X-BAND TRAPATT AMPLIFIER*

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Abstract

The design and performance of broad-band TRAPATT amplifiers in X-band are described along with a discussion of critical circuit parameters. Bandwidths of 10% and peak powers up to 38 watts have been achieved using coaxial circuits with single and multichip diodes.

Introduction

Wideband TRAPATT amplifiers have been reported at frequencies between 1 and 5 GHz with bandwidths up to 15%.[1,2] At higher frequencies TRAPATT amplification has been achieved using an injection-locked oscillator,[3] but no wideband stable amplifier operation has been reported. This paper describes an X-band pulsed TRAPATT amplifier which has demonstrated bandwidths of 10% with 5 dB gain. The design of the coaxial amplifier is described along with performance data on five units. Data are included for amplifiers utilizing stacked mesa diodes (higher peak power) and for ring diodes on diamond heat spreaders (improved thermal characteristics).

Circuit Description

The coaxial amplifier circuit consists of the diode package and mount, a length of transmission line, a low pass filter, and three tuning slugs. A cross sectional drawing of the amplifier structure, which is similar to the S-band amplifier of reference 1, is shown in Fig. 1.

A five-section Chebyshev low pass filter with a cutoff frequency of approximately 12 GHz was designed for the 0.162 inch diameter coaxial line. The filter, which consists of a series of alternating low and high impedance sections of transmission line machined on the center conductor, was fitted with a teflon sleeve for support in the coaxial line. To adjust the phase of the harmonics reflected from the filter, the amplifier was constructed initially with spring fingers on the center conductor so that location of the filter relative to the diode could be optimized experimentally. The type of low pass filter characteristic utilized in the amplifier does not appear critical provided adjustment of the filter spacing with respect to the diode is available.

Three 16.5 ohm slugs of varying lengths were positioned on the output side of the low pass filter and were used to tune the amplifier response by adjustment of the load impedance at the fundamental frequency. These slugs had little effect on the loading at harmonic frequencies because of the low pass filter. The principal effect of the three slugs was to smooth the amplifier passband; very little effect on the frequency of operation or bandwidth was observed.

The amplifier center frequency was adjusted by varying the corner inductance of the diode mount. This adjustment was accomplished with a series of tuning rings having various inner diameters as shown in Fig. 1.

In order to suppress oscillations in the amplifier, adjustment of the diode package parasitics was necessary. Time domain computer simulations of the TRAPATT mode reported by Carroll and Crede[4] showed that an increase in the package lead inductance caused a decrease in the diode trigger voltage, thus tending to suppress oscillations. Similar computer simulations, along with experiments, revealed that the inductance of a single gold wire (0.94 nhy) in the conventional short pill package was sufficient to suppress oscillations. In most cases at X-band the inductance of a pair of gold wires in the short pill package was insufficient to suppress oscillations and stable amplification could not be obtained. TRAPATT oscillators generally require much lower lead inductance (two-four wires or a wire mesh) thus making amplifier and oscillator package requirements incompatible.

Adjustment of the package parasitics was also required for broad bandwidth operation. Small variations in the package parasitics resulted in large variations in amplifier bandwidth. Control of the package parasitics was achieved by varying the number and length of contact wires between chip and package as well as by varying the height of the chip with respect to the cap on the package. Package capacitance and inductance were both optimized experimentally for the amplifier.

All experiments on TRAPATT amplifiers indicate that package parasitics are the most critical circuit parameters in amplifier design. In some instances tuning of the circuit via adjustment of the package parasitics resulted in increases in amplifier bandwidth by a factor of two or more. Adjustment of other circuit parameters had little effect other than shifting center frequency and suppressing holes in the passband.

Diodes

Diodes utilized in the amplifier were of the p^+n^+ type. The n-type layer of 8×10^{15} donors/cm^3 was grown by vapor epitaxy on an arsenic doped substrate with a resistivity of 0.001 ohms-cm. Gas flow and growth parameters during the epitaxial process were adjusted to ensure an abrupt nn^+ interface. The p^+n junction was formed by diffusion of boron to a junction depth of 1.5 microns. The thickness of the n layer was adjusted so that the drift width ranged between 0.8 and 1.3 microns.

Performance

Typical photographs of amplifier detected RF output pulse and spectrum are shown in Figs. 2 and 3 respectively. These photographs correspond to the amplifier center frequency of 8.25 GHz. Gain for this particular amplifier was approximately 5 dB. Rise and fall times for the applied RF pulse were approximately 20 nanoseconds and little or no deterioration of pulse rise time was observed due to the amplifier. The ripple shown on the RF output pulse was due to the input signal. A thirty percent voltage drop and twenty-five percent current rise were observed at the amplifier center frequency. At the 3 dB band edges the changes in current and voltage were normally somewhat less.

