KA BAND SATELLITE EQUIPMENT USING EUROPEAN GAAS TECHNOLOGY

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Abstract - **The present paper describes a set of GaAs MMIC developed by Alenia Aerospazio (ALS) in cooperation with United Monolithic Semiconductors (UMS) using a standard 0.25 PHEMT process. Low noise amplifiers, mixers and control functions have been implemented with excellent results, useful for all future implementations.**

I. INTRODUCTION.

Application of MMIC technology in satellite equipment is already assessed and is also well documented in equipment up to Ku band [1],[2],[4],[5]. The amount of the transmitted data and the saturation of the channels in the Ku-Band part of the spectrum require new satellite services functions in the range from 20 to 30 GHz. The new market trend for multimedia transmission foresees a huge amount of miniaturized equipment for which the application of MMIC technology with stable processes and at affordable price appears to be mandatory.

On the basis of the main mission objectives of satellite systems several architectures can be envisaged. The transparent configuration whose principle block diagram is shown in Fig.1 is well suited, for instance, for DHT-TV based services where a wide range of transmission data rates without on-board switching is requested.

The regenerative payload configuration is optimally suited for multicarrier and/or multibeams configurations. The most attractive application for MMICs lies, of course, in channel amplifiers (CAMP) optionally including a TWT lineariser (LCAMP) which, depending on the complexity, are present in high quantities. Receiver modules (RX), integrating LNAs and downconverters, are further useful applications for the MMICs: the Euroskyway (Alenia Aerospazio Multimedia Constellation) payload, for instance, integrates 32 such front-ends per satellite.

When using MMIC technology a tradeoff must be done between different factors: modularity, integration scale, low price (e.g. standard process), identifying a minimum number of building blocks necessary to implement different equipment. Keeping in mind this concept, a set of MMIC has been identified to cover the needs of the CAMP, LCAMP, RX whose microwave sections are fully MMIC based.

- <u>Low Noise Amplifiers</u> are extensively used in all the mentioned equipment. Although RX operates at 30 GHz while CAMPs and linearisers operate at 20 GHz, a single wideband design effectively covers both bands while providing optimized noise figure performance at 30 GHz.
- <u>Voltage Variable Attenuator</u> is used in CAMP as gain control element and in LCAMP and RX as element for tuning and gain compensation.
- <u>Balanced Mixer</u> is used in the 30-20 GHz RX featuring a strong suppression of in band spurious e.g. the second LO harmonic.
- <u>Phase Shifter</u> is used as element for electronic tuning of linearisers and as phase tracking element in special applications as multiport TWT amplifiers.
- <u>Voltage Controlled Oscillator</u> MMIC at 10 GHz has been developed for implementation of VCDRO in the 30 -20 GHz receivers.

II. TECHNOLOGY DESCRIPTION.

A standard 0.25 um low noise PHEMT process and a multiproject approach were chosen to develop all the circuits. UMS Facilities were chosen as foundry and two 3-inch wafers were processed for the development run. Typical process parameters are: Ft = 60 GHz , Noise figure = 1.5dB @ 40GHz with 8dB associated gain, Power density = 0.25W/mm @ 1 dB gain comp., Idss=300mA/mm; Gm = 500 mS/mm; Vp=-0.7 Volts; Vbds=5.5V. The chosen process is currently used extensively for commercial and military applications and has already been successfully pre-evaluated by ESA for space applications [3]. In order to have the highest probability of success, more than one version for each circuit was implemented on the same wafer.

III. MMIC DESCRIPTION.

A. Low Noise Amplifier.

Inductive source feedback was used to reach optimum noise figure and good return loss at the same time. A three-stage configuration and a RF parallel feedback allowed getting the specified gain-bandwidth performances (20 dB over 17-32 GHz). Each stage is self-biased to allow the use of a single bias at equipment level and reduce the drift with temperature.

