A LOW NOISE SOLID STATE AMPLIFIER FOR REPLACEMENT OF A Ka-BAND TWTA

P. H. Wolfert, J. D. Crowley, and F. B. Fank
VARIAN ASSOCIATES, INC.
SOLID STATE MICROWAVE DIVISION
611 Hansen Way
Palo Alto, CA 94303

ABSTRACT

A low noise solid state amplifier for replacement of a Ka-band TWTA is described. Eight stages of amplification, which utilize cathode notch InP Gunn diodes, provide a gain of 37 ± 3 dB with an associated N.F. ranging from 13.3 to 16.3 dB in the 27-39.5 GHz band.

Introduction

Solid state replacement of TWTA's is a long standing goal to take advantage of the much longer inherent lifetime and better reliability of solid state devices. GaAs FET amplifiers have been used for frequencies up to 18 GHz. For the 18 to 26 GHz band, a tunnel diode/Gunn diode amplifier has been developed [1]. The design of a Ka-band (26 to 40 GHz) amplifier as described in this paper was made possible by the recent development of low noise InP Gunn diodes [2] and wide band circulators* which provide full band coverage with 0.5 dB single pass insertion loss and 15 dB minimum isolation.

InP Gunn Diode

Ka-band GaAs Gunn diodes cannot provide noise figures competitive with the 16 to 17 dB N.F. of the TWTA's. A N.F. ranging from 9.5 to 13.5 dB with a gain of 5 dB over the full band was achieved with an InP Gunn diode as illustrated in Figure 1. The diode utilizes an N^- cathode notch to produce a uniform field in the active layer of the device, which is necessary for the achievement of low noise figures. A composite doping profile of the epitaxial layers of the wafer which was used to make the diodes is shown in Figure 2.

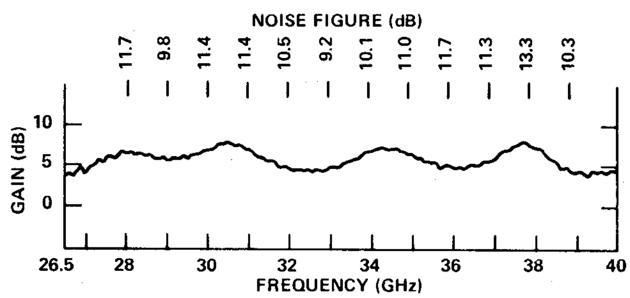

FIGURE 1: GAIN RESPONSE AND N.F. OF SINGLE STAGE InP GUNN DIODE AMPLIFIER.

Amplifier Layout

The amplifier consists of eight circulator coupled stages with isolators at input, output, and between every two stages as shown in the block diagram in Figure 3. The power supply is a nominal 30 KHz off-line DC-to-DC converter followed by eight adjustable linear regulators. Packaging of these components into the TWTA outline with identical RF terminal locations was very tight, requiring special electroformed waveguide sections. A photograph of the amplifier with cover removed is given in Figure 4.

