# X-BAND MONOLITHIC GaAs PIN DIODE VARIABLE ATTENUATION LIMITER

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## ABSTRACT

Monolithic GaAs PIN diode attenuator/limiter circuits have demonstrated 26 dB of variable attenuation at X-band while maintaining under 1.5 to 1 input and output voltage standing wave ratios (VSWRs). Insertion loss is 0.8 dB at 10 GHz in the 0 bias condition. Passive limiting provides 15 dB of isolation at RF input power of 2.0 W cw. These results are obtained using a vertical PIN diode process on metallorganic chemical vapor deposition (MOCVD) material.

## INTRODUCTION

Figure 1 shows the block diagram of a conventional transmit/receive (T/R) radar module. A variable attenuation limiter between the low-noise amplifier (LNA) and the circulator provides burnout protection under both transmit and receive conditions. During the transmit mode, the variable attenuation limiter is biased at 3 mA, providing 26 dB of isolation for the LNA. A VSWR less than 1.5 to 1 is presented to the circulator, a requirement necessary to prevent load-pulling of the power amplifier. During the receive mode, the limiter operates at 0-mA bias to achieve minimum insertion loss and provide passive RF limiting protection for the LNA. This monolithic microwave integrated circuit (MMIC) can also be integrated into transmit or receive channels as a well-matched attenuator, providing analog gain control range up to 26 dB. In the configuration of Figure 1, the variable attenuation function can be used to extend the dynamic range of the receive channel. A number of these circuits have been fabricated and RF tested. The fabrication is discussed, along with the circuit design and RF performance.

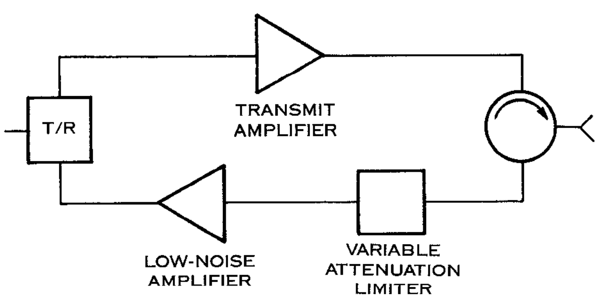


**Figure 1. Simplified Radar Module Block Diagram**

## GaAs PIN DIODE FABRICATION

The vertical PIN diode is fabricated on MOCVD-grown layers as shown in Figure 2(A). The fabrication process for the PIN diode begins with deposition and patterning of Au/Zn/Au for the P+ contact [Figure 2(A)]. The P+ is alloyed for 1 minute at 370°C. The mesa for the PIN diode is etched to the I/N+ interface using the Au/Zn/Au as a mask [Figure 2(B)]. Au/Ge/Ni is deposited and patterned to form the contacts for the N+ [Figure 2(C)]. The Au/Ge/Ni is self-aligned to the Au/Zn/Au and P+ mesa. The Au/Ge/Ni is alloyed at 430°C for 3 minutes. The diodes are isolated by etching through the N+ layer [Figure 2(D)]. After the contact metals are alloyed, interconnect metals are patterned and lifted off [Figure 2(E)]. After interconnect level is patterned and lifted off, Ti/Au is deposited, patterned, and plated to form airbridges and transmission lines [Figure 2(F)].

## PERFORMANCE

To date, a number of PIN diodes have been fabricated and tested. The voltage-current characteristic of a PIN diode with an 18-$\mu$m diameter mesa is shown in Figure 3. The breakdown voltage exceeds 40 volts at 10 $\mu$A. The saturation current is approximately 4 nA. This represents the high-quality junction grown by the MOCVD reactor and the absence of surface effects found in lateral structures. The ideal factor is 2, which is typical for PIN diodes. The parasitic resistance is approximately 2 ohms. The storage time, measured with a 50-ps rise time is approximately 2 ns. This places the lower frequency limit at 80 MHz.

## RF DESIGN

Figure 4 shows the circuit schematic of the variable attenuation limiter. Variable attenuation levels are achieved through biasing of the PIN diodes. The diode impedance is current-dependent and results in a continuously variable attenuation as a function of current for the

