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A MEDIUM POWER SOLID STATE AMPLIFIER FOR V-BAND

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Abstract

A solid state amplifier for the 54 to 58 GHz band is described. The amplifier uses two layer InP Gunn devices. Three stages of amplification provide an output power of 100 mW at a gain of 15 dB. The small signal gain is 30 dB; the noise figure is in the 15.5 to 16.5 dB range. The design of a broadband low-loss V-band circulator, which was used in the amplifier, is also described.

Introduction

Continuing development of millimeter wave InP Gunn devices has made it possible to provide stable amplification at V-band with output power levels in the 100 mW range. This paper describes a three-stage amplifier for the 54 to 58 GHz band, with an output power of 100 mW and an associated gain of 15 dB. To assure amplifier stability, the bandwidth of the circulator must be larger than the bandwidth of the diode circuit. To meet this requirement, a wide-band low-loss circulator for V-band was developed.

InP Gunn Diode

The millimeter wave Gunn diodes used in this amplifier have two epitaxial layers, an n+ buffer layer followed by an active layer.[1] The epi layers are produced by vapor phase epitaxy, using the chloride transport process. The active layer doping is in the 10^{15} to 10^{16} cm^{-3} range, slightly lower than that used for CW oscillator diodes, but higher than that used for low-noise amplifier diodes. Devices are fabricated from wafers using an integral heat sink process. The finished device consists of a chemically etched InP mesa on a plated gold heat sink.

An output power in excess of 100 mW was demonstrated with selected diodes. Figure 1 shows the gain response of a single-stage circulator coupled test amplifier operated with matched source and load impedances. The small signal gain is 12.5 dB, the output power is 100 mW at 6 dB remaining gain; stability was good. With multistage amplifiers, the bandwidth had to be restricted to about 8 GHz due to the limited bandwidth of the isolators.

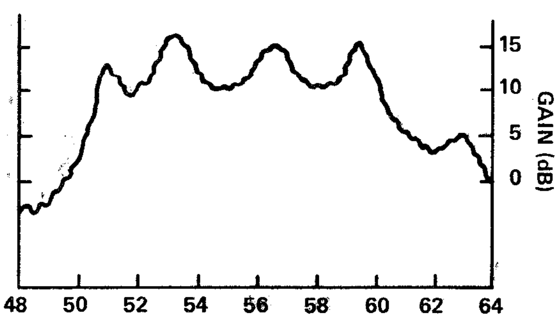

FIGURE 1. SMALL-SIGNAL GAIN RESPONSE OF SIGNAL-STAGE TEST AMPLIFIER

The gain ripple can be shifted in frequency by a change of the distance between diode and circulator. With multistage amplifiers, an overall flat response can be achieved by stagger-tuning the ripples of the individual stages.

Amplifier Layout

The amplifier consists of three circulator coupled stages, with an isolator at the input and between stages. Figure 2 is a block diagram of the amplifier. All three-port circulators are identical and are cascaded in line with diode circuits or RF loads attached to the #2 ports on one side. Three separate linear voltage regulators, one for each diode, operate from an input voltage of 12 Vdc and have output voltages adjustable from 6 to 9 volts. DC power requirement per amplifier stage is 4.5 W. Figure 3 is a photograph of the amplifier with cover removed.

