X-BAND 22W SSPA FOR EARTH OBSERVATION SATELLITE

M. Zoyo, N. Cartier, J.Y. Touchais, P. Maynadier,
E. Midan, P. Sgard, H. Buret, M. Peschoud

Alcatel Space Industries
BP1187 26 av. J.F. Champollion 31037 Toulouse, FRANCE
Phone: +33.(0)5.34.35.45.43, Fax: +33.(0)5.34.35.69.47
E-mail: Marc.Zoyo@space.alcatel.fr

***Abstract* — An X-band high power Solid-State Power Amplifier (SSPA) using power HFET chip devices has been successfully developed for the earth observation satellite payload of the SPOT 5 program.**
The use of MMIC chips for the low power section allows to decrease significantly the mass and the size of this equipment and to reduce the production cycle due to the reduced tuning effort.
The hybrid technology is used in the driver module and the power level section because it is attractive in terms of power and efficiency performances.
This SSPA exhibits an output power of 22 watts with DC power consumption less than 91W. The output power is regulated by an ALC loop for input power between -20dBm and +15dBm.

I. INTRODUCTION

Thanks to the advantages of SSPAs in term of better reliability, light weight and small size with regard to the TWTA [1], they are used in many space applications as communication satellites [2], navigation satellites [3] and now for the earth observation satellites.
Recently, significant investigations have been made to develop high efficiency High Power Amplifiers (HPAs) at X-band [4].
The whole low level RF chain is realised with MMIC chips which allow a maximum integration of microwave functions in a small surface, except the end stage of the driver module for which the use of power transistor chips is necessary to obtain a good linearity.
The low power consumption is achieved by using high efficiency power amplifiers for the power section.
This paper describes the performances of the newly developed HPA module and SSPA equipment.

II. SSPA CONFIGURATION DESCRIPTION

The X band SSPA consists of two main trays, a DC tray containing an electronic power converter (EPC) circuitry with its dedicated telemetries and telecommands (TM/TC) and an RF tray containing RF modules, dedicated biasing network and Automatic Level Control (ALC) loop.
The EPC consists of two isolated pulse width modulation converters (PWM), one for the positive main output and one for the low power output with post-regulators. Input filter and main protection are implemented for both converters (figure 1). The V1 voltage is adjustable by the Vref voltage in order to compensate the variation law of the output power in temperature.
The EPC achieves an efficiency higher than 85%.

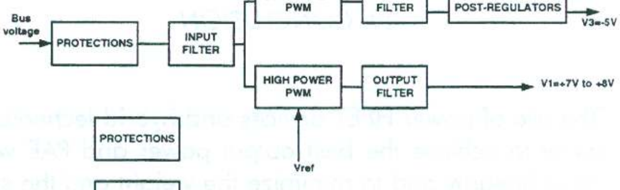


Fig 1 : Block diagram of the SSPA EPC

The block diagram of the SSPA RF chain and an external view of the X-band SSPA are shown in figure 2 and figure 3 respectively.
It consists of :

- A microstrip attenuator to provide a good input VSWR (1).
- Two low level modules, each one composed of a MMIC variable attenuator and a MMIC Low Level Amplifier (2)(3). The attenuators are voltage commanded by an ALC loop and are used to compensate for input power variation and for RF modules gain drifts.
- A microstrip attenuator (4).
- A module composed of a MMIC flatness corrector followed by a MMIC low level amplifier (5). The flatness corrector is used to obtain a flat gain in the specified frequency band.
- A driver module (6). The driver module is operated with back-off to keep a good linearity for the low level section. The ALC loop which is temperature compensated is used to keep the driver output power constant whatever the input power.

