C-BAND SOLID STATE TWT REPLACEMENT

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ABSTRACT

An all solid state TWT replacement for FM/FDM applications from 5.9 to 6.4 GHz has been developed. Output capability is 10 Watts at 40 dB gain. Gunn effect, IMPATT, and Read diode amplifiers are employed.

INTRODUCTION

The recent development of high efficiency Read-profile IMPATT diodes[1] and their incorporation into microwave amplifiers[2] has made practical an all solid state replacement for medium power traveling wave tubes. A solid state replacement has the immediate advantage of a low voltage (100 V) power supply, in contrast to the more complex and higher voltage (several kV) TWT supply. In addition, the longer life expectancy of solid state amplifiers promises substantial cost savings in the long run.

To drive the Read amplifier to its proper operating level, a Gunn effect input amplifier was used, followed by an IMPATT amplifier employing flat-profile diodes. These driver amplifiers provide low noise operation comparable with TWTs.

In this paper we shall discuss the design of each amplifier in the chain, and the performance of the complete solid state TWT replacement.

AMPLIFIER DESIGN

Overall

In order that the overall noise figure compare favorably with TWT performance (25 dB typical), a high gain Gunn amplifier front end is used. Three IMPATT stages were used to bring the Gunn amplifier output up to the level of 33 dBm required to operate the Read stages efficiently.

Figure 1 summarizes the amplifier design. Nominal noise figures for each Gunn, IMPATT, and Read stage are included, and it is clear that the Gunn amplifier should dominate the noise figure.

Gunn Effect Amplifier

It is well known that stable amplification may be achieved in a GaAs n^{++}-n_o-n^{++} diode if the product of donor density n_o and the active layer width L is less than 10^{+12} cm^{-2} approximately. Diodes of active layer width 14 μm and donor level, 4 to 5 x 10^{14} cm^{-3} were used. The threshold voltage was 5.0 Volts. Above 15 Volts the diodes were stable in the amplifier circuit.

Each amplifier stage consists of an input isolator, a circulator, a double-tuning stub for achieving flat response, a transformer to drive the Gunn diode at the required impedance level, and a stabilizing stub. The three ferrite MICs and the diodes are mounted to a copper circuit carrier. Care was taken to suppress reverse coupling between stages.

IMPATT Amplifier

Raytheon IMPATT diodes were used in the IMPATT amplifier. These diodes are similar to diodes previously used in a C-band amplifier[3] except that the breakdown voltage was about 68 Volts and the capacitance at zero bias was 11 pF. To avoid reliability problems, the IMPATT diodes were biased at 70 to 80 percent of their maximum rated current of 180 mA.

Stage 6 is equipped with a lightly coupled output detector which provides 0.5 Volts during normal operation. This voltage is used to turn on the Read diode voltage regulator during normal operation.

Read Amplifier

Raytheon Read diodes with low-high-low modified Read doping profiles were used in stages 7 and 8. The diodes had initial breakdown voltages of 50 Volts and capacitance at zero bias of 18 pF.

Earlier work on X-band Read diode amplifiers[2] has indicated that operation at high input levels, where the power-added efficiency is high, causes extreme changes in the negative resistance characteristic from the small signal characteristic. The change makes it virtually impossible to design an efficient high power Read amplifier which is stable in the absence of drive. Thus, the DC drive to the Read stages is turned on only when the RF drive exceeds a certain level, about 0.5 Watts.

The non-linearities of the Read diode also tend to produce subharmonic output under conditions of high drive power. A stabilizing resistor followed by a $\lambda/2$ stub is placed in the circuit very close to the Read diode to eliminate spurious output.

The power-added efficiency of the Read amplifier stages is roughly 10 percent for

stage 7 and 15 percent for stage 8.

Complete TWT Replacement

Figure 2 shows an outside view of the complete all solid state TWT replacement. The external dimensions are 9.5" W x 2.4" H x 6.5" D. The input and output waveguide connections are made to CMR 137 flanges. Weight of the unit is 8½ pounds.

Figure 3 shows, from left to right, the Gunn, IMPATT, and Read diode amplifiers, with the covers removed to show an all-ferrite MIC circuitry inside. The center section holds the regulators. Bias voltages of 100 VDC and 28 VDC are brought in from the connector on the left of the unit.

AMPLIFIER PERFORMANCE

The complete solid state TWT replacement unit, designated Model VCM-5016, was tested for use in an FM/FDM communications radio in the range 5.925 to 6.425 GHz. Figure 4 shows the output power across the band for input drive levels of 0 and -10 dBm. The increase of power toward the high end is due primarily to the Read output stages.

Differential phase versus frequency appears in Figure 5. The maximum variation of $\pm 1.2^{o}$/40 MHz is comparable to medium power TWTs. The third Gunn amplifier stage appears to be responsible for a major portion of the phase non-linearity.

