A 10-WATT, C-BAND FET AMPLIFIER FOR TWTA REPLACEMENT

Dr. P. T. Ho, C. M. Pham, and R. L. Mencik

Ford Aerospace & Communications Corporation
Western Development Laboratories
Palo Alto, California

ABSTRACT

This paper describes the development and performance of a 10 W, high efficiency FET amplifier to be used in communication satellites for TWTA replacement. This seven-stage MIC power amplifier provides 50 dB gain with DC to RF conversion efficiency of 33.4% at C-band frequency (3.7 to 4.2 GHz).

Introduction

The advances of GaAs Field Effect Transistor technology have pushed the power output capability of the FET to the point where it is competitive with C-band TWTAs [1,2]. Compared to TWTAs, FET power amplifiers offer superior RF performance, weight and size savings, and solid state reliability [3,4]. This paper describes a 10-watt, C-band, 7-stage FET amplifier using commercially available FETs. This power amplifier was designed for space application with emphasis on DC to RF conversion efficiency.

Amplifier Design

A block diagram of the 10-watt, 7-stage amplifier with input and output power level indicated is shown in Figure 1. The completed amplifier consists of a 5-stage driver amplifier and a 2-stage, 4-way power combining output amplifier. Four FETs were used in the output stage to meet power requirements, and the output power of individual FETs is combined using 3 dB interdigitated couplers [5]. The power amplifier is constructed in modular form, each module consisting of two parallel combined power FETs with 5-watt power capability. The input matching circuits and the power dividing interdigitated coupler are fabricated on one single alumina substrate. The output matching circuits and the power combining interdigitated coupler are fabricated on another substrate of the same dimensions. By putting the matching circuits and the coupler on a single substrate, we can reduce the number of substrates for each parallel power combined amplifier module from six to two, significantly lowering the manufacturing cost. The circuit can also be layed out more efficiently on the substrate to reduce the size and weight of the amplifier. The output power amplifier consists of three 5-watt modules, each of which was assembled and tested individually before integration. Figure 2 is a photograph of the 10-watt, 2-stage, 4-way power combining output amplifier. To maximize amplifier efficiency, all the FETs in the output amplifier stage are operated in Class AB mode with output matching circuit matched for best possible efficiency. This 2-stage output amplifier provides 10 dB gain with power added efficiency equal to 37.1%.

