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A 5.5 WATT 20 GHz SOLID STATE POWER AMPLIFIER FOR ON-BOARD SATELLITE COMMUNICATION

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ABSTRACT

A Solid State Power Amplifier for on-board applications in the 20 GHz down-link frequency band is presented.
An output power of 5.5 Watts with 47 dB gain and 17 % DC to RF efficiency have been achieved combining in parallel six 1.0 Watt power FET's by means of a novel very low-losses and extra-small waveguide power divider/combiner.
The overall unit, including Electronic Power Conditioner, results compact and reliable: an attractive solution as replacement for Ka-band Travelling Wave Tube Amplifier in space.

INTRODUCTION

Solid State Power Amplifiers (SSPA) result to be a very attractive solution in space applications for their size, weight, reliability, and simpler power conditioner compared to the Travelling Wave Tube Amplifiers (TWTA). The recent years have seen great improvements in the characteristics of power FET's realized on GaAs substrate (GaAsFET) and several Watts are now available from devices operating in the frequency range from the L-band up to the X-band [1], [2].
Nevertheless, at higher frequencies , it is still necessary to combine several single power GaAsFET's by using an appropriate power combining technique and employing an effective linearizing system in order to obtain significant power from the SSPA with good efficiency.
In the sphere of ESA contracts and in view of future exploitation of on-board SSPA for K-band applications, an amplifier, completed with EPC, has been realized by SIEMENS TLC Laboratories. Other critical aspects, such as size, weight, thermal dissipation and hermeticity have been investigated and optimized as well realizing in this way a state-of-the-art unit fully qualified at space-grade level.

POWER DEVICES AND AMPLIFIER DESIGN

Two families of parts, suitable to be employed in space programmes, are presently capable of covering in the K-band a range of output power from 100 mW to 1 Watt: the RPK series munufactured by Raytheon (US) and the EC series produced by Thomson (F).

The most powerful GaAsFETs of each series have similar characteristics: gate lenght of 0.5 um, periphery gate lenght of 2400 um, GaAs substrate thickness of 25 um and via-hole source connections. In the same line-up the two series can be employed indifferently, so that the double source for the most critical devices can be assured.
Samples of FET's in chip form (size 1400 x 350 um) were characterized in terms of S-parameters at different biasing conditions in different frequency ranges, so to extrapolate a model and simulate the non-linear behaviour of the device approaching the compression point [3].
A single power stage was then implemented for testing on a miniaturized carrier (only 5 x 6 mm): great care was taken to avoid undesired resonances of input/output matching networks realized on thin film Alumina substrates.
The choice of the carrier material was also studied so to maintain good thermal dissipation and compatibility with the thermal expansion rate of Alumina.
An output power of 30 dBm with 5.5 dB of associated gain and 25% of power added efficiency were finally measured (see Fig. 1).

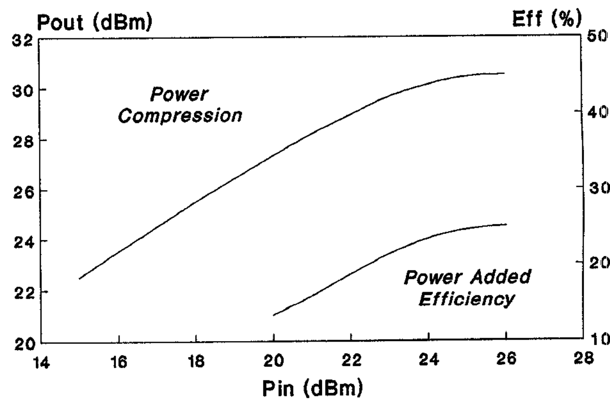

Fig. 1 - 1.0 Watt Single Power Stage

Considering that an available gain of +5.5 dB is enough to recover a division by three (corresponding to -4.8 dB), an optimum paralleling configuration was defined: in facts, a power stage can drive effectively other three

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power stages assembled in a power module, leaving also the margin for combination losses, temperature variations and packaging losses.
Two power modules, for a total of six devices (see Fig. 2) were therefore combined in parallel to obtain the required power from the SSPA.

