DEVELOPMENT OF MICROWAVE COMPONENTS FOR SATELLITE COMMUNICATIONS

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ABSTRACT

In Brazil, the demand for interconnecting various points over the large national Territory, led TELEBRÁS (The Federal Government Company for Telecommunications) towards the formulation of a Research and Development Programme aiming at the realization of a Telephony and T.V. Signal Transmission-Reception Earth Station for Satellite Communications. Various Universities and local industries are taking part in the Programme.

The Hybrid Integrated Circuit Division at the Microelectronics Laboratory, Escola Politécnica, University of São Paulo, is mainly concerned with the design and development of the microwave circuits for the *Receiver* (3.7 to 4.2 GHz - Low-Noise Amplifier and Down-Converter) and the *Transmitter* (5.9 to 6.4 GHz - Up-Converter and Medium Power Amplifier).

The microwave modules described in this paper have been assembled together with other components, resulting in a complete Earth Station, which has been under test, operating successfully since May 1981 for TV signal reception. The prototypes are under optimization in order to be industrialized in the near future.

I - INTRODUCTION

In 1976, with the installation of a Satellite Communication System in Brazil, the TELEBRÁS decided to formulate a Research and Development Programme in this field, comprising two basic projects:

- The ERTV Project, aiming at the development of a T.V. reception station; and
- The ETP Project, aiming at the development of a Telephony station.

The main objetive of this Programme is to prepare qualified personnel, responsible for applied research and production of laboratory and industrial prototypes for the Satellite Earth Stations.

The development of these devices would fill the demand for expanding the National Telecommunication System, operating at present with the Intelsat IV A, as well as for preparing it to operate with the Domestic Satellite to be launched in 1985. A relative autonomy in the field is expected to be reached.

The implementation of this Programme combines the action of several institutions. (Fig. 1).

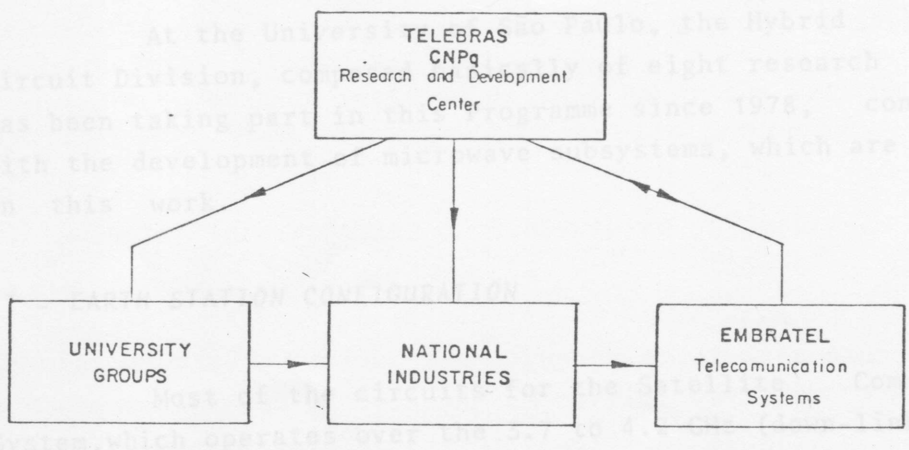


Fig. 1 - Diagram of the R & D. activities on telecommunications in Brazil

- *TELEBRÁS - CPqD* - Research and Development Centre, responsible for the planning , coordination, management, preparation of project specifications, testing and technical evaluation of the system.

- *UNIVERSITIES* - The main function of the Universities, within this programme, is to create expertise on the field of Satellite Communication Systems. Groups of qualified professionals are built up, in order to conduct research and development activities, aiming at the production of laboratory prototypes for the overall System. Some public and private Universities have been contacted by TELEBRÁS, and research contracts have been established under this objective.

- *INDUSTRIES* - Run in large scale manufacturing of the sytem modules and equipment. At the moment, local industries cannot easily absorb recent advances, but they are being prepared to assume the task in a near future.