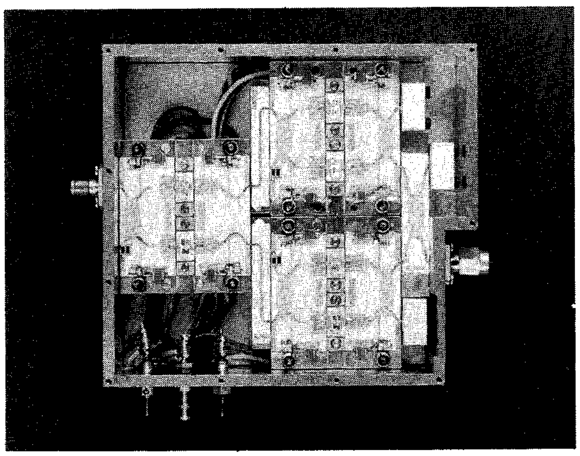

Figure 2. Photograph of the 2-Stage, 4-Way Power Combining Output Amplifier

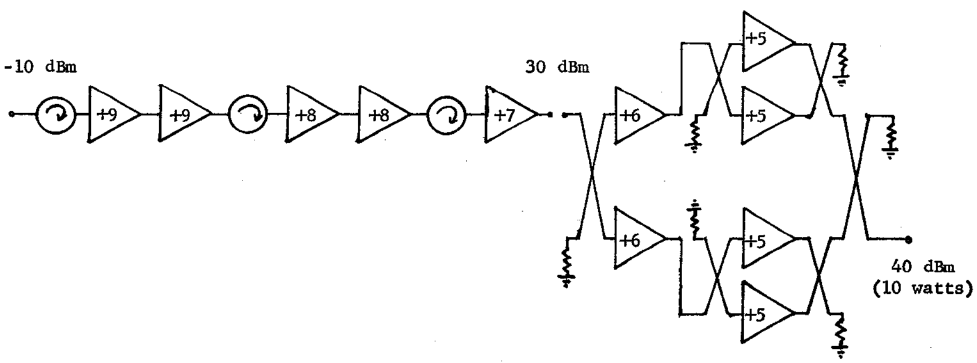

Figure 1. Block Diagram of the 10-Watt, 7-Stage FET Amplifier

Single ended approach was chosen for the driver amplifier to reduce overall power consumption. The driver amplifier is made of five FETs with integrated circulator. To minimize the linearity impact of the driver stage on the overall amplifier performance, the FETs in the driver amplifier were operated in linear Class A mode. The 10-watt TWTA replacement FET amplifier is packaged in two separated chassis, both of which are mounted on a common platform. Figure 3 is a photograph of the completed amplifier.

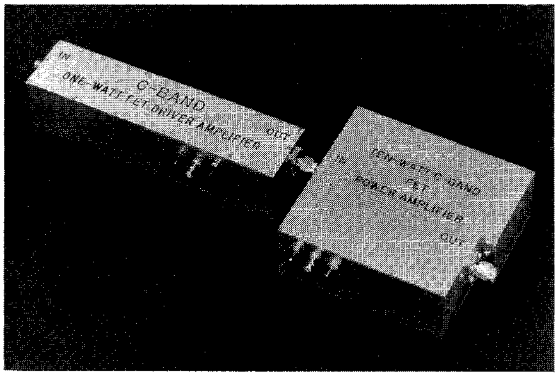

Figure 3. Photograph of the Complete 10-Watt, 7-Stage FET Amplifier

Amplifier Performance

Table 1 summarizes the performance of the 10-watt TWTA replacement FET amplifier. The power transfer function and the power conversion efficiency of the amplifier are shown in Figure 4.

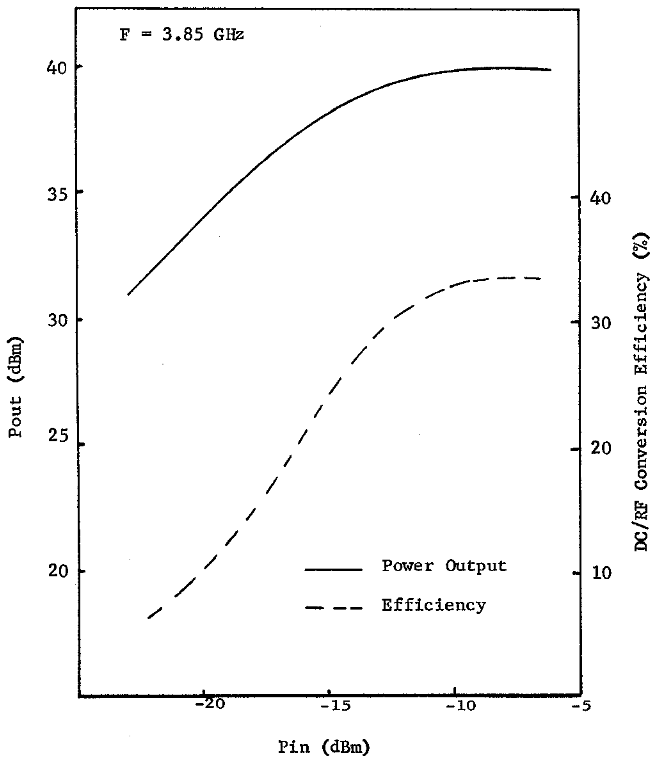

Figure 4. Power Transfer Function and Power Conversion Efficiency of the 10-Watt FET Amplifier

