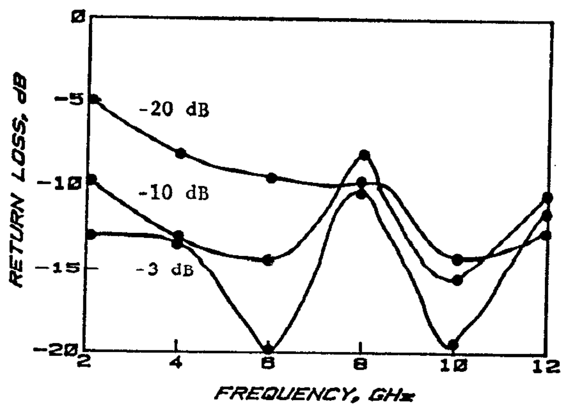

Figure 6. Return Loss vs. Frequency

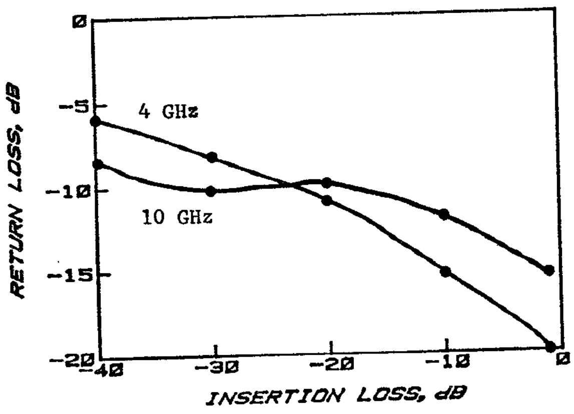

Figure 7. *Return Loss vs. Attenuation*

Conclusions

The new approach to absorptive PIN diode attenuators presented here offers the possibility of optimizing conflicting parameters in a single design. Reliability is enhanced due to soft failure modes providing graceful degradation. Its small size and simple bias arrangement makes it desirable for a wide range of applications where performance is critical. Fast speeds (10 nsec), good impedance match, wide dynamic range (50 dB) and simple current driver circuits make this new attenuator type an important consideration for new designs.

References

1. D.G. Fink, *Electronics Engineers' Handbook* McGraw-Hill 1975, Section 22 - 25.