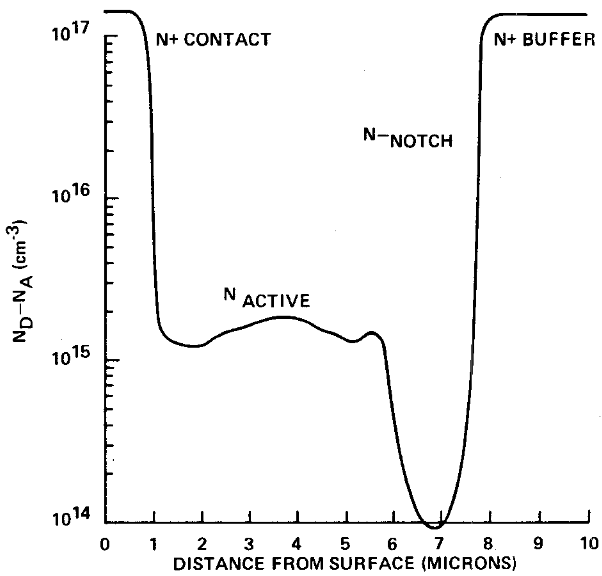

FIGURE 2: DOPING PROFILE OF InP CATHODE NOTCH WAFER

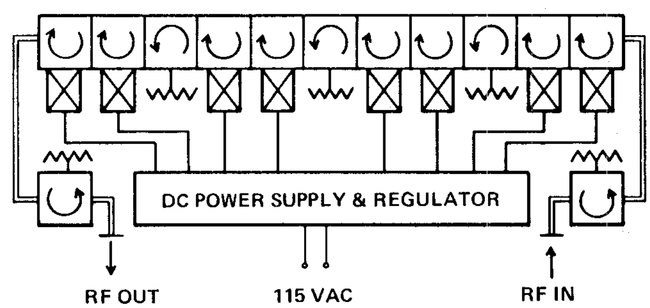

FIGURE 3: BLOCK DIAGRAM OF SOLID STATE AMPLIFIER

*Circulators supplied by PAMTECH, Canoga Park, CA

0149-645X/81/0000-0441$00.75 © 1981 IEEE

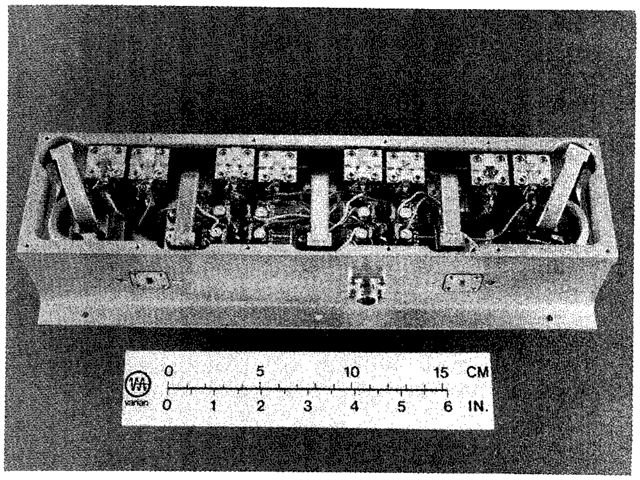

FIGURE 4: SOLID STATE AMPLIFIER WITH COVER REMOVED.

Diode Mount

The diode mount is a reduced height waveguide section with the diode mounted in the center as illustrated in Figure 5.

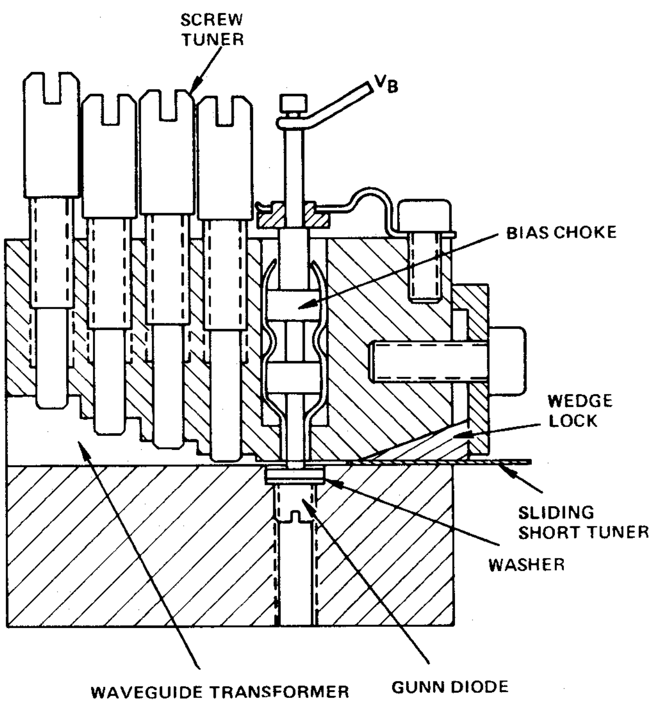

FIGURE 5: CROSS SECTION OF DIODE CIRCUIT.

A sliding short is used to resonate the diode reactance. A three section 14:1 Tchebbyschev transformer with a center frequency of 32.4 GHz and a fractional bandwidth of 0.8 matches the diode to the circulator. Screw tuners at each transformer section were used to fine tune the gain response. Elimination of contact problems by a wedge locked sliding short and spring contacts to the screw tuners resulted in a remarkable stability through temperature cycling and handling. Almost identical gain responses of individual stages were obtained due to the large tuning flexibility of the diode circuit in spite of variances of diode parameters.

Tuning and Cascading of Stages

The initial goal was to tune individual amplifier stages for a flat stable gain response and low N.F. over the whole 26.5 to 40 GHz band as shown in Figure 1. This performance was achieved with a small number of selected diodes. With most diodes only about 85% band coverage was possible.

An alternative approach uses stagger tuning of cascaded stages which resulted in close to full band coverage without stability problems. Amplifiers with a gain ramp peaking at the upper band edge (high-tuned) were cascaded with amplifiers with a gain ramp of opposite slope (low-tuned) to produce an overall flat response. The typical gain responses of circulator coupled high and low tuned stages are given in Figure 6. All diode circuits were tuned in a single stage test setup. No retuning was required for multi-stage operation.

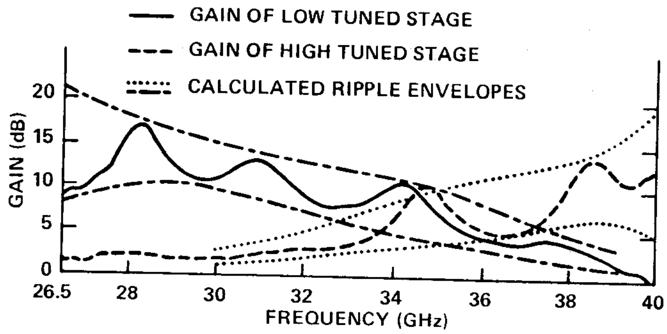

FIGURE 6: GAIN RESPONSE OF LOW AND HIGH TUNED AMPLIFIER STAGES.

