OCTAVE BAND MIC ELECTRONICALLY VARIABLE ATTENUATORS USING PIN DIODES*

by

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A series of C- and X-band thin-film microstrip electronically variable attenuators have been developed, using PIN diode chips in an iterated structure, which exhibit half-to-full octave bandwidth capability. Using 10 PIN diodes, mounted singly and in pairs on a 1-inch square substrate, these attenuators exhibit less than 1.6 and 1.8 dB low attenuation insertion loss, about 34 and 27 dB maximum attenuation, and less than 1.6:1 and 1.4:1 VSWR over the 4 to 8 and 8 to 12 GHz frequency ranges, respectively.

The basic attenuator configuration is essentially that originally described by Hunton and Ryals[1], in which PIN diodes and pairs of PIN diodes, shunt mounted to RF ground, are spaced by quarter wavelengths at band center on a 50-ohm transmission line. In this configuration, the use of a large number of PIN diodes, with each diode representing a relatively small perturbation on the transmission line, provides the basis for a broadband well-matched operation. The maximum attenuation achievable therein is proportional to the number of diodes used.

The PIN diode attenuators under consideration were each fabricated in microstrip transmission line on 1-inch square, 25-mil thick alumina substrates, with the vacuum-deposited metallization consisting of a composite chromium-copper film. The conductor pattern is photoetched on the upper surface of the substrate and the entire metallization then gold flashed.

Figure 1 shows the 8 to 12 GHz thin-film microstrip PIN diode attenuator. The 4 to 8 GHz attenuator has an essentially identical configuration scaled to the lower frequency range. Each of these attenuators is composed of the following elements:

- Array of PIN diode chips, quarter-wave spaced on a 50-ohm transmission line and transversely series mounted in paralleled pairs or singly (at the ends of the array) to low impedance open-circuited stubs. The latter provide wideband low-reactance RF grounds for each of the diodes, so that the array is electrically equivalent to that of quarter-wave spaced shunt-mounted diodes. A total of 10 PIN diode chips are used in each case.

- Two identical bias input circuits, one for the transversely mounted diodes on each side of the main transmission line and each consisting of a two-pole RF isolated BRF bias input circuit and a high-impedance line interconnecting the RF grounding stubs associated with the diodes at their respective low-impedance (diode) ends.

- Quarter-wave short-circuited high-impedance shunt stub providing a dc ground return for the main transmission line.

The 10 PIN diode chips employed in these attenuators were readily available, inexpensive HP-5082-0012 devices consisting of a PIN junction formed on an appropriately metallized 15 mil-square Si chip. The metallized bottom contact of the chip was bonded directly to the thin-film conductor pattern of the microstrip circuit, whereas connection from the latter to the top contact of the chip is made via a 1-mil bonded wire. The low-to-moderate level RF equivalent circuit of these RF-grounded PIN diode chips (Figure 2) consists of the parallel combination of the dc-bias dependent junction conductance and the small (≈ 0.10 pF) fixed junction capacitance in series with the bulk and contacting resistance of the Si chip (≈ 5 ohms), the lead inductance of the contact wire (≈ 0.5 nH), and the low-Q series resonant circuit associated with the open-circuited grounding stub at its quarter-wave center frequency. The latter is chosen higher than the attenuator band center in order to resonate out the PIN diode reactive parasitics at midband. This representation of the RF-grounded PIN diode has been verified by measurements made over the 4 to 12 GHz frequency range.

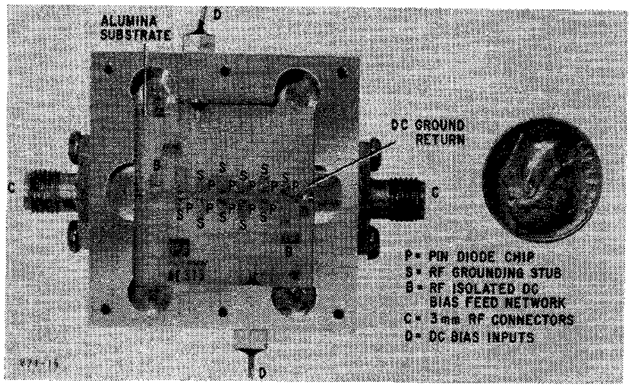

Figure 1. Thin-Film Microstrip 8 to 12 GHz PIN Diode Attenuator

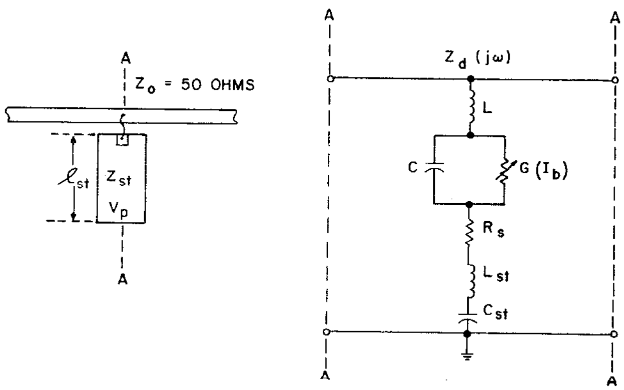

Figure 2. Equivalent Circuit of RF-Grounded PIN Diode Chip

The behavior of the bias-dependent junction conductance, $G(I_b)$, zero at reverse bias essentially varies directly with dc current over the useful range of forward bias current [$G(\text{mhos}) \approx 0.06\, I_b(\text{mA})$]. In the multidiode attenuator configuration under consideration, the 10 diodes

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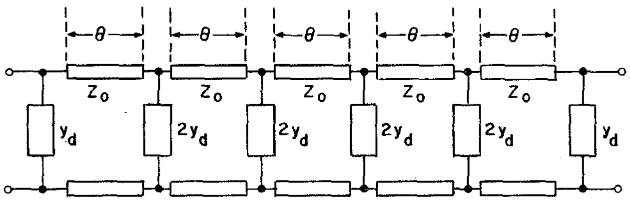
are uniformly biased at zero or reverse voltage in the minimum attenuation state and at a forward current (~250 μA/diode) corresponding to about a 50 to 100 ohm junction resistance in the forward biased maximum attenuation state. By limiting the range of junction conductance as previously described, the contribution of the series reactance of the diode parasitics and RF ground stubs (compared with 50 to 100 ohms) is negligible over the order of an octave bandwidth, thus making more feasible the realization of a broadband, well-matched structure.