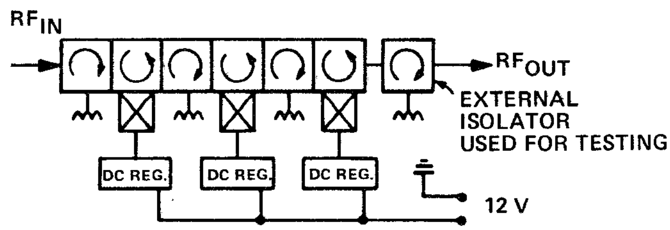

FIGURE 2. BLOCK DIAGRAM OF AMPLIFIER SOLID-STATE

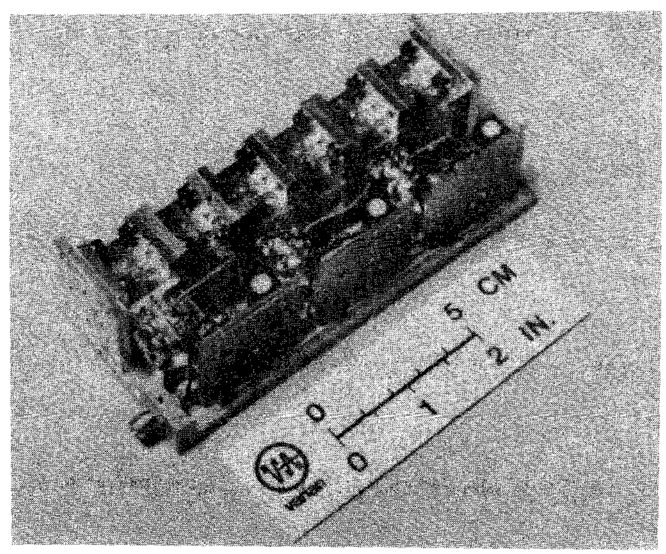

FIGURE 3. V-BAND SOLID-STATE AMPLIFIER

Diode Circuit

The Gunn diode is mounted in a coaxial cavity with a coupling aperture to a full height waveguide, as shown in Figure 4. DC bias is introduced via a three-section Teflon coated bias choke. The end section of the choke forms the inside conductor of the coaxial cavity. The center frequency of the gain response is tuned by selection of a choke with the proper end-section length.

The shape of the gain response, such as single tuned (one peak) or double tuned (two peaks), can be tuned by changing the thickness of the ring spacers on top of the diode flange. Adjustments of center frequency and band-pass shape were independent of each other. The gain bandwidth product remained constant for different bandwidth settings.

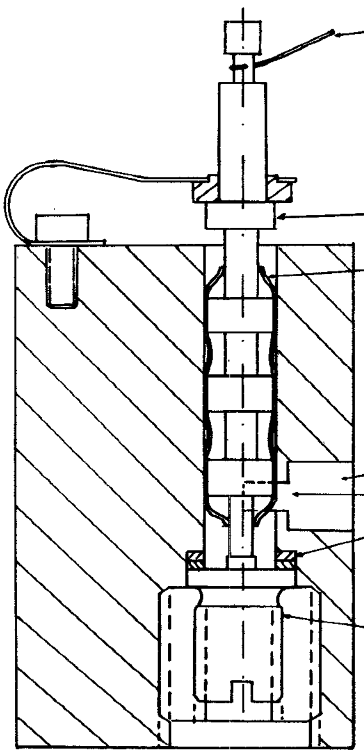

FIGURE 4. CROSS SECTION OF DIODE CIRCUIT

The gain ripple, as shown in the gain response of Figure 1, is a direct function of diode circuit gain minus circulator isolation.[2] For a moderate assumption of 8 dB gain and 3 dB peak-to-peak ripple, the required isolation is about 23 dB. This stresses the importance of a high quality circulator with sufficient bandwidth to avoid large gain ripple amplitudes, particularly at the band edges. The major problem in the development of this amplifier was instability of the high power output stage due to out-of-band oscillations caused by residual gain of the diode circuit at frequencies where circulator isolation had dropped too low.

V-Band Circulator

Since a high quality V-band circulator was not available from outside sources, it was developed in-house. The circulator has three ports with special flanges provided for direct cascading. Figure 5 illustrates the design of the junction. A cylindrical ferrite is located at the center of a waveguide Y

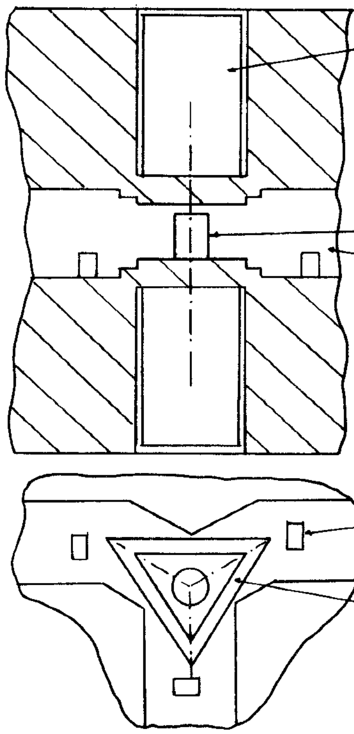

FIGURE 5. DESIGN OF CIRCULATOR JUNCTION

junction. A two-step triangular transformer matches the ferrite to the waveguide terminals. Dielectric chips are used for fine tuning. Figure 6 shows typical insertion loss, return loss, and isolation of the circulator. The corresponding data for different ports are almost identical, showing very good symmetry of circulation and matching.