The circulator introduces a ripple which can be attributed to a deficiency in circulator isolation [3]. The phase of the ripple can be shifted by insertion of waveguide spacers between diode circuit and circulator. The peak-to-peak ripple R in dB is given by:

$$I-G = 20 \log \left\{ \log^{-1}\left(\frac{R}{20}\right) - 1/\log^{-1}\left(\frac{R}{20}\right) + 1 \right\} \quad (1)$$

where G is the reflection gain in dB and I is the circulator isolation in dB. From measured average gain and circulator isolation, the ripple magnitude was calculated and plotted in Figure 6. The envelopes fit closely to the ripple peaks and valleys of the measured responses. Notice that for a moderate assumption of 8 dB gain and 3 dB peak-to-peak ripple, the required circulator isolation is about 23 dB. Existing circulators have much lower isolation, particularly at the bandedges. Despite the lower isolation, an overall flat gain response of the

8 stage amplifier was obtained by offsetting the ripple phases of the individual stages against each other using waveguide spacers of different thicknesses between diode circuit and circulator.

The overall N.F. is determined by the N.F. of the first two to four stages. A high tuned stage having the highest N.F. was taken as the first stage, followed by a low tuned stage. This about equalizes the overall N.F. at the high and low end of the 8 stage bandpass. Operating the first two stages at a reduced bias with some sacrifice of gain resulted in about a 1.5 dB improvement in overall N.F.

Amplifier Performance

The gain response and N.F. of the 8 stage amplifier at room temperature is given in Figure 7. The 1 dB compression point of the amplifier at band center is at +5 dBm, and the maximum limited power output is +14 dBm. The gain response vs temperature over a 10 to 60°C range was measured. The gain remains fairly constant over the lower half of the band but drops from about 40 dB at 10°C to 20 dB at 60°C at the upper edge of the band. Table I summarizes the main electrical and mechanical data of the amplifier in comparison with the W.J. and Teledyne TWTA's.

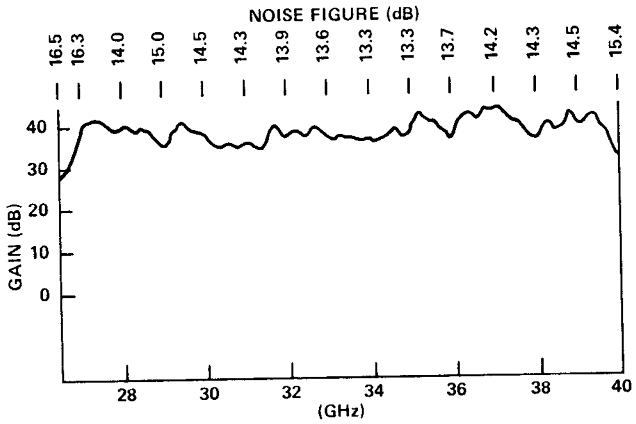

FIGURE 7: GAIN RESPONSE AND N.F. OF SOLID STATE AMPLIFIER.

TABLE 1.
COMPARISON OF TWTA AND SOLID STATE AMPLIFIER DATA

	W. J.* TWTA WJ-467-6	TELEDYNE* TWTA M9346	VARIAN SSA VSK-7407IA
Frequency Range (GHz)	26.5–40	26.5–40	27 – 39.5
Noise Figure (Max, dB)	17	17	16.3
Small Signal Gain (Min, dB)	35	40	35
Saturated Power Output (Min. dB)	+6	+6	+6.5
VSWR – Input (Max)	2.5:1	2:1	1.4:1
– Output (Max)	2.5:1	2:1	2:1
Prime Power (115 VAC, Watts)	---	20	46
Size (Inches)	2.5x3.0x12.0	2.5x3.0x12.0	2.5x3.0x12.0
Weight (Pounds)	6	7	6.5

*From manufacturer's data sheet

Conclusions

A solid state amplifier for replacment of the TWTA was successfully developed. The amplifier meets or exceeds the TWTA's performance in the 27 to 39.5 GHz band. The gain at the band edges can be improved by using diode circuits of different design for the low and the high tuned stages, in particular, step transformers with different center frequencies, and by selecting diodes for low and high frequencies. The gain drift with temperature, which is a device characteristic, can most likely be reduced by using devices with shorter active layers. The required DC input power can be reduced by about 1/3 by improving the conversion efficiency of the power supply.

Acknowledgement

This work was supported by the Naval Ocean Systems Center (NOSC), San Diego, CA 92152 under Contract No. N66001-79-C-0283.

References

1. Aercom Industries, Sunnyvale, CA, "18-26 GHz TWTA Replacement," Microwave Journal, Vol. 21, No. 4, pp. 40, April 1978.

2. 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.

3. 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.