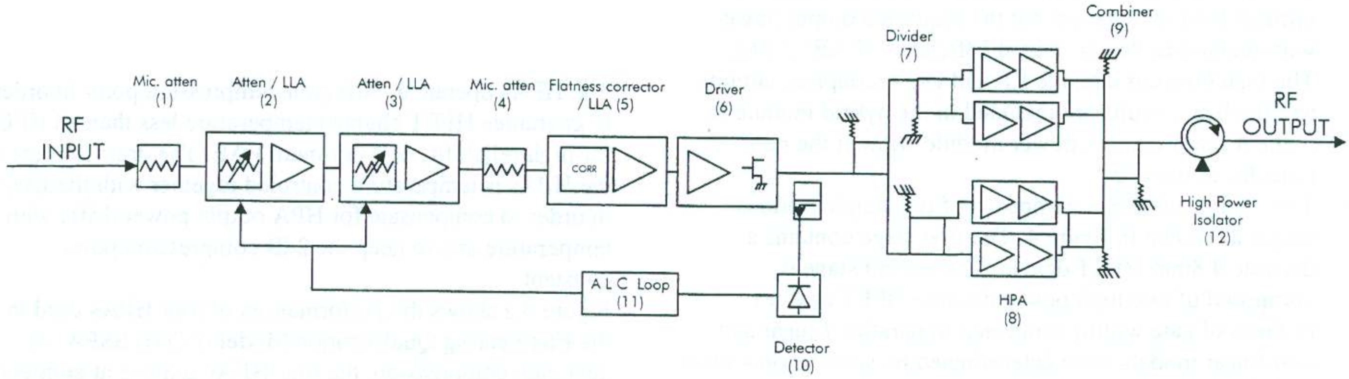


Fig 2 : Block diagram of the SSPA RF chain

- A microstrip power divider by four (7). This divider, placed at the output of the driver module, includes a 20 dB coupler and is used to couple a small part of the RF signal to the RF detector.
- A high power stage, made of four HPAs in parallel (8) in order to get the proper output power.
- A microstrip branch-line power combiner by four with low insertion losses (9).
- A RF power detector (10).
- An output isolator with an internal power load, allowing good in-band output matching and protection for the HPAs against short or open circuit (12).

The whole RF functions are assembled in hermetic microwave package using the Alcatel's qualified hybrid line. Each modules are fully tested before being integrated. Printed Circuit Boards (PCBs) are used for RF modules biasing and the ALC loop.

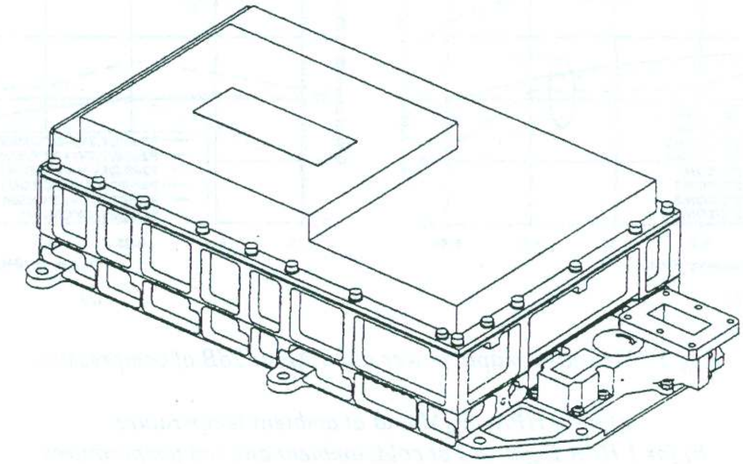


Fig 3 : External view of the X-band SSPA

III. POWER MODULES DESIGN AND PERFORMANCES

An appropriate methodology is used to design the hybrid HPAs [4]. At first, it consists of developing non-linear electrical models of power HFET devices based on S-parameters and DC pulse measurements. Then, simulated load pull method is performed with a microwave simulator in order to find, under AB class operation, the optimal load impedances for the requested output power with maximum Power-Added Efficiency (PAE) [5][6]. The matching circuits, the RF and DC decoupling circuits and the bias circuits are included in the hybrid module to make it a self-content power module without the need of outside circuitry [3].
The hybrid module is composed of two amplifications stages as shown in figure 4. The first stage contains a discrete 4.8mm HFET device. The second stage is composed of two high power discrete HFET devices (9.6mm of gate width) connected in parallel. Linear and non-linear models were determinated by scalling on 4.8mm HFET device.

