The Design of a Linear L-Band High Power Amplifier for Mobile Communication Satellites

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ABSTRACT

This paper describes a linear L-band solid state high power amplifier designed for the space segment of the M-SAT mobile communication system. This amplifier has been developed by SPAR AEROSPACE LTD with support from the Canadian Government. It is capable of producing 35 Watts of RF power with multitone signal at an efficiency of 25 % and with intermodulation products better than 16 dB below carrier.

INTRODUCTION

The high power amplifiers that provide the L-band downlink power are the most critical elements of the mobile satellite payload. Since 1980 SPAR has gained a solid understanding of the design implications for such amplifiers.

A number of linear HPA's have been designed and built, reflecting the evolution of the M-SAT regulatory issues, one rated at 100 Watts operating at 866 to 870 MHz[1], one at 50 Watts operating between 1.545 and 1.555 GHz[2] and one at 35 Watts operating between 1.530 and 1.559 GHz. The first two designs utilize bipolar power transistors, the third GaAs MESFETs (of which a total of six have been built). In addition to this work, various high efficiency techniques have been evaluated.

The subject of linear high power amplification is complex and requires a high degree of analytical capability particularly in the area of the evaluation of the multicarrier nature of the signal and its impact on the design. Sophisticated test set-ups are required to accurately simulate this multicarrier signal.

Key design parameters in addition to efficiency and linearity are overdrive and mismatch protection, phase and gain tracking between the amplifiers and multipaction elimination.

This paper presents design details of the GaAs FET amplifier together with measured performance.

DESIGN CONSIDERATIONS AND REQUIREMENTS

Linearity and Efficiency

Linearity must be defined in the context of the specific signal being amplified. The signal to be amplified will consist of many individual carriers spread randomly across a 29 MHz band centered at 1.5445 GHz. The resulting signal envelope will have a noise-like amplitude profile and contain frequencies from DC to 29MHz. The amplifier must be capable of processing this signal without distortion of its amplitude and frequency make-up.

In practice, some degree of distortion is acceptable allowing an increase in efficiency.

Overdrive and Mismatch protection

Because the amplifier will have to operate below saturation for linearity reasons, there is a potential risk of an above nominal demand for DC power. Clearly this cannot be allowed to happen where more than 75% of the total payload DC power is used by the HPA's. The amplifier must therefore contain a means of accurately controlling power demand, without degrading linearity.

The amplifier should be capable of surviving an open or short circuit at its output. (Note that this is usually achieved with an output isolator which also assure a good output impedance, but because of uncertain phase characteristics and a relatively high insertion loss, its use is considered undesirable.)

Phase and gain tracking

The M-SAT satellite employs a multi-beam concept where groups of up to 8 HPA's are embedded between hybrid matrices. For each amplifier's signal to split and combine efficiently, the dynamic gain and phase characteristics of each amplifier must be closely matched under all conditions.

Multipaction

The likelihood of multipaction breakdown within the unit is high considering the power levels involved. The design must be such that this phenomena cannot occur.

Power Converter

An Electronic Power Converter (EPC) is required to provide the amplifier's specific supply voltages from the spacecraft's power bus, to receive telecommands and to provide the interface for telemetry signals.

DESIGN APPROACH

The first L-Band HPA used 35 Watt bipolar transistors employing dynamic bias [2]. The major problem with this approach was the degradation of linearity as envelope bandwidth increased beyond 10MHz. In addition its complexity, hence reliability projections were disturbing.

The decision to undertake a new design in late 1987 (in reaction to the WARC-MOB'87 allocation of 29MHz) coincided with the introduction of a 20 Watt GaAs MESFET. Despite having a significantly lower power output than bipolar, the FET has intrinsic linearity, higher gain, lower thermal resistance, is relatively simple to bias, hence is an attractive alternate. Fundamental differences between the two devices result in the comparison of a complex and sensitive design (bipolar) with a simple stable and reliable one (FET).