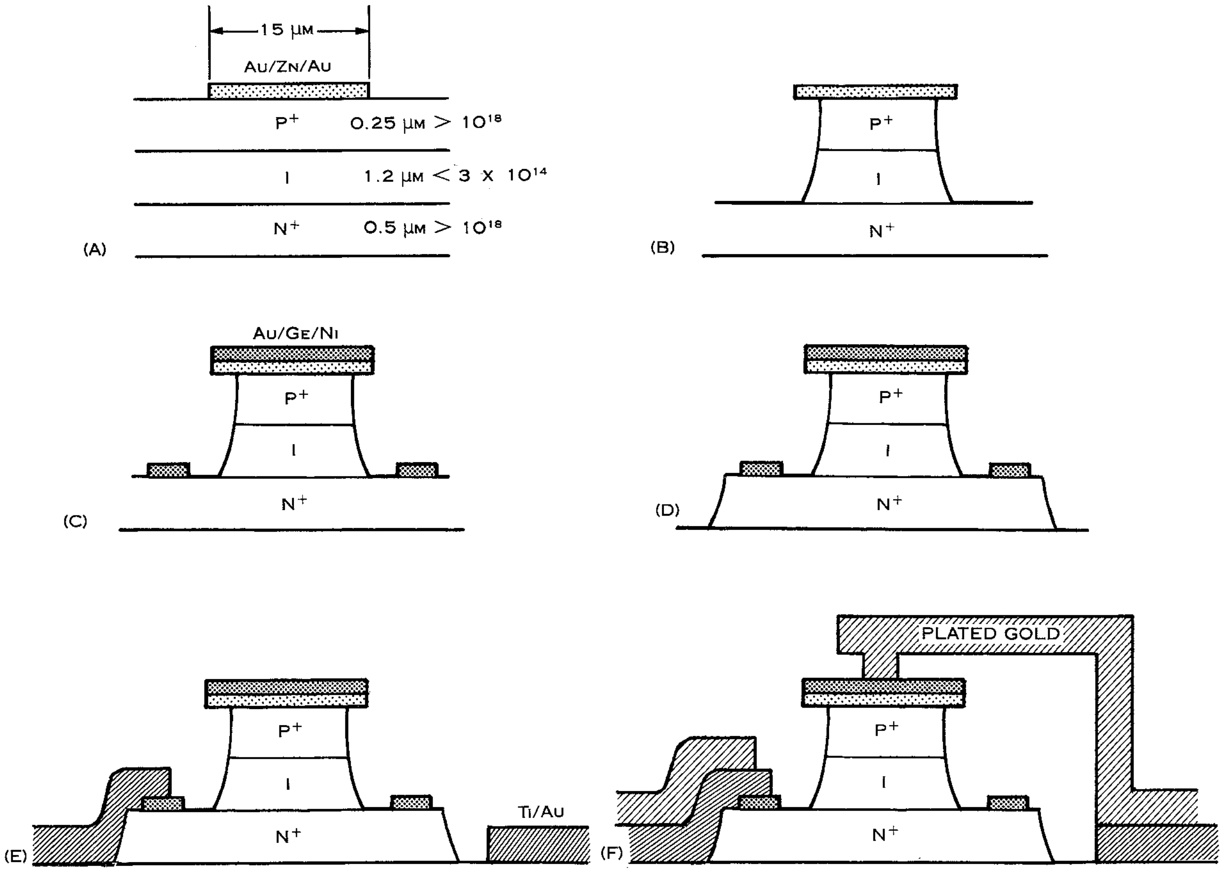


**Figure 2. Vertical PIN Diode Process**

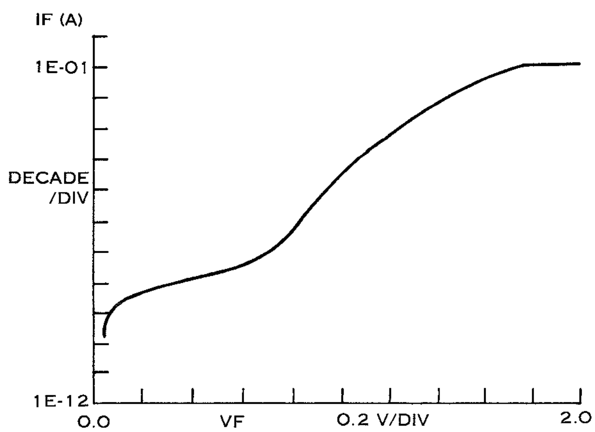


**Figure 3. PIN Diode Forward I/V Characteristics**

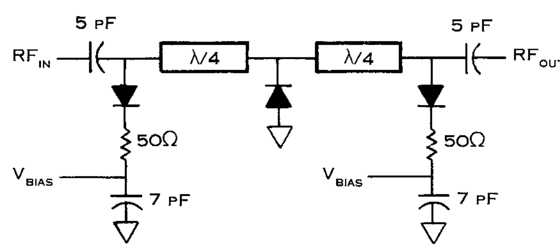


**Figure 4. Variable Attenuator/Limiter Schematic Diagram**

overall attenuator. The impedance and length of the quarter-wave transmission lines are chosen to provide input VSWR less than 1.5 to 1 across X-band. The 50-ohm load is thermally designed (Figure 5) to handle 2 watts DC and/or RF power. The size of the PIN diodes is also chosen to handle the current when 2 watts is dissipated in the load.