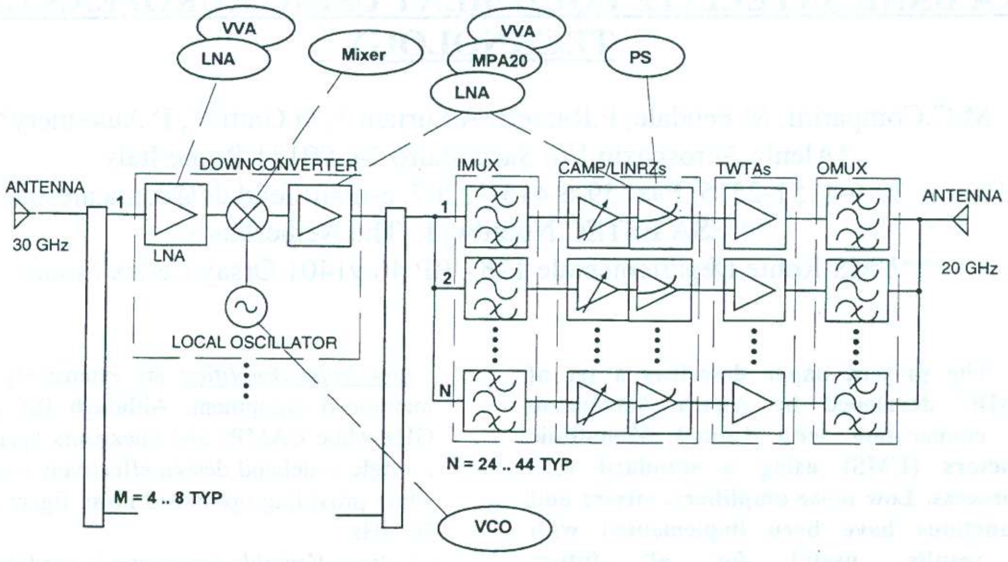

Fig. 1: Generic transparent payload architecture including MMIC usage plan.

In order to recover for the pinch-off voltage variations, a series of groundable pads are available on MMIC to properly adjust the source resistors.Photo of the chip is shown in fig. 2.

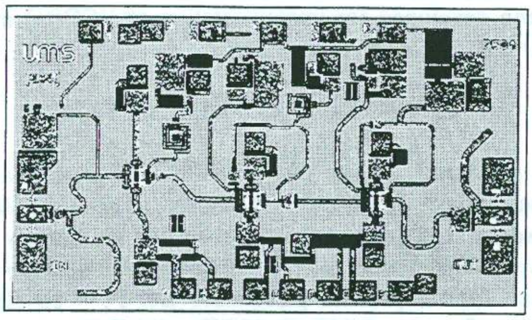

Fig.2. LNA chip. (2x1.2mm)

B. Voltage Variable Attenuator

A simple configuration based on two shunt cold FETs embedded within a pair of Lange Couplers has been implemented. Drain and source of each FET have been shorted by means of an inductor. The gatewidths of the two FETs on each branch of the circuit have been chosen in order to optimize the linearity of the circuit increasing the 1dB compression point. Resistive dividers have been implemented on the chip itself to properly feed the FETs and have the possibility to use both negative or positive control voltage. In any case the control is through a single bias. Lange couplers have been folded to reduce the total chip area and all the layout was particularly studied to minimize the parasitic effects. MMIC dimensions are 1,2x2,0mm MMIC picture is shown in figure3.

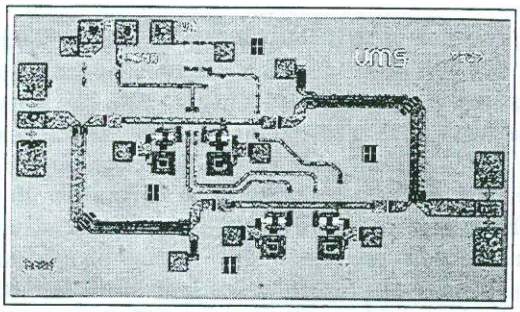

Fig. 3. Attenuator chip.