Past experience, which included knowledge of efficiency enhancing and linearization techniques, enabled a sensible evaluation of the options. It was concluded that the best approach for the next version of HPA would be to use GaAs FETs in a simple Class A-B configuration.

The design activities were initiated by a thorough evaluation of 20 Watt L-band GaAs MESFETs. Devices from two manufacturers were tested, with similar results. The evaluation process involved the determination of quiescent (drain) current and the gate and drain wideband impedance characteristics commensurate with linearity and efficiency. This was carried out through extensive measurement characterization processes with the help of automated test systems in conjunction with non-linear computer analyses. This evaluation process considered the inherent idiosyncratic behavior of GaAs FETs, particularly when biased in Class B, such as low frequency oscillations, memory of saturation, etc.. From these results, the optimum operating conditions were determined and an output amplifier module was designed and tested. Results from this module indicated that it would be possible to meet the basic requirements by combining four such modules in parallel.

UNIT ELECTRICAL DESIGN

The block diagram of the complete amplifier is shown in Figure 1. All the active devices of the RF chain are GaAs MESFETs sharing two common supply lines of -10 and +10 Volts.

The first module is a wideband L-Band amplifier (A1) designed with two cascaded GaAs MESFET devices. It has 20 dB of gain with a 1 dB compression point of +19 dBm.

Module A2 is a voltage controlled attenuator which not only limits the drive signal when necessary, but also provides the means to compensate unit gain change with temperature, and to accurately set the initial gain. It is followed by a voltage controlled phase shifter (A3) that allows initial setting of the unit's phase and provides compensation for phase changes with temperature.

Module A4 is a medium power amplifier with a GaAs MESFET biased in Class A. It provides a gain of 14 dB with a saturated output power above +27 dBm. It is followed by a 10 Watt GaAs MESFET amplifier (A5) biased in Class A-B that provides 13.5 dB of gain.