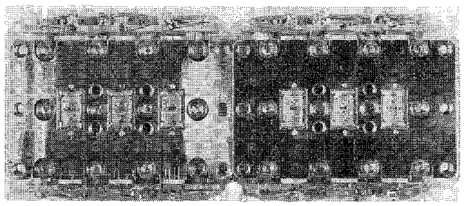

Fig. 2 - Power Modules Assembling

The complete block diagram of the 20 GHz SSPA is finally shown in Fig. 3, whereas a picture of the low level section is given in Fig. 4.

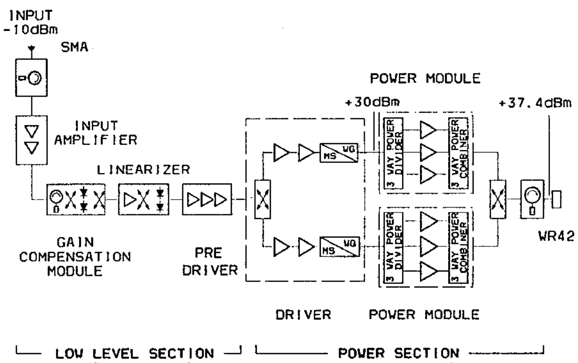

Fig. 3 Amplifier Block Diagram

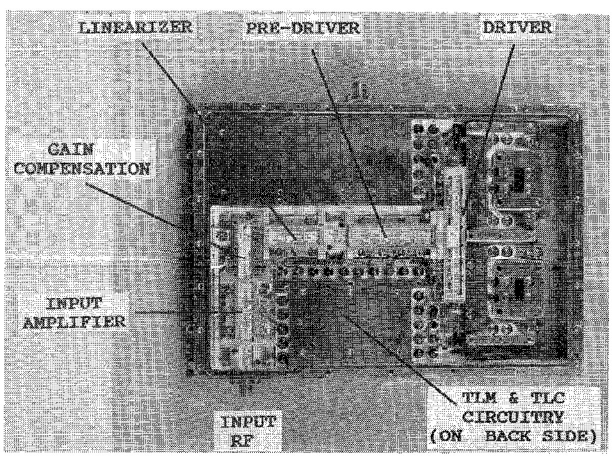

Fig. 4 - Low Level Assembling

POWER DIVIDER/COMBINER AND LINEARIZING TECHNIQUE

One of the critical aspects in paralleling several power stages is the proper combining technique, since output losses heavily affect the performance of the amplifier [4].
A novel 3-way waveguide power combiner (see Fig. 5) was therefore studied and optimized by means of a powerful electromagnetic simulator, such to offer excellent electrical characteristics together with extra small dimensions [5].

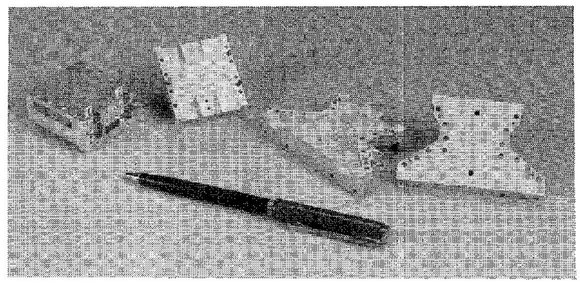

Fig. 5 - 3-Way and 2-Way Waveguide Combiners

It consists of a six ports junction: the three output ports are on one side, whereas the input and the two isolated are on the other. The theoretical behaviour can be deduced writing the 6 x 6 S-parameter matrix and applying the relevant conditions [6]. No tuning was necessary to adjust the performance: excess through losses were measured to be less than 0.1 dB with negligible unbalances, while return losses and isolation among all ports are better than -20 dB.
It should be noted that each divider/combiner section sizes only 40 x 43 x 25 mm (the weight is 60 g.) to interface a power module housing three power GaAsFET.
Fig. 6 shows the power section assembling including the driver module, two final power modules, the 2-way output combiner and the output isolator.