C. Phase Shifter.

Classical reflective approach was used for this circuit. Each branch of a Lange coupler is connected to a reactive load composed of a resonant circuit implemented by means of semi-lumped elements. Inductors implemented on microstrip lines are resonated with variable capacitors which have been implemented using planar schottky diodes derived from the structure of the FET. Resistive dividers implemented on the chip, reduce the sensitivity and allow a better control of the phase vs voltage. In order not to exceed the scaling limits for the active devices, more than one diode was used to get the overall required capacity. Chip dimension are 1,2x2,0mm. Layout is shown in fig.4.

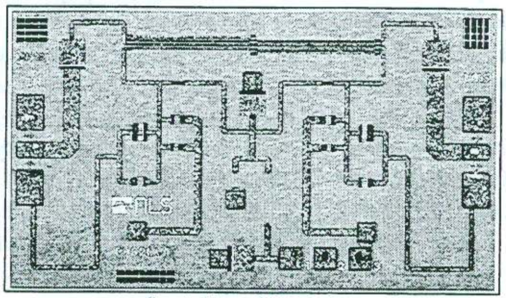

fig. 4. Phase Shifter chip

D. 30-20 GHz Balanced Mixer.

A cold FET resistive mixer was designed where the 10 GHz LO is fed to the FET gates via a passive lumped-element 180° balun. A distributed element balun isolates the 30 GHz RF and 20 GHz IF, while ensuring rejection of the 2nd LO harmonic from the IF output. By properly biasing the gate, the best compromise can be found between amplitude linearity and LO power requirement (thus harmonics' level). Realized chip is shown in figure 5.

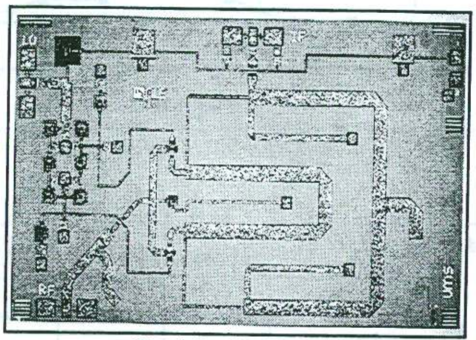

Fig. 5. Realized Mixer.

E. Voltage Controlled Oscillator.

This MMIC has been developed in VCDRO and fully MMIC version. A negative resistance has been obtained at the gate of a FET using capacitive feedback on the source. In the VCDRO version, the amount of feedback has been chosen to allow oscillation when the MMIC is connected with a microstrip coupled to a dielectric puck. The same MMIC allows to have oscillation in the range between 8 and 12 GHz just changing the dimensions of the puck.

In the fully MMIC version a resonator has been implemented inside the chip using two coupled lines properly terminated with planar schottky diodes used as variable capacitors. Both the MMIC version contain a buffer amplifier integrated on the chip to reduce the pulling. Oscillator MMIC realized for the VCDRO version is shown in fig. 6. Chip dimensions are 1,2x2mm.

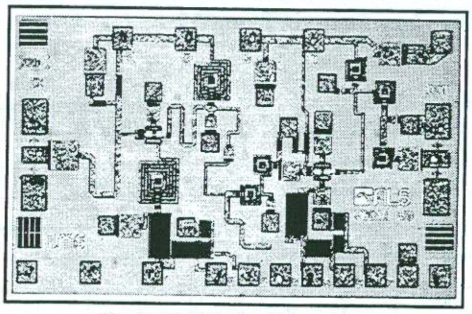

Fig. 6. 10 GHz Oscillator chip.