- *EMBRATEL* - A branch company of TELEBRÁS, has the attributions of implanting, expanding, operating and maintaining the Microwave Terrestrial Links as well as the Satellite Earth Stations.

At the University of São Paulo, the Hybrid Integrated Circuit Division, composed basically of eight research engineers, has been taking part in this Programme since 1978, contributing with the development of microwave subsystems, which are described in this work.

II - EARTH STATION CONFIGURATION

Most of the circuits for the Satellite Communication System, which operates over the 3.7 to 4.2 GHz (down-link) and 5.9 to 6.4 GHz (up-link) frequency bands, are locally designed and constructed. Figure 2 shows the Earth Station simplified block diagram.

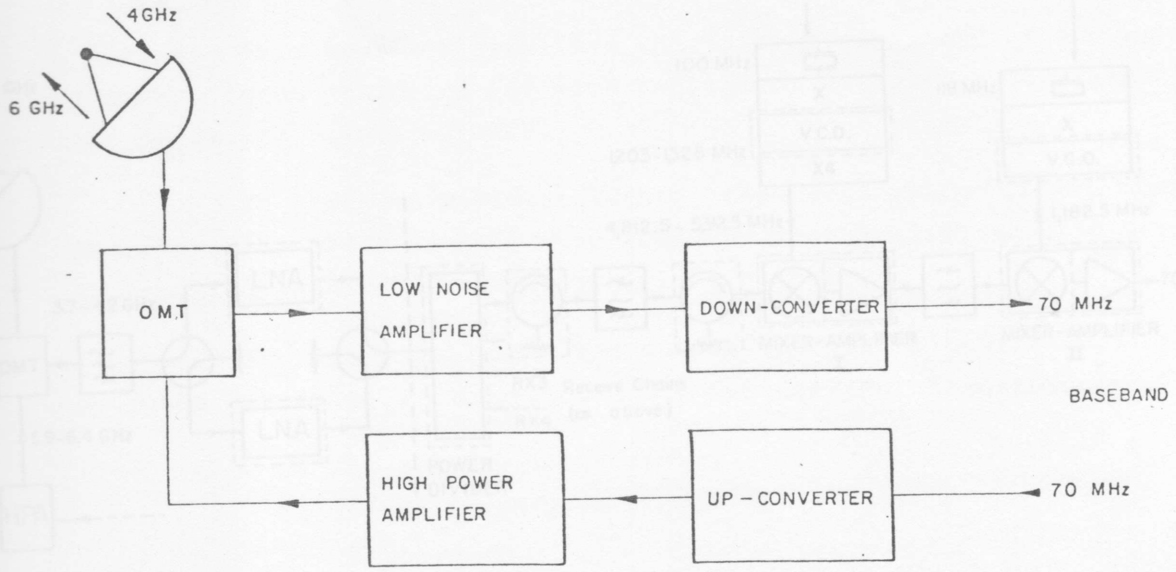


Fig. 2 - Simplified Block Diagram of 4/6 GHz Earth Station

The earth station down-converter receives the 4 GHz signal from a low-noise amplifier, selects a single 36 MHz channel at the time for reception,and down-converts it into an output signal level suitable for demodulation at a remote side.

The up-converter translates the 70 MHz baseband signal to any of the 12 channels within the 5.9 to 6.4 GHz up-link band.

In subsequent sections of this paper the various earth station sub-systems whish have already been developled by our group are presented.

III - *LOW-NOISE AMPLIFIER AND DOWN-CONVERTER DESCRIPTION*

The receiver scheme adopted is based upon the Intelsat IV earth station configuration. The down-converter uses double frequency conversion and accepts any FM carrier between 3700 and 4200 MHz translating it to an I.F. frequency of 70 MHz.

Figure 3 shows a block diagram of the microwave signal processing section with a spare LNA as used for some stations.