The amplifier has a small signal gain of 53 dB with saturated output power of 10 watts. The overall DC to RF power conversion efficiency is 33.4%. This is comparable to the efficiency of the single collector TWTA used at C-band frequency in many of today's space programs. The intermodulation distortion of the amplifier was measured with two equal amplitude carriers 2 MHz apart. Figure 5 depicts the results of the two tones measurement. At 1 dB back-off from saturation, the third order intermodulation distortion is -16 dBc. Compared to the TWTA, the solid state amplifier shows 3 dB improvement in the carrier to third order intermodulation ratio. The AM/PM conversion of the FET amplifier is less than 3^o/dB over the input dynamic range of -30 dBm to -5 dBm, which again is superior to the 7^o/dB of an equivalent TWTA.

Table 1
Performance of the 10-Watt, TWTA Replacement FET Amplifier

Parameters	Performance
Overall frequency band	3700 to 4200 MHz
Center frequency of channel	3850 MHz
Channel bandwidth	40 MHz
Saturated output power	10 W
Gain at saturation	50 dB
Bandpass flatness	0.2 dB/40 MHz
DC/RF efficiency	33.4%
C/IMD(3) at 1 dB power back-off	16 dB
AM/PM coefficient	3^o/dB
Input/output VSWR	1.2

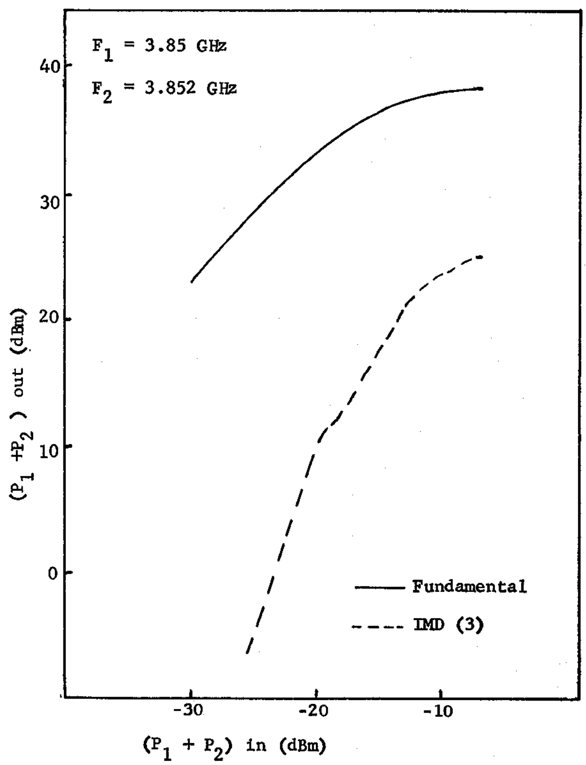

Figure 5. Intermodulation Distortion Product of the 10-Watt FET Amplifier

The bias sensitivity of the amplifier was measured by adjusting the FET drain and gate bias voltages independently. The test data indicates that the amplifier is sensitive to the gate voltage variation and is not sensitive to the change in drain voltage. The gain of the amplifier decreases by 0.3 dB and phase shift increases by 2.7° for every 0.1 V increase in the gate bias voltage, while the amplifier gain drops only 0.1 dB with phase shift decreased by 0.7° for every 0.1 V increase in drain voltage.

The completed FET amplifier was evaluated over a wide range of operating temperatures (-15° C to +55° C). With no temperature compensation circuitry, the small signal gain of the amplifier changes by 7 dB, and the saturated power output of the amplifier varies by 1 dB. The intermodulation distortion products stay fairly constant over the temperature, with slight improvement at -15° C because of the increased power output capability of the FET at this low temperature. The maximum AM/PM conversion stays approximately the same over the measured temperature range.