Performance data for 5 amplifiers are shown in Table I, where 2 sets of data are given. The diode

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performance includes only the one-port amplifier circuit whereas the module performance includes losses of the circulator, bias T, and OSM adaptor, each of which is a separate component. Loss of these three components is approximately 0.6 dB per pass, yielding a total reduction in amplifier gain of 1.2 dB. Integration of these components in the amplifier structure should reduce the loss to less than .4 dB per pass which would result in a significant improvement in module performance.

The frequency response of amplifier module No. 4 is shown in Fig. 4. As seen from the curve, the gain is well behaved and smooth over the passband provided the amplifier circuit is carefully adjusted to eliminate spurious signals and holes in the passband. With a batch of diodes closely matched in capacitance and fabricated from the same slice, the general amplifier response was found to be reproducible although fine tuning at the fundamental frequency was sometimes required to eliminate narrow-band holes in the passband and to achieve the maximum bandwidth.

Gains of the amplifiers vary between 4.7 and 6.3 dB with the higher values normally associated with narrower bandwidths. The maximum gain observed for this type amplifier was approximately 7 dB.

The saturation curve for amplifier module No. 1 is shown in Fig. 5. At power levels below the lowest value plotted, the diode dropped out of the TRAPATT mode. The dynamic range varies considerably from unit to unit, depending on tuning but 6 dB below the maximum power point seems typical for the drop mode point. Above the maximum power point the gain falls off rather rapidly with increasing input power. At other frequencies within the passband the saturation characteristics vary somewhat and must be examined carefully while tuning.

Amplifier unit No. 2 contained a stacked pair of circular mesas connected in series for achieving higher peak powers.[5] Power output for the unit was 33.9 watts with 4.9 dB gain and 13.1 percent efficiency over a 3 dB bandwidth of 8.9 percent. Another such unit demonstrated 16.2 percent efficiency with 38 watts output and bandwidth in excess of 6%.

A comparison of amplifier efficiency with that of oscillators at the same frequency using similar diodes reveals a rather large reduction in efficiency for the amplifier. An exact comparison using the same diode for both oscillator and amplifier is not feasible due to conflicting package requirements for the two cases, but a reduction of 30% in efficiency is indicated for the amplifier. A similar reduction in efficiency has been observed with E-band amplifiers. An explanation for the reduction in efficiency is probably related to non-optimum device loading. The circuit has been designed for low reactance slopes and consequently the diode may not be properly matched at the fundamental and harmonic frequencies over the bandwidth of the amplifier. With the conventional five-slug oscillator structure extremely sharp reactance slopes are present and the load impedance can be properly matched to the diode at the single frequency of oscillation and its harmonics, thus yielding device voltage and current waveshapes compatible with higher efficiency.

Conclusions

Wideband TRAPATT amplifiers have been demonstrated at X-band for pulsed applications. For high peak power, short-pulse requirements stacked mesas resulted in significant increases in amplifier peak power. The tuning of TRAPATT amplifiers has been found to be critically dependent on diode package parasitics which must be optimized experimentally for stable operation and maximum bandwidth.

Acknowledgements

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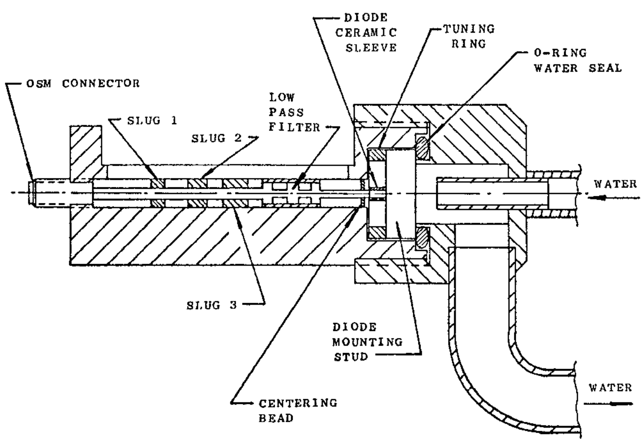

Fig. 1. X-band TRAPATT amplifier.

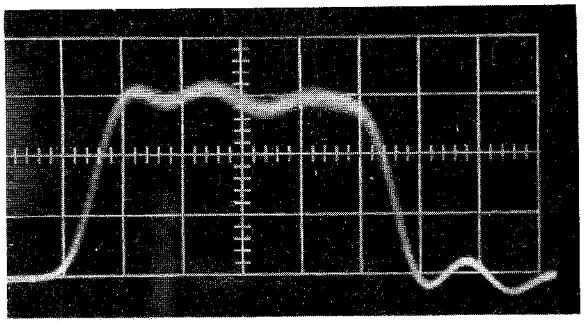

Fig. 2. Detected RF output pulse of amplifier (horizonal scale = 20 nsec/cm).