IV. SIMULATIONS AND MEASUREMENTS.

Simulations have been performed using commercial available software properly recompiled to insert the Smart Library developed by UMS. Modeling of passive and active elements was performed by UMS on the basis of a huge number of collected data. Due to the high operation frequency, the effect of the bonding wires and/or wafer probe has been properly taken into account during the simulation and the maximum allowed value for it was properly checked by measurements.

As far as the MMIC test is concerned, small signal as well as large signal and noise measurements have been performed 100% on wafer. Comparison between simulations and measurements showed the validity of the modeling and the effectiveness of the circuital approaches. This was especially verified for non linear MMIC circuits. As matter of reference figure 7 shows comparison between simulation and measurement of Oscillator MMIC.

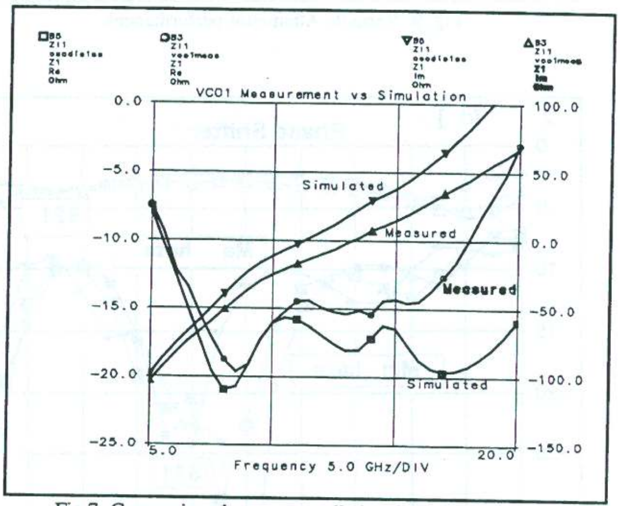

Fig.7: Comparison between small signal measurement and simulation of the 10 GHz VCO.

On wafer measurements for 30 Ghz LNA are reported in figure 8, while obtained performances for variable attenuator are shown in fig. 9. Figures 10 and 11 report the obtained performances on phase shifter MMIC.

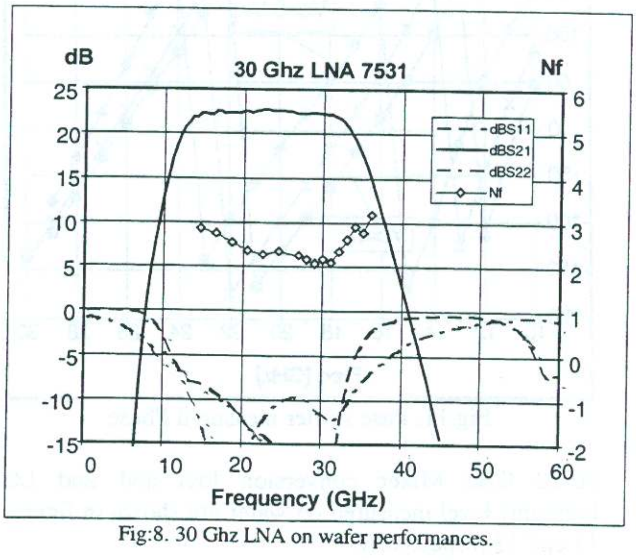

Fig:8. 30 Ghz LNA on wafer performances.

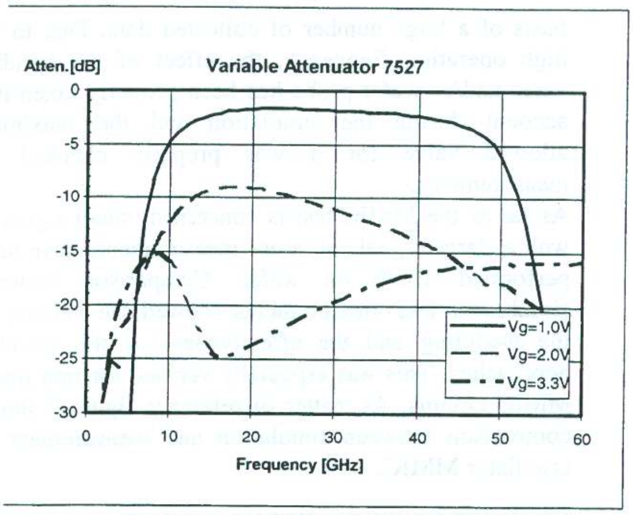

Fig. 9. Variable Attenuator performances.