## RF PERFORMANCE

Figure 5 shows a photograph of the X-band variable attenuation limiter circuit. RF performance versus bias current is shown in Figure 6. Table 1 summarizes the attenuator performance across the 9- to 10-GHz band while Table 2 summarizes the broadband 8- to 12-GHz response for several bias conditions. The average insertion loss is listed, along with worst case input/output return loss over the band. The average relative phase shift is also shown. This 0.8-dB insertion loss attenuator achieves 25 dB of continuous variation with only 3-mA dc current consumption. VSWRs of 1.3 to 1 at both the input and output over the entire attenuation range provide excellent impedance match to circuits on either side of the attenuator. The large signal performance is shown in Figure 7. Passive limiting of 15 dB is achieved at a 2-W input level.

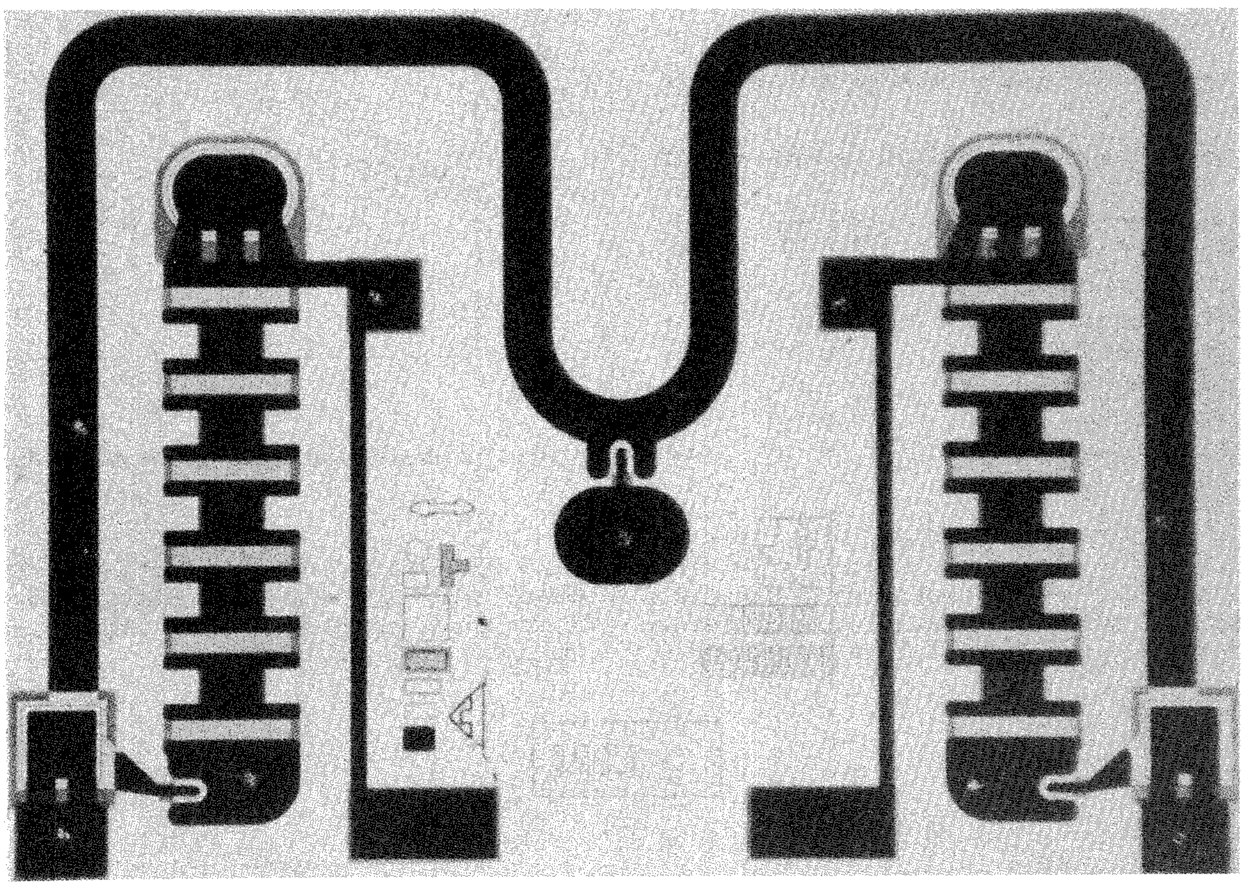

**Figure 5. Variable Attenuator Limiter**

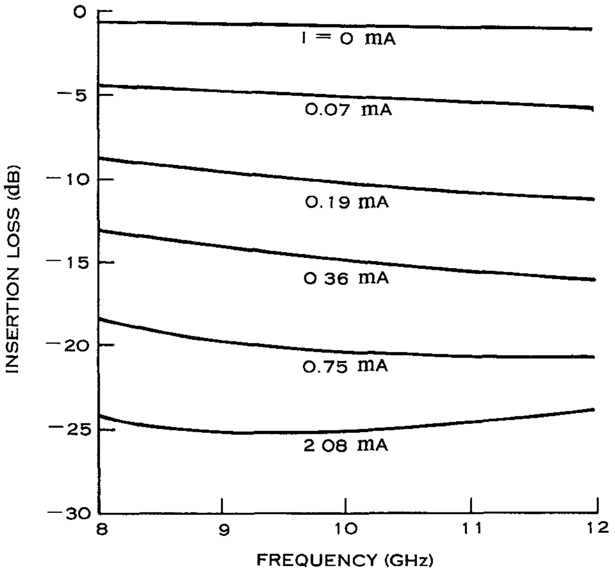


**Figure 6. Matched Attenuator Performance Versus Bias Current**

TABLE 1. VARIABLE ATTENUATION LIMITER RF PERFORMANCE (9 GHz to 10 GHz)

| Bias (V)/(mA) | Insertion Loss (dB) | Input Return Loss (dB) | Output Return Loss (dB) | Relative Phase ( ) |
|---|---|---|---|---|