Reliability

One of the advantages of the power FET amplifier over TWTAs is higher reliability with simpler power supply requirements. TWTAs have exhibited fabrication problems, cathode degradation, high voltage breakdown, potting problems, and a sensitivity to power on/off cycling. In addition, TWTAs require high voltage power supplies, which have contributed to the failure of many TWTAs (ie, failure to turn on and premature shut-down). The FET amplifier can be built with a relatively simple low voltage power supply. Based upon step stress test of the FET, the device has demonstrated acceptable mean time to failure (MTTF) rate of 10^7 hours at a normal operating junction temperature of 110° C. Using space qualified parts and established failure rates, reliability analysis indicated that the failure rate of the FET power amplifier is about half that of the TWTAs. Figure 6 shows the RF life test data of a C-band, 7-watt, 3-stage FET amplifier [6]. This 7-watt amplifier uses serial power combining techniques to combine three FETs at the output stage. The amplifier chain operates at elevated ambient temperature of 50° C with FET channel temperature equal to 100° C. Over 9,000 hours of RF life test data have been accumulated. No changes were observed in RF output power or DC bias current.

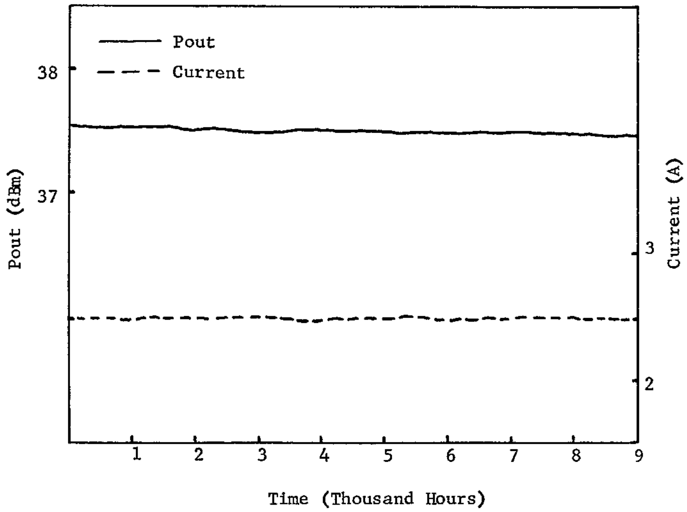

Figure 6. RF Life Test Data of 7-Watt, 3-Stage FET Amplifier

Conclusion

Excellent performance of solid state power FET amplifiers has been demonstrated. This 10-watt, C-band engineering model delivers 10 watts of output power, 50 dB gain, and 33.4% DC to RF conversion efficiency. The FET amplifier shows excellent limiting characteristic under overdrive. At both saturation and power back-off, the FET amplifier is superior to the TWT amplifier in linearity. With additional advantage in amplifier weight and size, a C-band FET power amplifier is an ideal candidate for TWTA replacement in future communication satellites.

References

1. H. Suzuki, K. Suyama, and M. Fukuta, "GaAs Power FET," Fujitsu Scientific & Technical Journal, June 1976.

2. J. V. DiLorenzo, "GaAs FET Development--Low Noise and High Power," Microwave Journal, Vol. 21, No. 2, February 1978.

3. P. T. Ho, M. D. Rubin, and J. G. Wherry, "Solid State Power Amplifiers in Communication Satellites," AIAA 7th Communications Satellite Systems Conference, San Diego, California, April 1978.

4. C. L. Cuccia and P. T. Ho, "The Impact of the FET on the Satellite Transponder--A Technology Perspective," AIAA 7th Communications Satellite Systems Conference, San Diego, California, April 1978.

5. J. Lange, "Interdigitated Strip-Line Quadrature Hybrid," G-MTT International Microwave Symposium Digest, May 1969.

6. P. T. Ho, "A 7-Watt C-Band FET Amplifier Using Serial Power Combining Techniques," Symposium Digest, 1978 IEEE MTT-S International Microwave Symposium, Ottawa, Canada, June 1978.