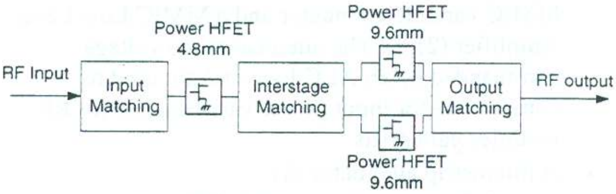
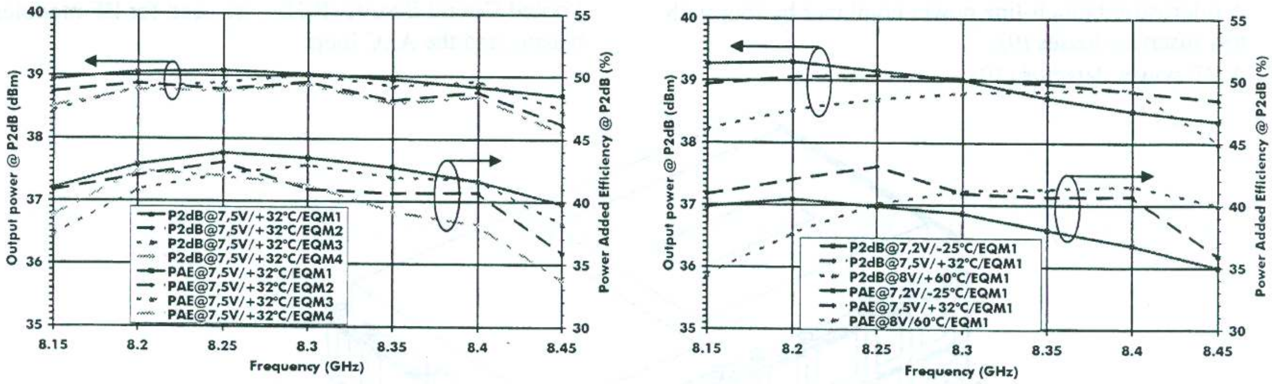


Fig 4 : Block diagram of the HPA

The HPAs operate at 2dB gain compression point in order to guarantee HFET channel temperature less than +110°C for high reliability and optimum PAE. The drain voltage of the HPAs is temperature controled together with the EPC in order to compensate for HPA output power drifts with temperature and to keep the 2dB compression point constant.
Figure 5.a shows the performances of four HPAs used in the Engineering Qualification Model (EQM) SSPA. At 2dB gain compression, the four HPAs achieve at ambient temperature an output power greater than 38.5dBm with an average PAE at 2dB higher than 40% over the frequency band of 8.2-8.4GHz.
The output power and PAE at 2dB gain compression of one HPA for 3 temperature conditions are shown in figure 5.b. The drain voltage of HPAs is tuned in order to keep constant the same output power in the all operating temperature area.



a) *b)*

Fig 5 : Measured output power and PAE at 2dB of compression

a) for 4 HPAs EQM and at ambient temperature
b) for 1 HPA EQM and at cold, ambient and hot temperatures

IV. SSPA PERFORMANCES

The main characteristics of the SSPA are presented in the table 1.

Parameter	Measured value
Frequency bandwidth	8.2-8.39GHz
Output power	22W with ALC loop closed
Input power	-4dBm to +12dBm (overdrive)
Input VSWR	< 1.2:1
Output VSWR	< 1.2:1
DC power consumption	91W
AM/PM	< 4°/dB
Primary bus	22V to 39V
Mass	1.53Kg
Size	271x160x70mm^3
Design life	15 years

Table 1 : Main characteristics of the SSPA

Figure 6 shows measured output power and power consumption of the EQM SSPA at cold, ambient and hot temperature for an input power of 0dBm.

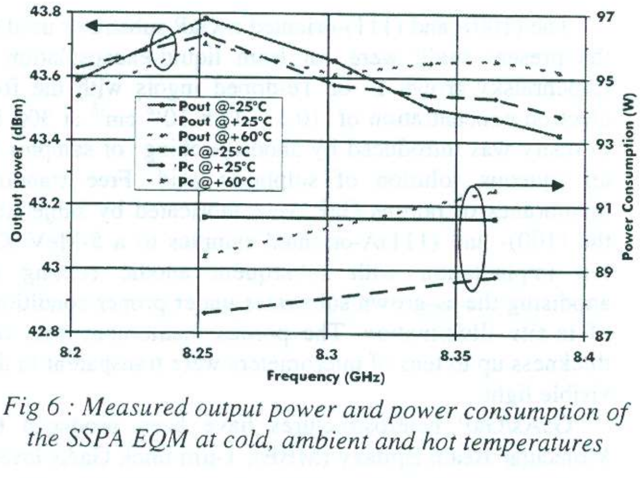


Fig 6 : Measured output power and power consumption of the SSPA EQM at cold, ambient and hot temperatures

On the frequency band 8.2 - 8.39 GHz the output power is higher than 22 watts. The DC power consumption is lower than 91 W at the ambient temperature.
The flight models for the SPOT 5 program are currently under production.

V. CONCLUSION

The combination of MMIC technology for the low level section and of hybrid technology for the high power section has allowed to develop a competitive space product.

This SSPA achieves an output power of 22W at X-band with a DC power consumption lower than 91 W.
The success of industrial development is due to the technical and technological mastery of this equipment.

VI. ACKNOWLEDGMENTS

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