AM-to-PM conversion is 6.5^{o}/dB maximum, occurring at the low end, and decreases to 1.6^{o}/dB at the high end of the band.

Second harmonic and other spurious outputs appear to be at least 25 dB down from the carrier with no external filtering. Noise was measured in a noise loading test set, and the following contributions were noted: idle, 4.0 pWpo; 2^{d} order 0.1 pWpo; and 3^{d} order, 1.9 pWpo. The idle and 2^{d} order contributions are comparable to TWT performance.

A power combiner output Read stage, employing two Read diodes, has been designed to boost the output power to 10 Watts. Figure 6 shows the output power at various input levels across the band 5.925 to 6.425 GHz. The increase of power and center frequency with drive level is associated with increased bias current caused by the large signal rectification property of the Read diodes.

CONCLUSION

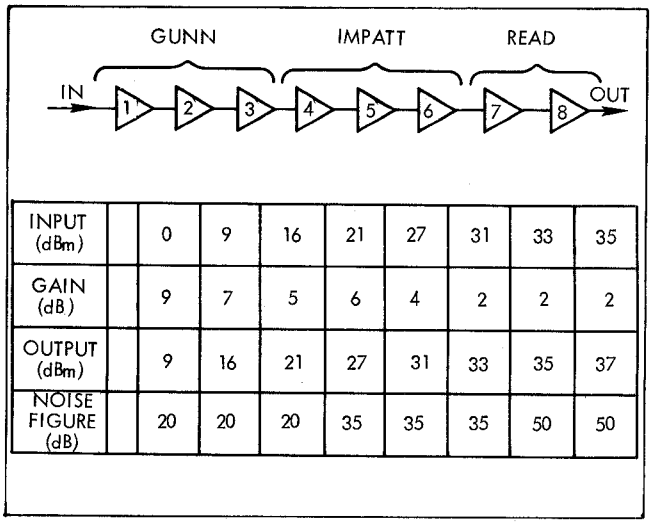
A solid state amplifier has been developed, the performance of which is competitive in most respects to existing TWTs for FM/FDM applications. The use of internal regulators eliminates the need for highly regulated external power supplies. Long term cost savings are expected, due both to the use of solid state technology and to the absence of high voltage power supplies.

REFERENCES

1. C. K. Kim, S. R. Steele, and R. W. Bierig, "High Power, High Efficiency Operation of Read Type IMPATT Diode Oscillators", Electronics Letters, Vol. 9, No. 8/9, May 3, 1973.

2. W. C. Tsai, C. K. Kim, and R. E. Gray, "High Efficiency Read Diode Amplifier", IEEE S-MTT International Microwave Symposium, Atlanta, Georgia, June 1974, pp. 309-311.

3. W. C. Tsai and C. W. Lee, "A C-Band All Ferrite Integrated Wideband High Power GaAs Avalanche Diode Amplifier", IEEE G-MTT International Microwave Symposium Digest, May 1972, pp. 179-181.



INPUT (dBm)	0	9	16	21	27	31	33	35
GAIN (dB)	9	7	5	6	4	2	2	2
OUTPUT (dBm)	9	16	21	27	31	33	35	37
NOISE FIGURE (dB)	20	20	20	35	35	35	50	50