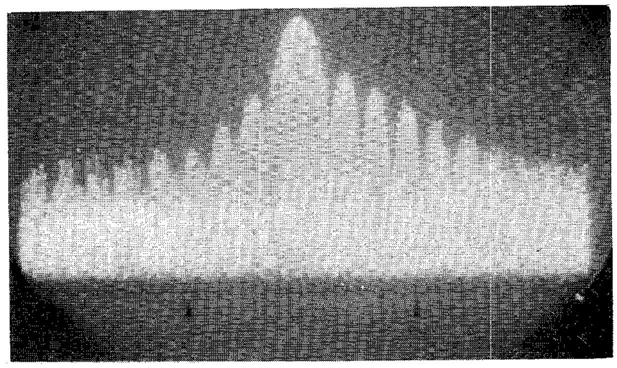

Fig. 3. Spectrum of amplifier RF output (log display).

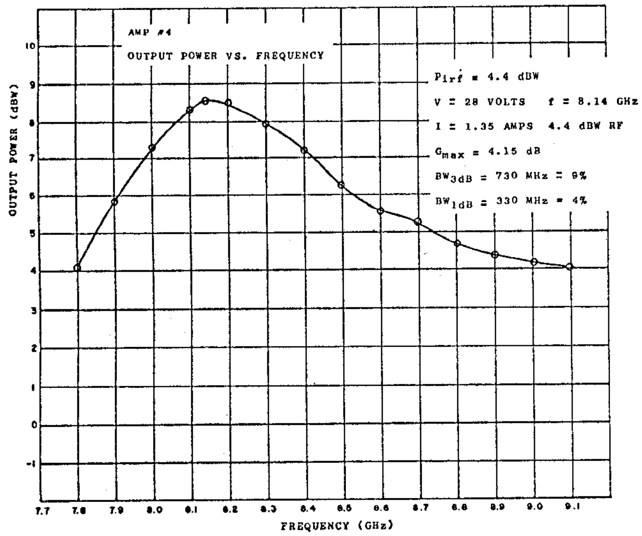

Fig. 4. Amplifier output power versus frequency.

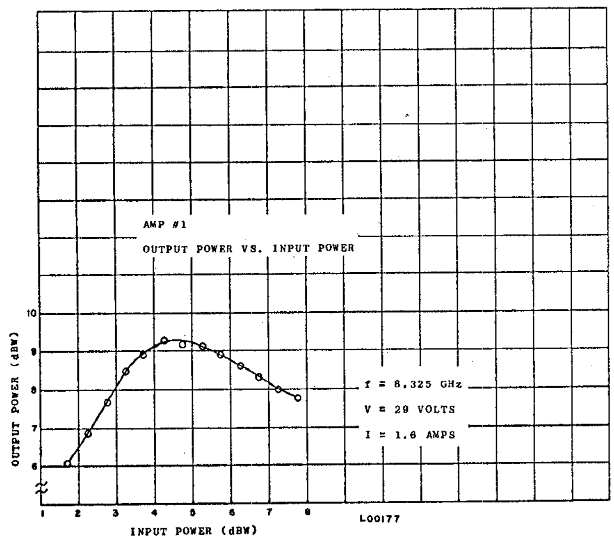

Fig. 5. Amplifier output power versus input power.

TABLE I

PERFORMANCE DATA FOR TRAPATT AMPLIFIERS

UNIT #	DIODE DESCRIPTION	CENTER FREQUENCY (GHz)	BANDWIDTH 3 dB MHz	BANDWIDTH 1 dB MHz	DIODE Po (Watts)	DIODE Gain (dB)	DIODE Eff. (%)	MODULE* Po (Watts)	MODULE* Gain (dB)	MODULE* Eff. (%)
1	Circular Mesa	8.325	390	175	9.8	6.3	16.1	8.5	5.1	12.7
2	Stacked Pair of Circular Mesas	8.350	745	390	33.9	4.9	13.1	29.5	3.7	9.7
3	Ring on Diamond	8.290	855	525	8.3	5.0	12.0	7.2	3.8	8.9
4	Circular Mesa	8.140	730	330	8.2	5.35	15.4	7.2	4.15	11.7
5	Ring on Diamond	8.495	735	310	7.7	4.7	13.3	6.7	3.5	9.6

*Module performance includes losses of circulator, bias tee, and OSM adapter.

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