A low insertion loss is important in power or low-noise applications. The prime parameter for this application is return loss and isolation, which are corresponding parameters if circulation is good and insertion loss is low. In the design band from 54 to 58 GHz, the insertion loss per pass is 0.2 dB, the return loss of each port is 20 $\pm$ 1.5 dB and the isolation is 20 $\pm$ 2.0 dB. Good performance is obtained over a much larger bandwidth. A < 0.3 dB insertion loss is observed over a bandwidth of 10.6 GHz. The bandwidth for >15 dB return loss or isolation is 10 GHz.

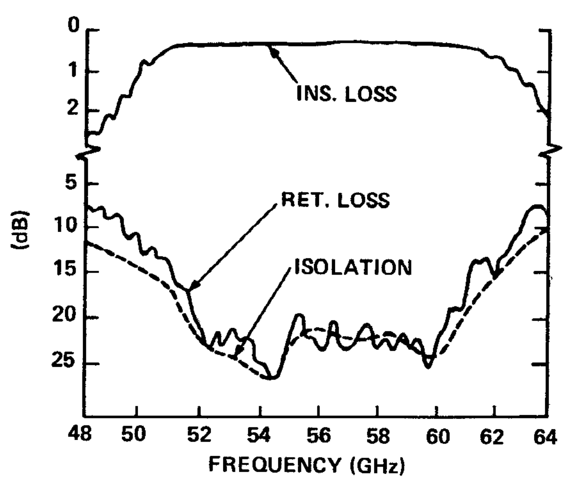

FIGURE 6. TYPICAL ONE-PASS INSERTION LOSS, RETURN LOSS, AND ISOLATION OF CIRCULATOR

Amplifier Performance

Typically, a reflection amplifier requires an output isolator to reduce the sensitivity to load mismatches. Therefore, all tests were made with an output isolator.

The gain versus frequency responses of the amplifier for different input power levels are shown in Figure 7. The trace for P_{in} = -25 dBm shows a small signal gain of about 30 dB. At higher drive power, the amplifier goes into limiting. Practically all gain ripples have disappeared at a drive level of -5 dBm and an associated gain of 25 dB. Figure 8 shows P_{out} versus P_{in} characteristics for three different frequencies. An output power of 100 mW is obtained at 15 dB remaining gain. The 1 dB compression point is at about +12 dBm. The amplifier was tested over a temperature range from 0^{o}C to 70^{o}C and showed no instabilities. Small signal gain responses for different temperatures are shown in Figure 9. A tilting of the gain response is observed at temperatures different than nominal. Output power versus temperature at band center for P_{in} = +3 dBm is given in Figure 10. The output power is fairly constant, with only 1.5 dB variance over the full 0^{o}C to 70^{o}C range. The noise figure of the amplifier is in the 15.5 dB to 16.5 dB range.