The dashed contour detaches the circuits under the Hybrid I.C. Division responsibility.

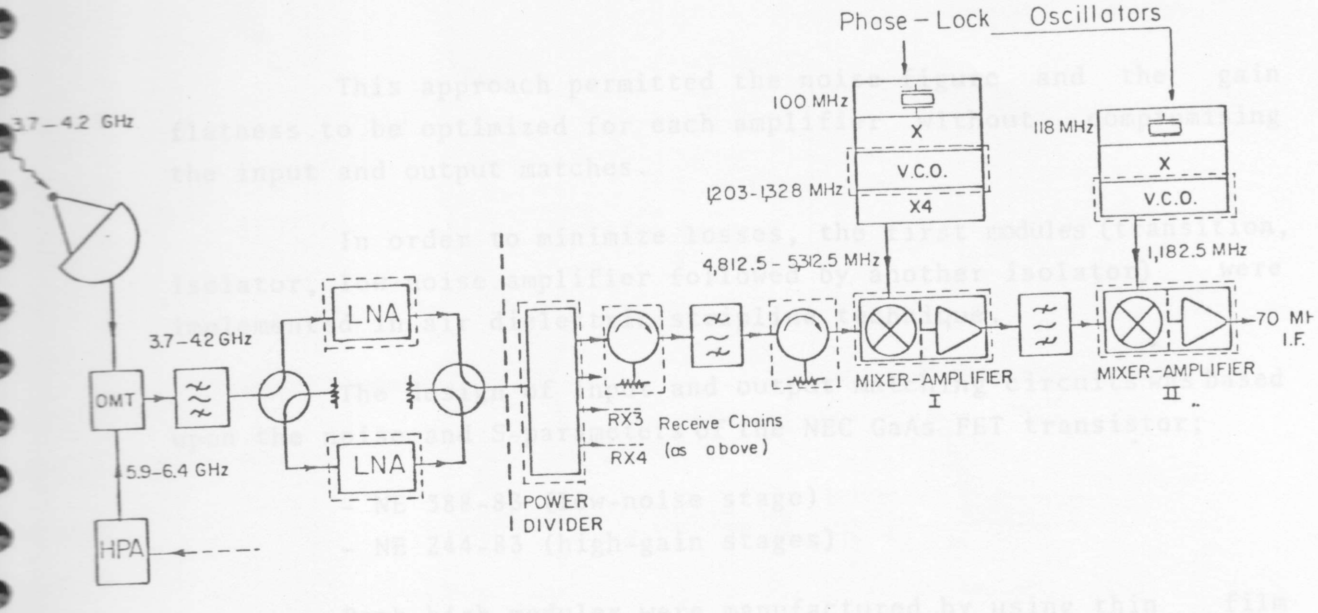


Fig. 3 – Detailed block diagram of the receiver

III - 1 - *Low-Noise Amplifier*

The antenna - mounted low-noise amplifier shown in Fig. 4 is composed of:

- a waveguide to stripline transition integrated to an isolator.
- a low-noise stage (13 dB gain and 1.5 dB noise figure).
- two high gain modules (13 dB gain/each separated by ferrite isolators.