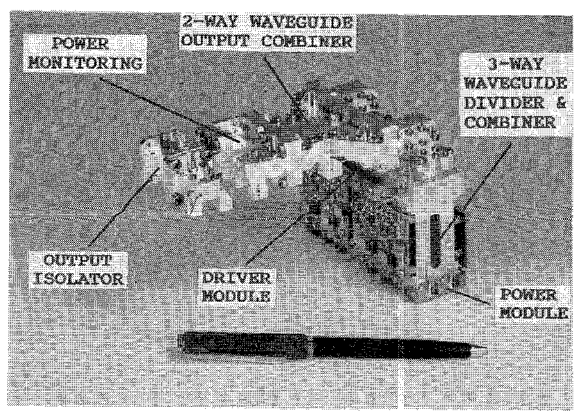

Fig. 6 - Power Section Assembling

The power section performance are given in Fig. 7.

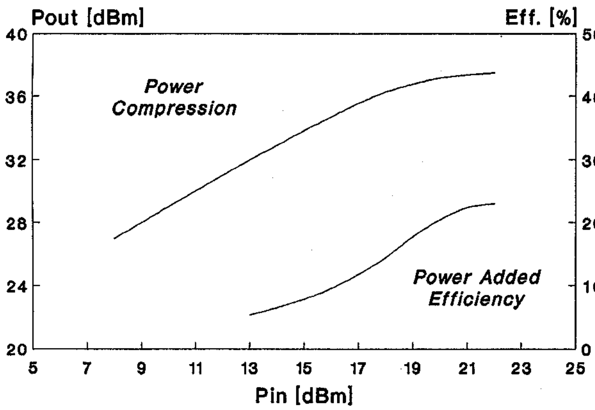

Fig. 7 - Power Section Performance

Efficiency is another aspect to be evaluated in SSPAs for space applications because power is costly and difficult to dissipate: in this light, compensation of AM/AM and AM/PM is used to decrease the intermodulation products which determine the Output Back Off (OBO) of the amplifier.
On the basis of past experience in SIEMENS TLC laboratories, a very simple linearizer module was realized (see Fig. 8) employing predistorting method. A medium power FET is biased near the pinch-off region such to modify its gain characteristic: if the input power increases, the drain current also increases and, as a consequence, the power gain of the device grows. This expansion gain, input-power dependent, compensates the AM/AM characteristic of the overall amplifier. Moreover, the variation of the drain voltage drives istantaneously a varactor phase shifter in order to recover the AM/PM behaviour of the amplifier.
Adjusting the gate bias of the FET and the varactor quiescent voltage, the two AM/AM and AM/PM distortions can be indipendently compensated [6].

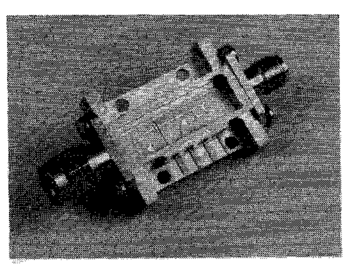

Fig. 8 - The Linearizing Module

ASSEMBLING AND SSPA PERFORMANCE

The assembling was studied in order to optimize the thermal dissipation without giving up compactness.
Accordingly, the most dissipative elements, i.e. the DC/DC converter and the RF power section, are placed on the bottom of the main box, whereas the low level RF part and the telemetry and telecommand circuitry are on the top.
Finally, the waveguide output combiner, the isolator and the output power monitoring are mounted on the top cover.
A special waveguide to microstrip adapter (patent pending) including the biasing filter was studied so to obtain a high packaging density for the power stages.
Consequently, a simulation by means of finite element method (see Fig. 9) was also performed in order to access the operating thermal conditions of the power modules.