Figure 1 Amplifier Design

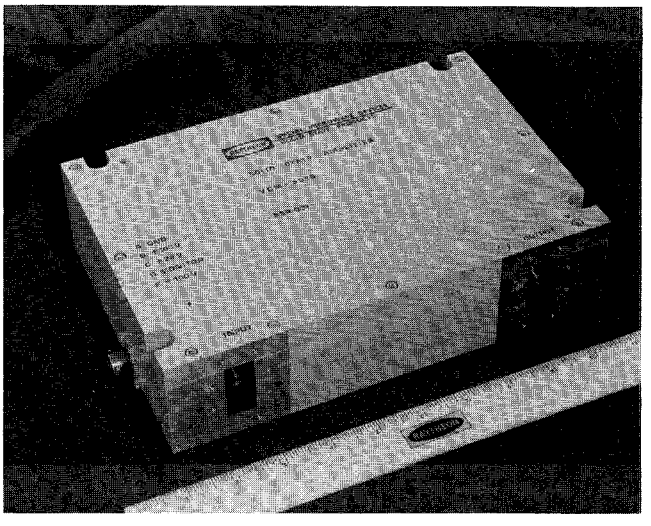


Figure 2 All Solid State TWT Replacement

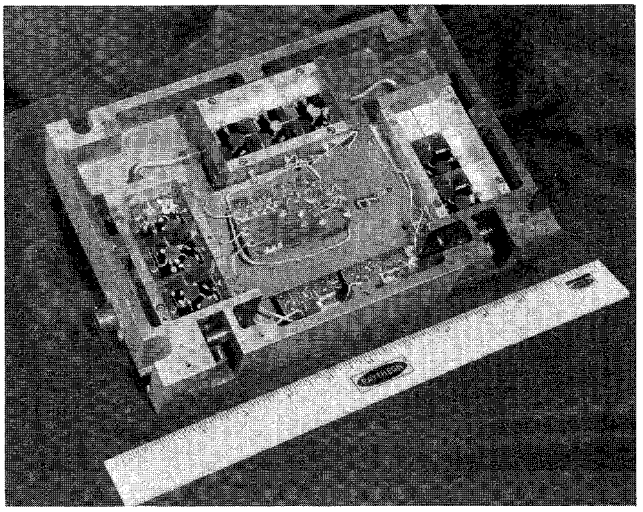


Figure 3 All Solid State TWT Replacement Internal View

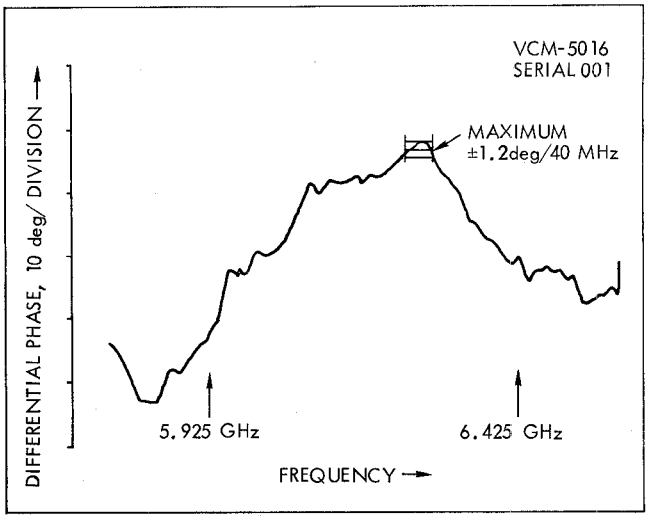


Figure 5 Differential Phase VS Frequency For 5 Watt TWT Replacement

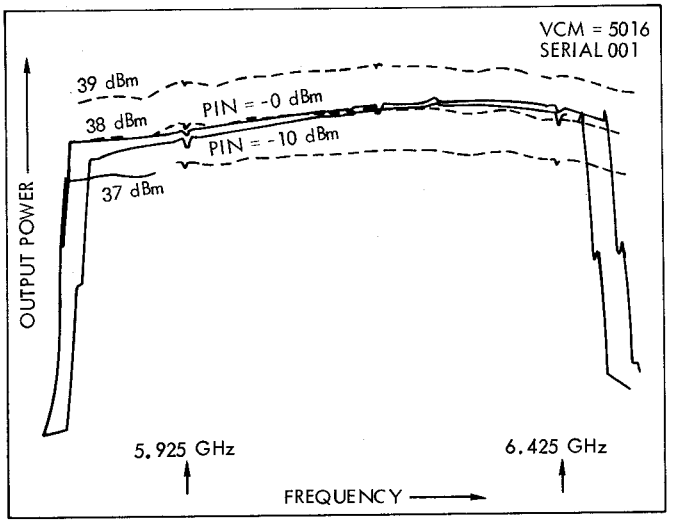


Figure 4 Output Power VS Frequency For 5 Watt TWT Replacement

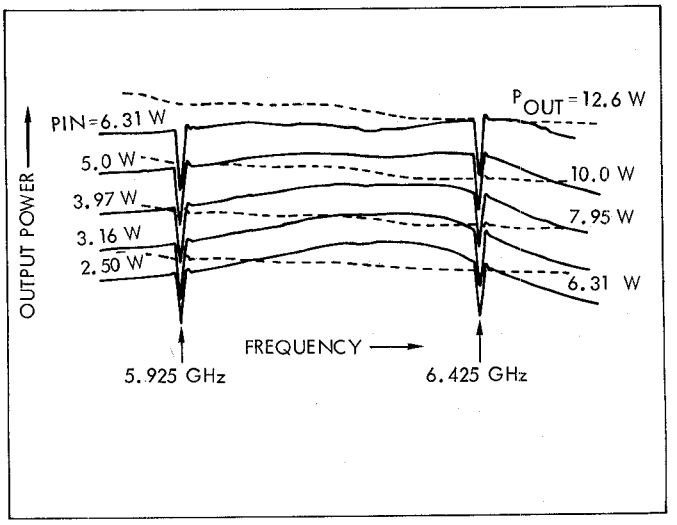


Figure 6 Output Power VS Frequency For 10 Watt Read Power Combiner Stage