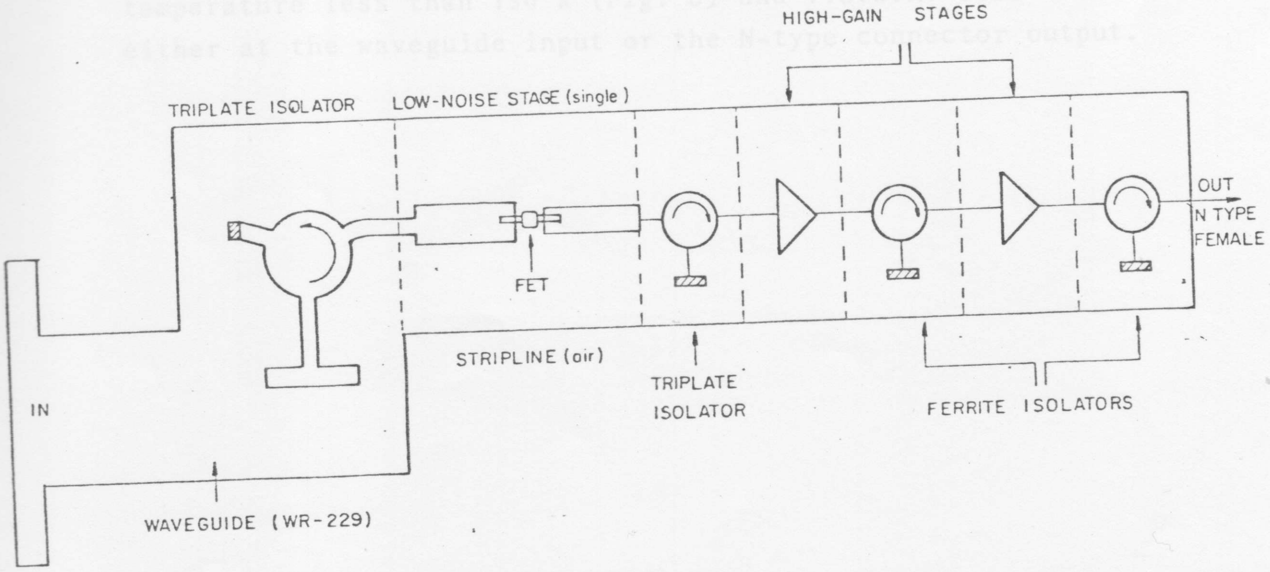


Fig. 4 – Schematic block diagram of L.N.A.

This approach permitted the noise figure and the gain flatness to be optimized for each amplifier without compromising the input and output matches.

In order to minimize losses, the first modules (transition, isolator, low-noise amplifier followed by another isolator) were implemented in air dielectric stripline technique.

The design of input and output matching circuits was based upon the noise and S-parameters of the NEC GaAs FET transistor;

- NE 388-83 (low-noise stage)
- NE 244-83 (high-gain stages)

Both high modules were manufactured by using thin film microstrip lines on quartz substrate (7059 Corning Glass). Figure 5 shows the final circuit of the first module comprising two stages, presenting 22 dB gain and 3 dB noise figure. The last module a single stage amplifier also manufactured on quartz substrate, presented 13 dB flat gain and maximum noise figure of 3 dB. Figure 6 shows the photograph of one the high amplifier and Figure 7 illustrates the various modules of the overall L.N.A. in a compact housing, measuring approximately 200 x 125 x 70 mm.

The performance of the overall component combines 47 ± 0.4 dB gain over the 3.7 to 4.2 GHz frequency band, with noise temperature less than 150°K (Fig. 8) and V.S.W.R. less than 1.20 either at the waveguide input or the N-type connector output.