| 0/0 | 0.74 ±0.07 | 17.9 | 17.4 | 0 |
| −2.0/0.07 | 4.9 ±0.18 | 24.9 | 21.2 | −6.0 |
| −2.1/0.19 | 9.8 ±0.36 | 21.7 | 20.8 | −12.9 |
| −2.2/0.36 | 14.5 ±0.45 | 20.8 | 20.8 | −13.1 |
| −2.3/0.75 | 20.0 ±0.37 | 20.4 | 20.8 | −4.4 |
| −2.5/2.08 | 25.2 ±0.03 | 19.7 | 20.1 | 16.91 |

TABLE 2. VARIABLE ATTENUATION LIMITER RF PERFORMANCE (8 GHz to 12 GHz)

| Bias (V)/(mA) | Insertion Loss (dB) | Input Return Loss (dB) | Output Return Loss (dB) | Relative Phase ( ) |
|---|---|---|---|---|
| 0/0 | 0.84 ±0.27 | 13.4 | 13.6 | 0 |
| −2.0/0.07 | 5.1 ±0.73 | 18.2 | 18.5 | −1.9 |
| −2.1/0.19 | 10.0 ±1.35 | 16.5 | 16.3 | −16.4 |
| −2.2/0.36 | 14.6 ±1.57 | 15.0 | 14.7 | −23.2 |
| −2.3/0.75 | 19.7 ±1.22 | 14.3 | 14.0 | −23.6 |
| −2.5/2.08 | 24.6 ±0.66 | 14.3 | 14.0 | −3.0 |

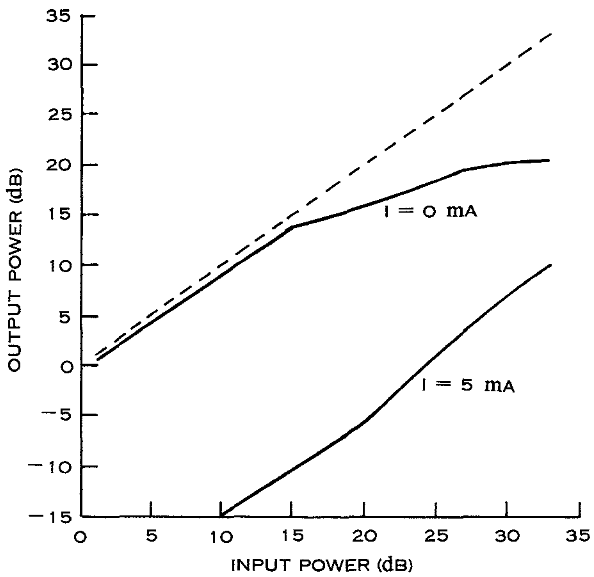


**Figure 7. Matched Attenuator Performance Versus Input Power**

## CONCLUSIONS

Monolithic GaAs PIN diode technology is capable of performing multifunction circuit roles in radar receivers with state-of-the-art performance, as demonstrated by this X-band variable attenuation limiter. The vertical GaAs PIN diode provides excellent passive limiting performance and also provides variable attenuation with minimal current consumption.