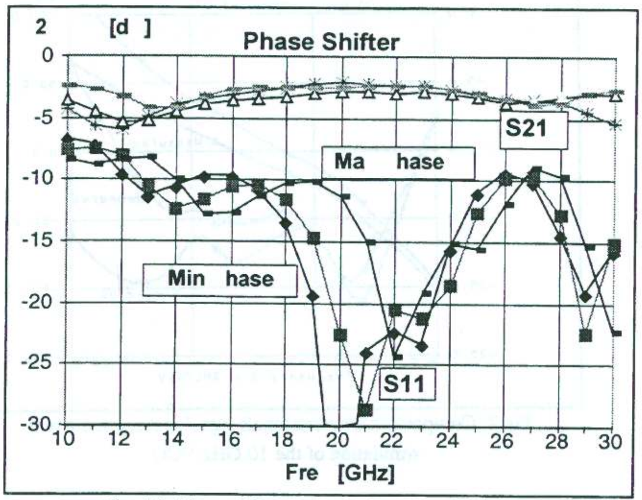

Fig. 10. Phase shifter measured performances.

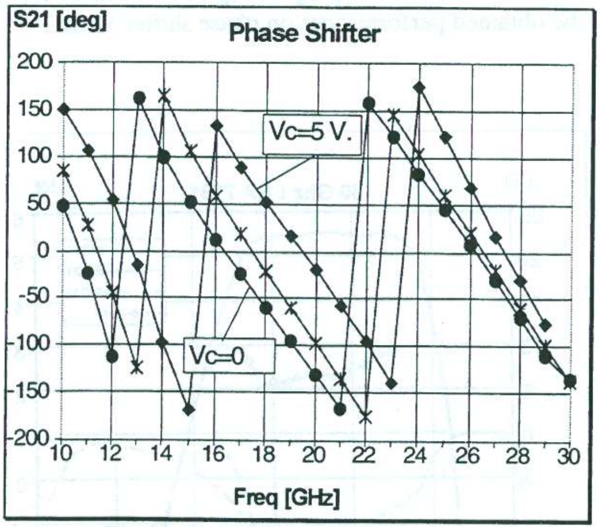

Fig.11. Pase shifter measured Phase

30-20 GHz Mixer conversion loss and 2nd LO harmonic level measured on wafer are shown in figures 12 and 13 respectively.

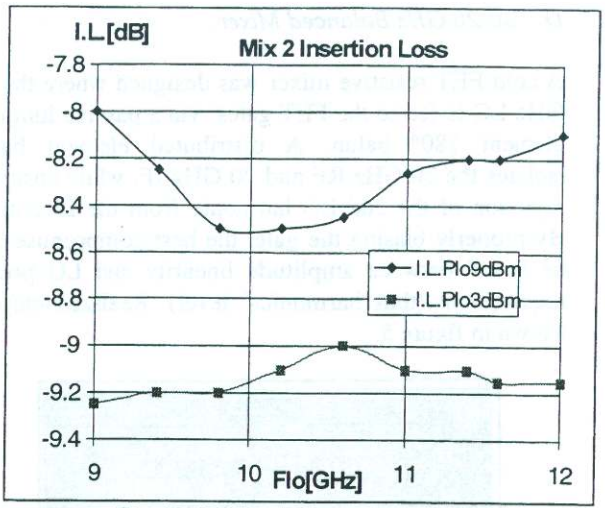

Fig. 12. 30-20. Mixer conversion loss.