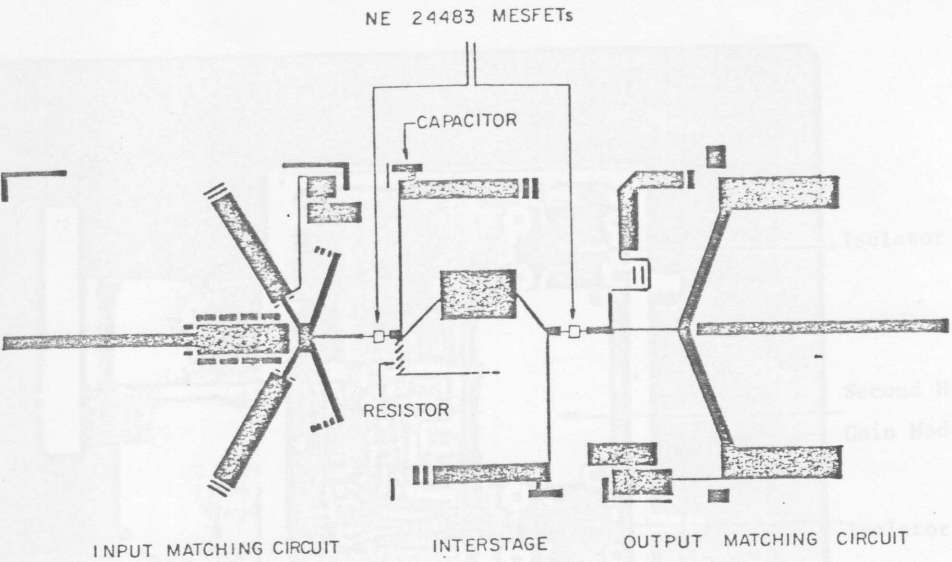


Fig. 5 - Photomask of the high gain module

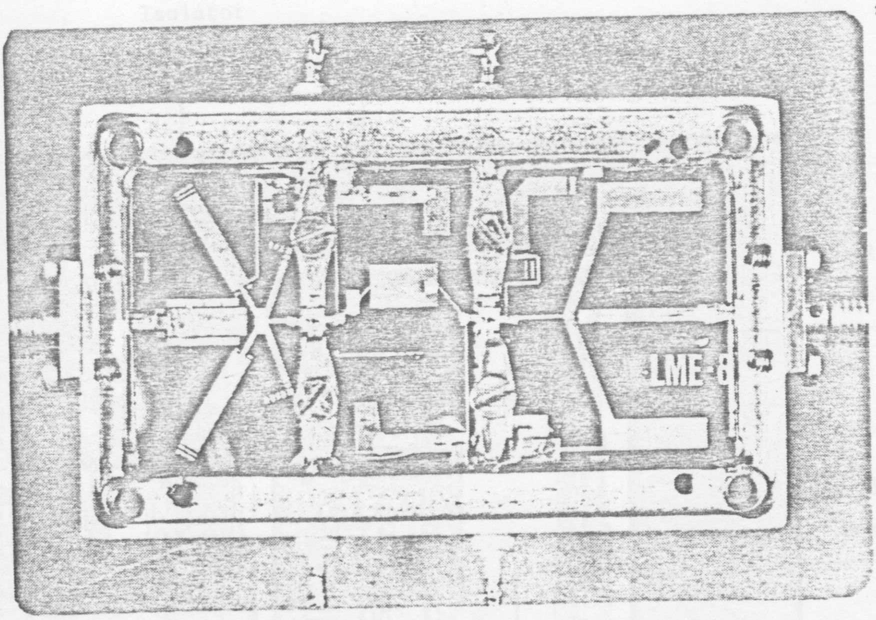


Fig. 6 - Photograph of 2 - stage high gain amplifier with cover removed