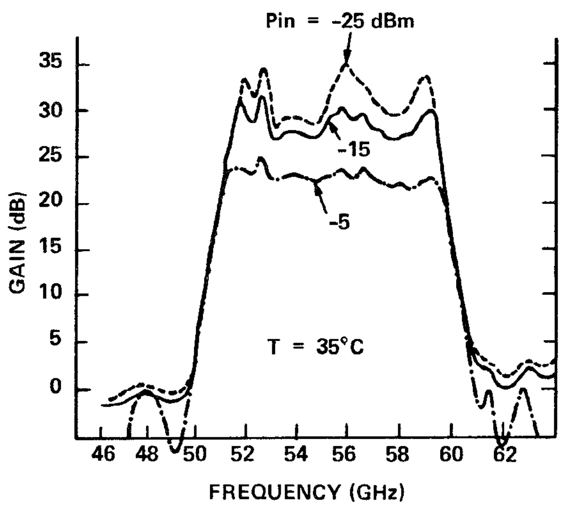

FIGURE 7. GAIN RESPONSE OF SOLID-STATE AMPLIFIER AT DIFFERENT DRIVE LEVELS

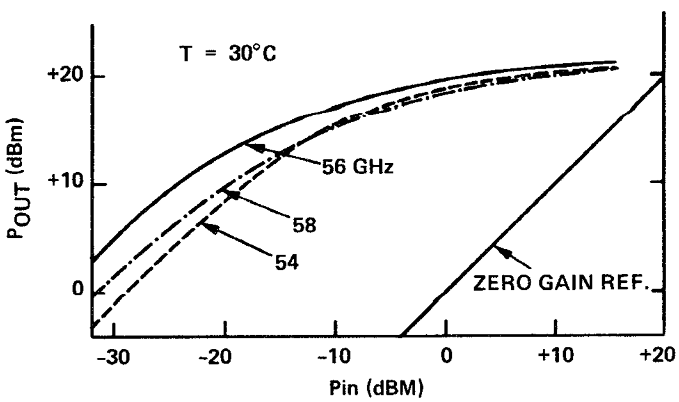

FIGURE 8. P_{OUT} vs P_{IN} OF SOLID-STATE AMPLIFIER AT DIFFERENT FREQUENCIES

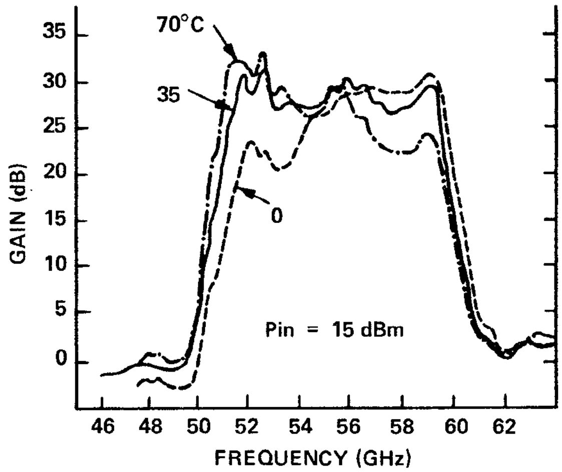

FIGURE 9. GAIN RESPONSE OF SOLID-STATE AMPLIFIER AT DIFFERENT TEMPERATURES

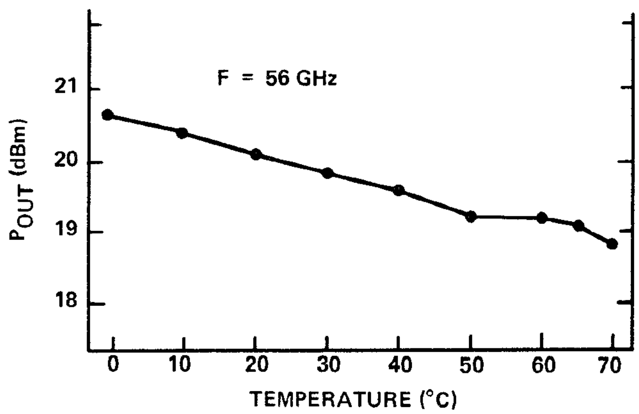

FIGURE 10. OUTPUT POWER vs TEMPERATURE OF SOLID-STATE AMPLIFIER FOR P_{IN} = +3 dBm AT 56 GHz

Conclusion

A solid state amplifier for the 54 GHz to 58 GHz band was successfully developed. The amplifier meets the development goal of P_{out} = 100 mW at 15 dB gain and has a flat, well-behaved gain response with a bandwidth in excess of 7 GHz. It has been demonstrated that powers in excess of 100 mW and bandwidths of 10 GHz and larger can be obtained with well-matched, single-stage amplifiers. A bandwidth limitation is imposed by the circulators and isolators. Design modifications of the circulator to increase the isolation bandwidth are presently under investigation.

References

1. J. D. Crowley, S. B. Hyder, B. R. Cairns, "InP Gunn Devices (26-60 GHz), Report, NOSC Contract No. N00123-77-C-0459, August 1979.

2. B. D. Bates and P. J. Khan, "Influence of Non-Ideal Circulator Effects on Negative Resistance Amplifier Design," IEEE 1980 Microwave Symposium Digest, pp. 174-176.