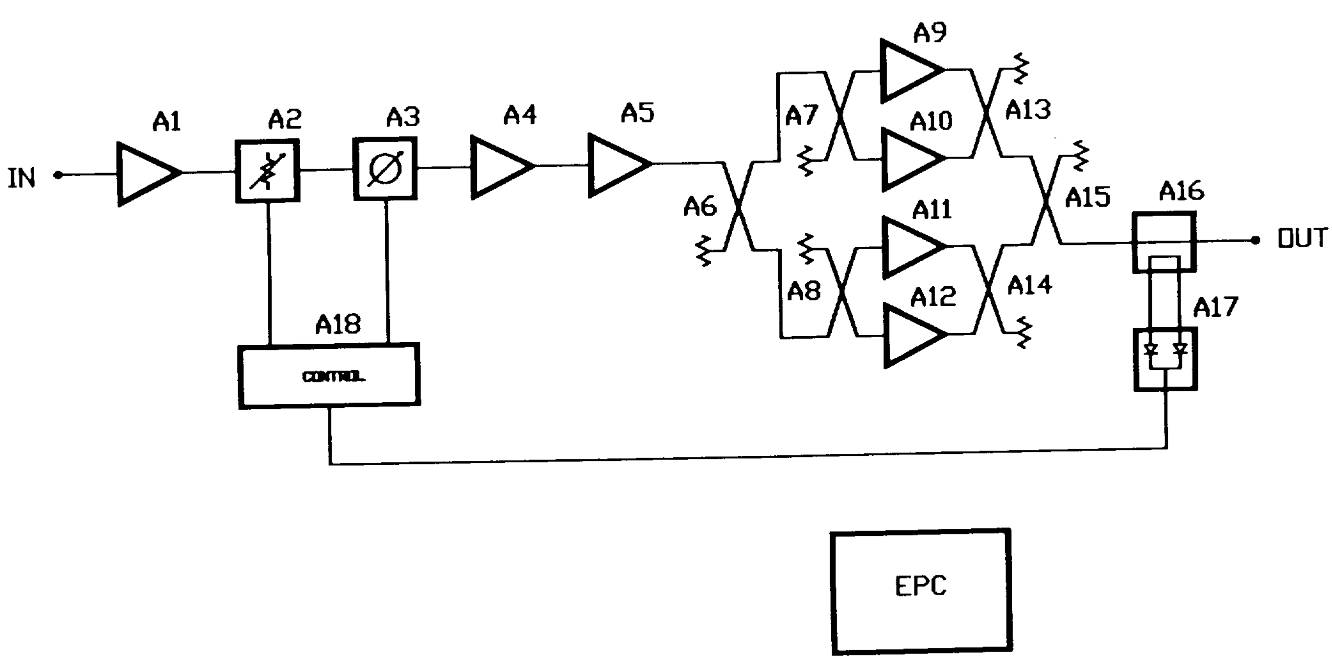

Figure 1: Block diagram of the amplifier

Four identical output modules (A9 to A12) as described above, are then combined in parallel using Lange couplers for power splitting and combining. The efficiency was optimized by careful selection of the operating point and bias impedances, along with an output matching circuit that reflects the second and third harmonics back to the device with the appropriate phases [3].

A bi-directional low loss coupler (A16) having 25 dB directivity, allows accurate signal detection for both incident and reflected power. Detection is achieved using two pairs of Schottky barrier diodes biased in their square law region (module A17). In each pair, one diode provides temperature compensation. Processing of the detected signals is accomplished in module A18, which provides output power telemetry and the control signal to the attenuator A2. A commandable override of the control signal is included. Module A18 also provides the control signal to the phase shifter A3.

The design of the Electronic Power Converter reflects the latest development in power conversion techniques. The main features of the EPC are, a high frequency of operation to minimize weight and size, excellent output load and line regulation, high efficiency (above 87% at full load), high reliability, low conducted and radiated emission levels, short circuit protection, sequential start-up to protect the HPA, and input/output monitoring.

MECHANICAL DESIGN

The HPAs' compartmentalized housing is of cast aluminium. The four output modules A9-A12 are mounted onto a common plate which is fitted into the unit from the bottom, forming the baseplate of the unit. This approach is used as the power transistors are soldered to the baseplate to obtain a well defined thermal resistance. By having a removable section, the assembly and test tasks are simplified.

RF modules are built with MIC hybrid techniques using alumina substrates mounted on kovar carriers. Packaged surface mount components are used in conjunction with circuit functions realized in microstrip transmission lines on alumina substrates.

The EPC consists of a printed circuit board assembly mounted on top of the RF chassis, the floor of the EPC forming the cover of the RF section. Connections between the two sections are achieved by hard wiring.

The dimensions of the overall HPA/EPC unit shown in Figure 2 are 28.2 cm long by 16cm wide by 6.9 cm high. The mass of the breadboard unit before weight relief is 2.9 Kg.

MEASURED PERFORMANCE

The unit development program has resulted in the production of two breadboard units and four 'quasi-engineering models'. Test results are summarized in Table 1.

All HPA's meet the basic requirements of output power, efficiency, linearity and gain. Temperature tests performed on the four QEM's show that the gain and phase tracking between units over temperature and power level are within 0.6 dBpp and 20^{o}pp respectively.

Note that the HPA's meet both input and output return loss requirements without using an isolator. Output return loss is ensured by the balanced structure of the four output modules. It has been measured with two different approaches, one by injecting a signal at the output at a different in-band frequency, and the other by performing a load pull test. Both methods confirmed a 20 dB return loss across the frequency band and over the dynamic range.