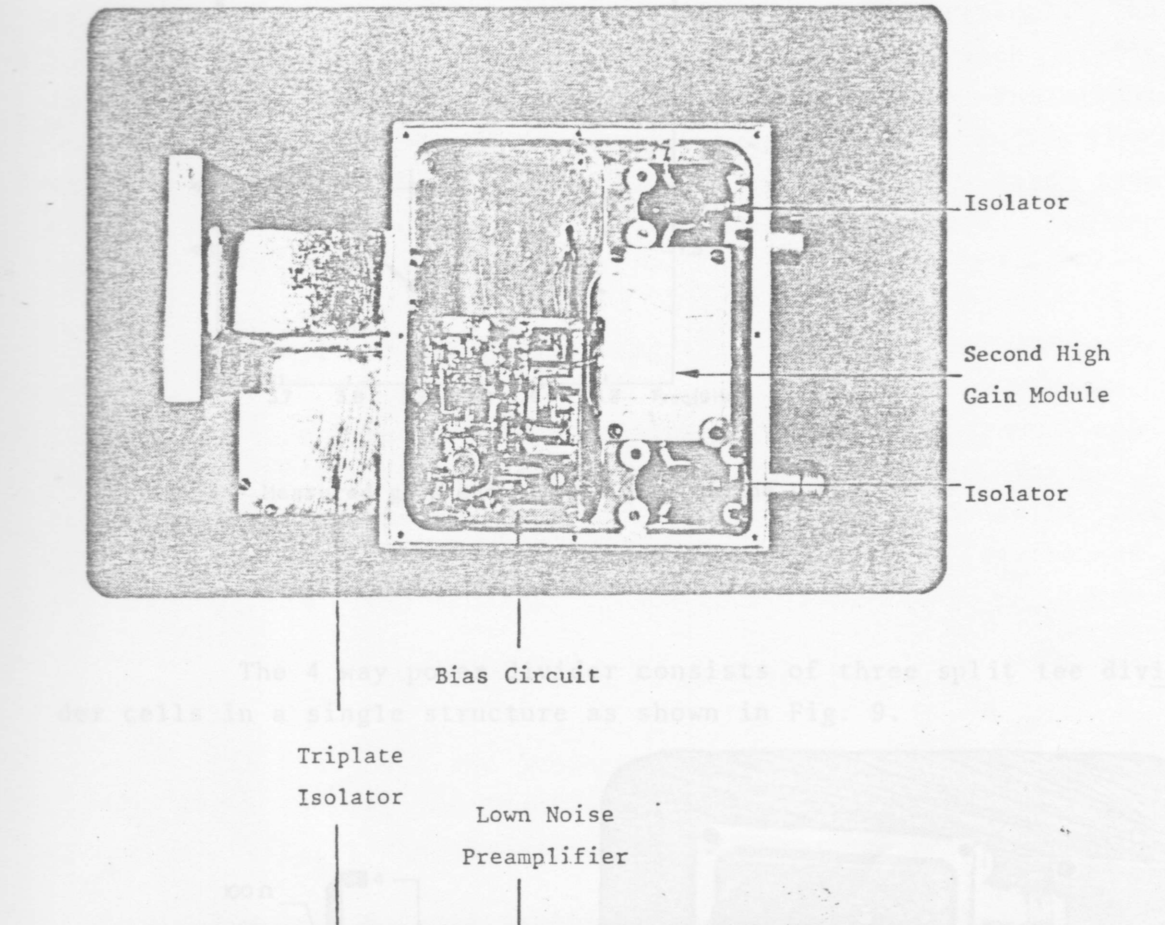


Fig. 7 - Internal view of the complete L.N.A.

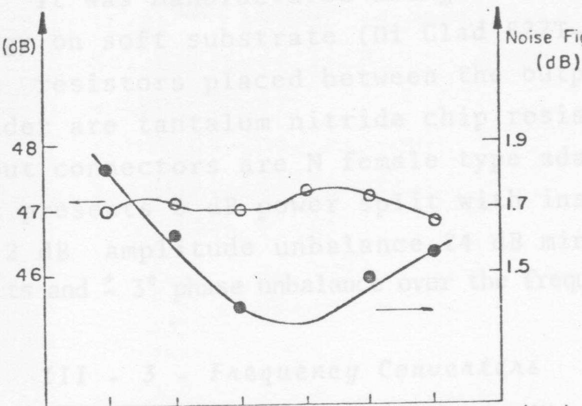
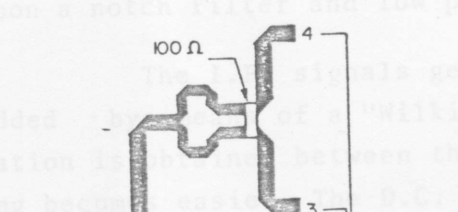