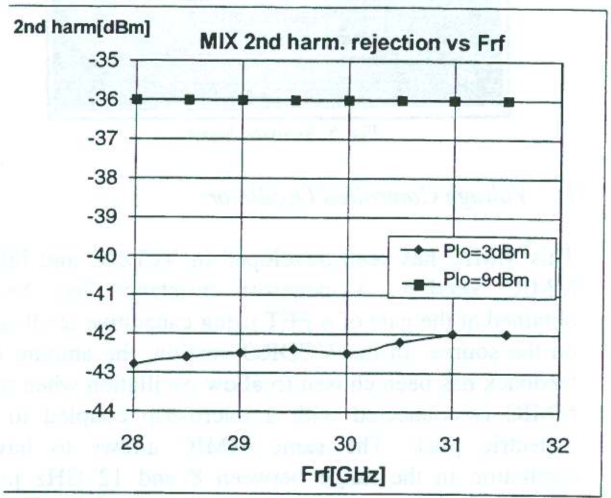

Fig. 13. Rejection of LO 2nd harmonic of the 30- 20 Ghz Mixer.

As already mentioned, non linear performances of all MMIC have been verified on wafer. Nevertheless fixtured measurements were necessary to verify temperature behavior and main performances of VCDRO whose condition for starting oscillation had been verifyed on wafer. As matter of reference, figure 14 shows the measured oscillation of the VCDRO assembled as shown in figure 15.

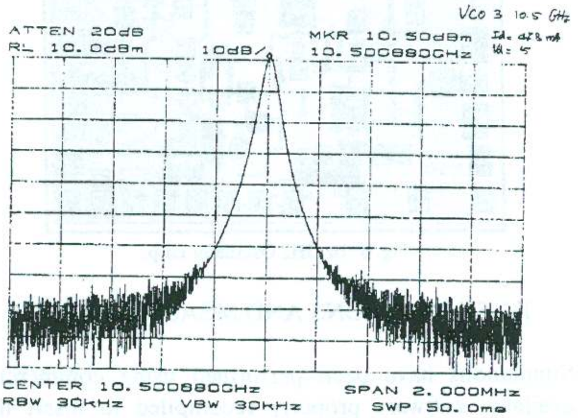

Fig. 14. Measured oscillation of the VCDRO.

Table I summarize all VCDRO main performances. The total size of the cavity is 15x15mm. The results of the other MMICs are summarized in table II.

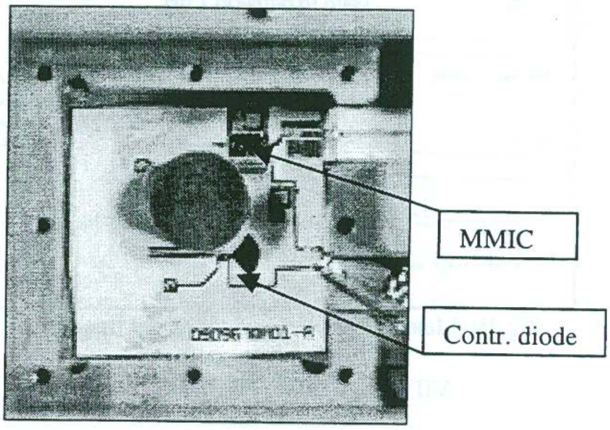

Fig.15. VCDRO assembled in test jig for measurement.

Table I. VCDRO measured performances.