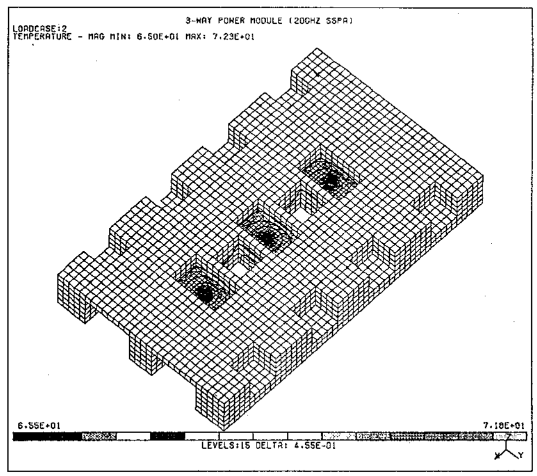

Fig. 9 - Power Module Thermal Analysis

The packaging of the RF parts employs a consolidated technology in SIEMENS TLC, making use of hermetic micromodules machined out of Vacoon 20 and Cu/W respectively for low and high power hybrids.
Concerning the reliability aspect, a preliminary analysis evidenced a failure rate of the SSPA (400 FIT including power conditioner) quite lower than a TWT Amplifier (2000 FIT) [7].
In addition, it should be pointed out that, due to built in decoupling provisions, a soft degradation would occur in the SSPA, should a single power stage undergo a failure.
The overall unit resulted compact and rugged, sizing 153 x 190 x 97 mm with a weight of 1800 g (see Fig. 10).
The SSPA has been characterized over the frequency range 19.7 - 20.2 GHz: output power is 5.5 Watt with a very flat response as shown in Fig. 11. Intermodulation test results are given in Fig. 12.
The gain of the SSPA is 47 dB with a total DC to RF efficiency of 17%.

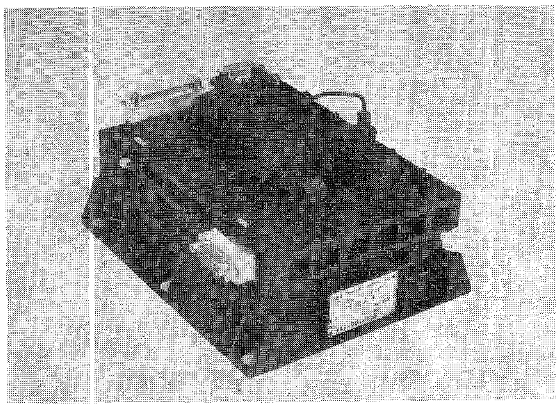

Fig. 10 - 20 GHz SSPA

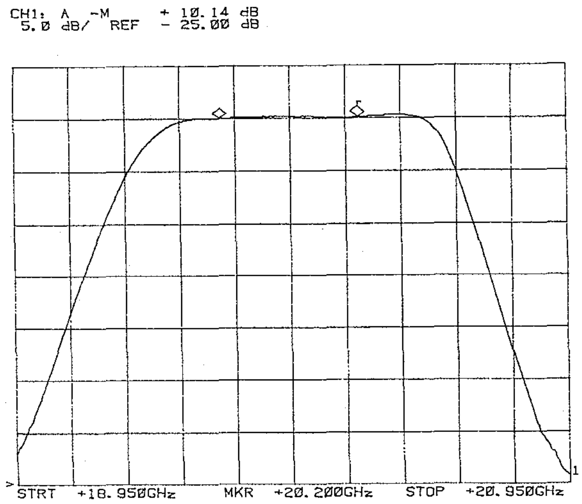

Fig. 11 - SSPA Frequency Response

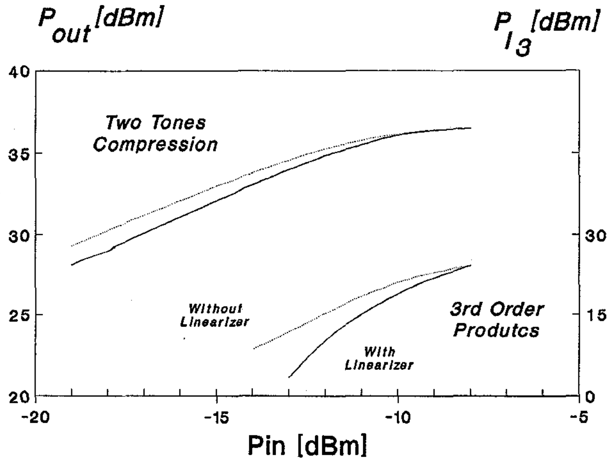

Fig. 12 - SSPA Linearization

CONCLUSIONS

An efficient SSPA for space application has been presented: an output power of 5.5 Watts was obtained in the frequency range 19.7 - 20.2 GHz with 17% of DC to RF efficiency by means of novel very low-losses and extra-small waveguide power divider/combiner.
Considering its compactness, reliability and electrical performance it represents an attractive solution as replacement for low power Ka-band TWTA in space applications.

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