Table 1
L-Band HPA Requirements and Measured Performance

Parameter	Target	Measured
Operating Frequency Range	1.530-1.559 GHz	1.530-1.559 GHz
Nominal Output Power	35 Watts	35 Watts
Peak Output Power		80 Watts
Gain	50 dB	50 dB
Efficiency (with EPC)*	25 %	25 %
Intermodulation distortion *	16 dB NPR	16 dB NPR
Gain vs Temperature (per 10^oC) (-5oC to 55^oC)	0.3 dB_{pp} 0.5 dB_{pp}	0.2 dB_{pp} 0.5 dB_{pp}
Gain Tracking between units	0.6 dB_{pp}	0.6 dB_{pp}
Phase Tracking between units	$28^o{}_{pp}$	$20^o{}_{pp}$
Mass (Breadboard) (Flight Model)	 2.6 Kg	2.9 Kg
Input / Output Return Loss	20dB min.	> 20 dB
Noise Figure	10 dB max.	6 dB at 60^oC
Spurious Modulation	-57 dBc max.	-68 dBc
Overdrive Level above nominal Duration Maximum RF Output Maximum DC Power	 up to 21 dB indefinite 40 Watts 155 Watts	 up to 25 dB indefinite 40 Watts < 155 Watts

* Measured at Nominal output power with a noise signal of 29 MHz bandwidth

The overdrive and output mismatch protection features of the HPA were tested successfully. The HPA showed no degradation in linearity (noise intermodulation) when overdriven by 25 dB. Under this condition, the output power is automatically limited to 40 Watts. The amplifier also proved that it can withstand an infinite VSWR on its output port for an indefinite time without any degradation. When submitted to such a condition, the protection loop attenuates the signal such that the amplifier is working almost at quiescent power.

Areas within the unit where multipaction is most likely to occur are the microstrip to non-microstrip signal interfaces. Representative sections of the unit were built and tested in vacuum at levels at least 6dB above the highest expected power. In addition, the Lange coupler and the directional coupler were both tested at 180 Watts. No evidence of breakdown multipaction was detected.

CONCLUSIONS

This paper has presented the key design considerations for a spaceborne linear high power amplifier. Using GaAs FET's as the key device, not only is the resulting amplifier's performance satisfactory, but the design is conceptually simple. In conjunction with the inherent reliability of the FET, this results in a unit that is optimum for space application.

REFERENCES

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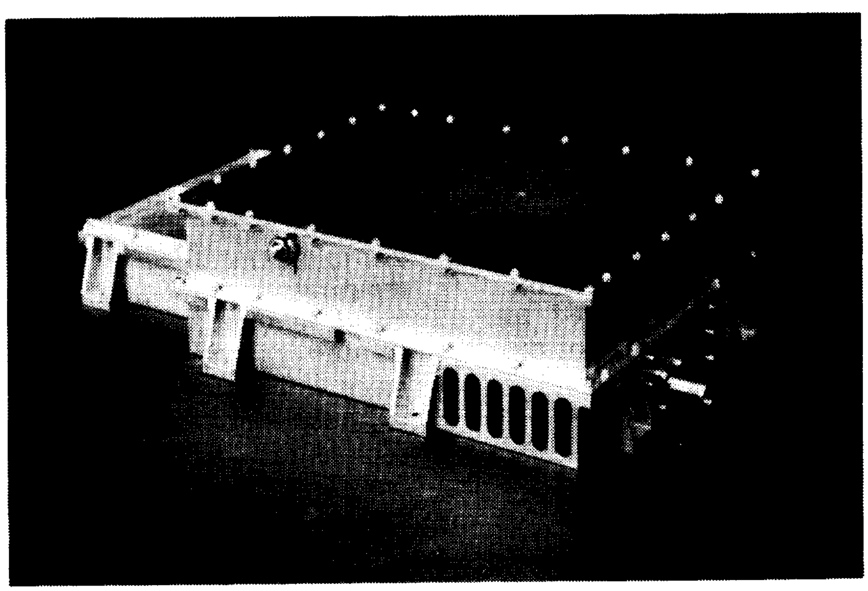

Figure 2: Overall HPA/EPC unit