Parameter	Value
Oscillation Freq.	9 – 12 GHz
Output Power	10 dBm
Phase Noise	-105 dBc/Hz @100KHz
DC Pow. Cons.	250 mW
Bias Voltage	5V
Tunability range	12 MHz @25 °C
Temper. Variation	28 KHz / °C

Table II Summary of Non Linear measurements

MMIC	1dBcp	Δgain; ΔIL vs. Temp (-20°C - +70°C)
LNA	10 dBm	1.2 dB
Attenuator	8 dBm (Pin)	1.0 dB
Phase Shifter	NA	20 degrees
Mixer	-9 dBm	NA

V. YIELD AND RELIABILITY.

Except for the Mixer which resulted wider because of the passive balun implementation, all the other chips have small dimensions: (2x1,2mm). This allowed to get a sufficient number of chips per wafer also considering that 3'' wafers have been processed and a lot of area was reserved for all the test structures necessary to test the MMICs themselves and for the process control monitoring. Typical yield for each MMIC in this development run resulted greater than 80% at the completion of the on wafer measurements. As matter of reference, figures 16a and 16b show the dispersion obtained on one wafer for the gain and the noise figure of the low noise amplifier respectively. Same result has been obtained for the other MMICs. Figure 17 shows, for instance, the dispersion on half wafer of the maximum obtainable phase shift for the phase shifter MMIC. Although not reported in the picture, the yield is calculated for minimum and maximum bias state.

As already mentioned, several tests have been performed on this process in the frame of the evaluation program for the use of such components in space hardware showing no appreciable degradation during more than 1500 hr accelerated life test [3]. Comparison between collected data and Arrhenius plots for the same technology shows that predicted MMIC life is higher than 10^5hr. @ 110 °C junction temperature and higher than 10^8hr. @ 50 °C.

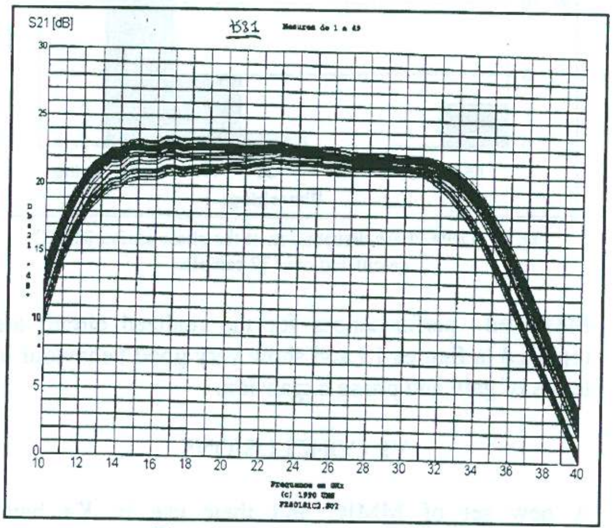

Fig. 16a. Dispersion on LNA gain.

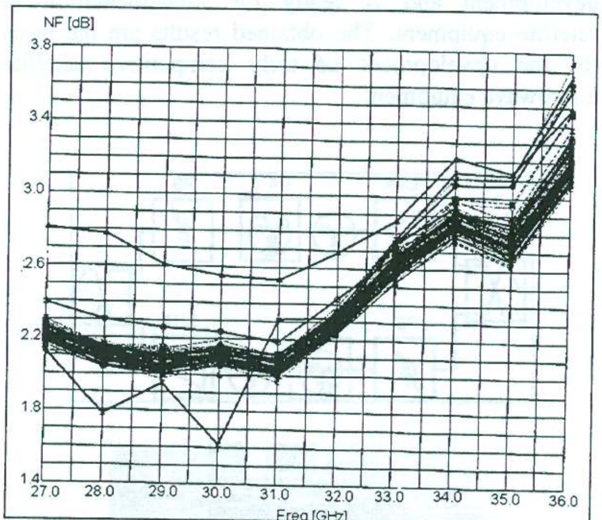

Fig. 16b. 30 GHz LNA: Dispersion on Noise Figure.

VI. MMIC APPLICATIONS.

All the MMIC described above have been successfully used in the implementation of a Ka Band linearizer whose blok diagram is shown together with complete assembly, in figure 18. The overall dimension resulted of 15 x 20mm. For this version of the linearizer conventional technology rather than LTCC was used to implement all the connections in order to avoid unwanted parasitic effects. A newer and smaller version of the same equipment is under development at the time of writing this paper.