Using the PIN diode equivalent circuit of Figure 2, and that of the attenuator in Figure 3, the predicted performance parameters[1] of the 10-diode structure are summarized as follows:

Center frequency:	6 GHz		10 GHz	
	Forward	Reverse	Forward	Reverse
Bias state ($g = GZ_o$)	1.0	0	0.65	0
Loss (-dB)	42	0.3	30	0.5
VSWR (max)	1.5:1	1.2:1	1.25:1	1.38:1



$y_d = Z_o/Z_d$; $\theta = \frac{\pi}{2}\frac{f}{f_o}$;

Figure 3. Equivalent Circuit of PIN Diode Attenuator

The ultimate bandwidth limitation on both insertion loss and VSWR is imposed jointly by the frequency dependence of the RF grounding resonators and the quarter-wave interconnecting lines. The introduction of impedance tapering of the end elements while maintaining uniform bias per diode is accomplished by using paralleled RF grounded diodes at all the intermediate diode positions and single diodes at the end positions. This impedance tapering has the effect of improving the passband match of the structure.

The measured performance characteristics of representative models of the 8 to 12 and 4 to 8 GHz 10-diode attenuators, presented in Figures 4 and 5, indicate reasonable agreement with the first-order theoretical predictions. The bandwidth limitations observed in both cases are upon the maximum attenuation at the lower band edge (due to the interelement spacing and RF grounding resonator), and upon the minimum insertion loss and VSWR at the upper band edge (due to the increasing reactive mismatch introduced by the low-loss-biased diodes). Therefore, even further improvements in bandwidth should be achievable using more diodes, more elaborate impedance tapering along the array, or more sophisticated RF grounding networks.

Reference

1. J. K. Hunton and A. G. Ryals, "Microwave Variable Attenuators and Modulators Using PIN Diodes," IEEE Trans on MTT, Vol 10, p 262-273, July 1962.

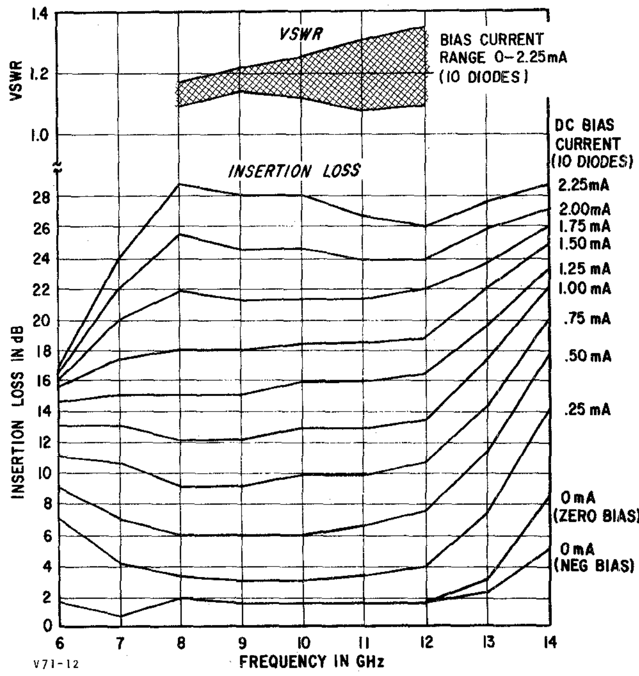


Figure 4. Measured Performance 8 to 12 GHz PIN Diode Attenuator

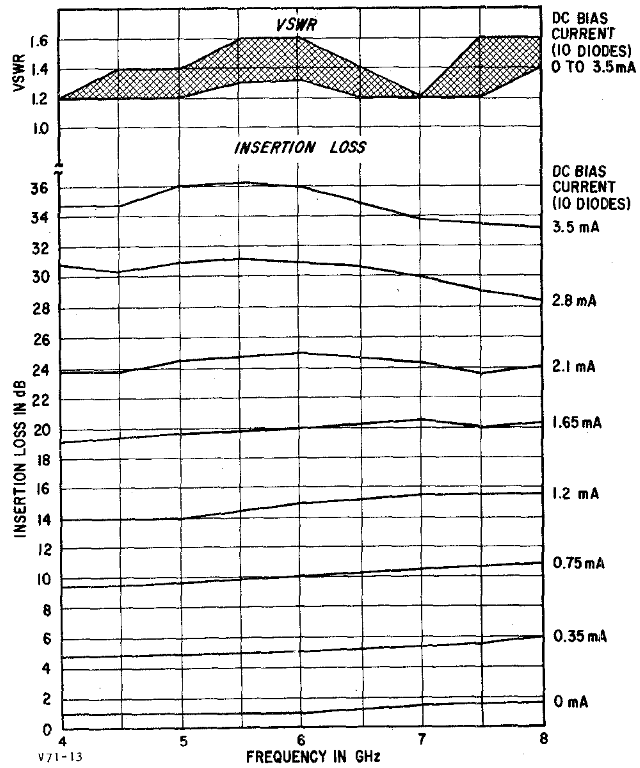


Figure 5. Measured Performance of 4 to 8 GHz PIN Diode Attenuator