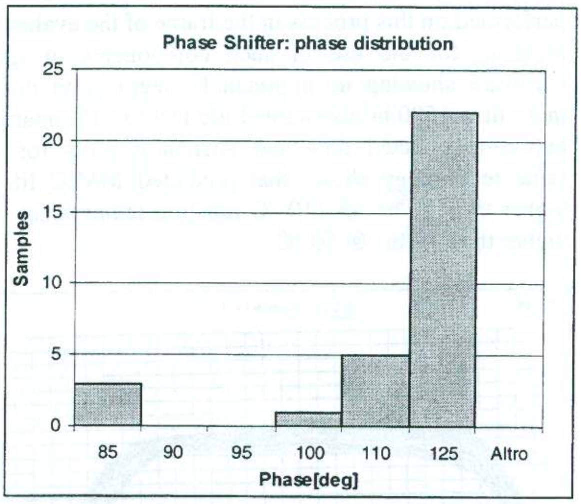

Fig. 17. Delta Phase distribution of the phase shifter MMIC calculated over 33 samples

Measured performances for the realized circuit are reported in figures 19 and show very good behaviour in terms of gain and phase expansion.

VI. CONCLUSIONS.

A new set of MMIC and their use in Ka band equipment was presented. This paper demonstrates that PHEMT technology is not only assessed in Ku band, but is also effective for all the present Ka band development and is ready for implementation in satellite equipment. The obtained results are the basis for the development of truly competitive satellite microwave equipment.

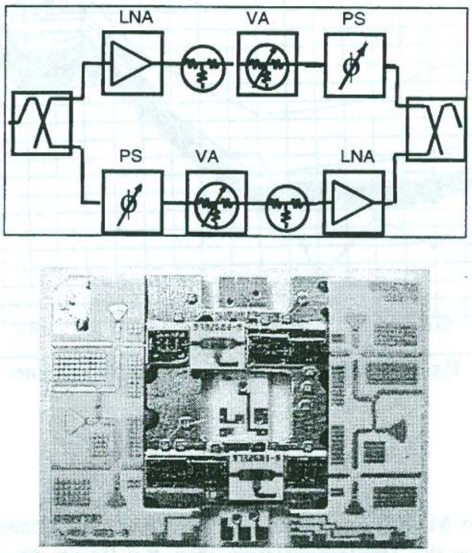

Fig. 18. Linearizer: Block diagram and assembly.

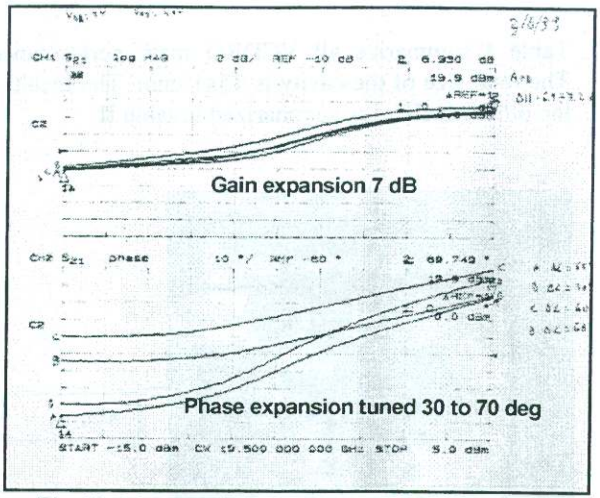

Fig.19. Measured Performances of the linearizer

VII. ACKNOWLEDGMENTS.

The present work has been developed in the frame of the ESA ESTEC contract No. 12550/97/NL/SB. The authors would like to thank all the UMS technical staff for their precious contribution in this successful development and for the several hints provided during the whole collaboration.

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