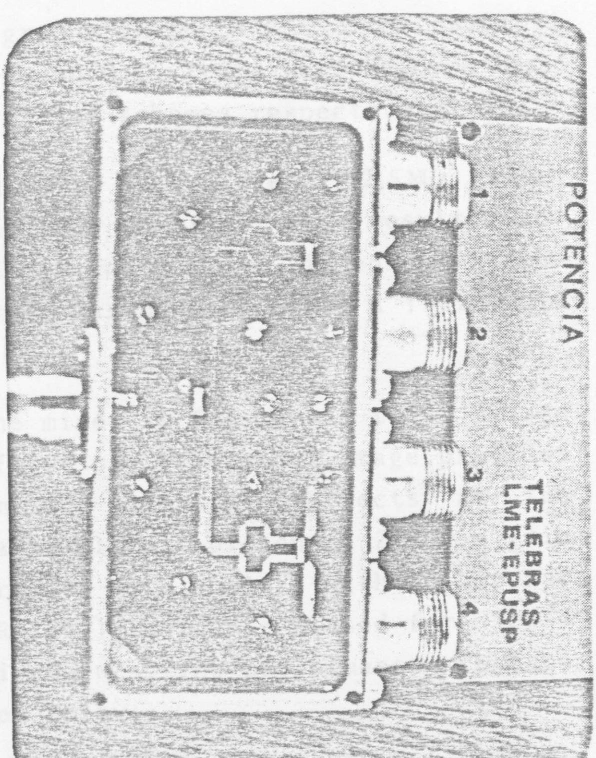
Fig. 8 - Measured gain and noise figure of the L.N.A.

III - 2 - Power divider

The 4 way power divider consists of three split tee divider cells in a single structure as shown in Fig. 9.



(a) Photomask



(b) Photograph

Fig. 9 - Power Divider

It was manufactured using conventional printed circuit technology on soft substrate (Di Clad 522T-Keene Corporation). The bridging resistors placed between the output ports of each split tee divider are tantalum nitride chip resistors (100 Ω). The input and output connectors are N female type adapted for microstrip line. The unit presents 6 dB power split with insertion loss less than 0.5, ± 0.2 dB amplitude unbalance, 24 dB minimum isolation between output ports and ± 3° phase unbalance over the frequency band (3.7 to 4.2 GHz).

III - 3 - *Frequency Converters*

Single balanced configuration for the mixer circuits were considered to meet the requirements of cost and performance. The structure uses "Miley" type hybrid, selected for its large bandwith and easy to manufacture in thin-film technique. We employed, as the mixing elements, beam lead Schottky diodes (H.P. 5082-2229).

- *Down-Converter Mixer-Preamplifier I*

The photomask and photography of the 4 GHz mixer preamplifier is shown in Fig. 10. The I.F. and O.L. traps were designed based upon a notch filter and low pass filter schemes respectively.

The I.F. signals generated at each diode (1.112,5 MHz), were added by means of a "Wilkinson" type combiner. As a result, isolation is obtained between the diodes and I.F. impedance matching becomes easier. The D.C. return was made by using a 1 mil gold wire lumped choke.

The I.F. output from the mixer is fed into a two stage preamplifier (1,112.5 MHz). The first one, a balanced stage, provides a low V.S.W.R. at the input, minimizing mismatching effects at the mixer-preamp interface. The overall amplifier presented 22 dB gain and 2.5 dB noise figure. Both circuits were built with bipolar transistors in chip form (HP-HXTR 2001), suitable biased for low-noise and high dynamic range achievements. The performance characteristics of this module are listed below:

- R.F. band:	3.7 to 4.2 GHz
- L.O. band:	4.8 to 5.3 GHz
- I.F. band:	1,112.5 ± 20 MHz
- Conversion Gain:	15 ± 0.5 dB

- Flatness: ± 0.1 dB
  (over any 40 MHZ segment)
- Noise Figure (SSB): 11.0 dB
- Output Power: + 16 dBm
  (at 1 dB compression)
- V.S.W.R. (all ports) < 1.5
- Isolation (L-R) > 13 dB

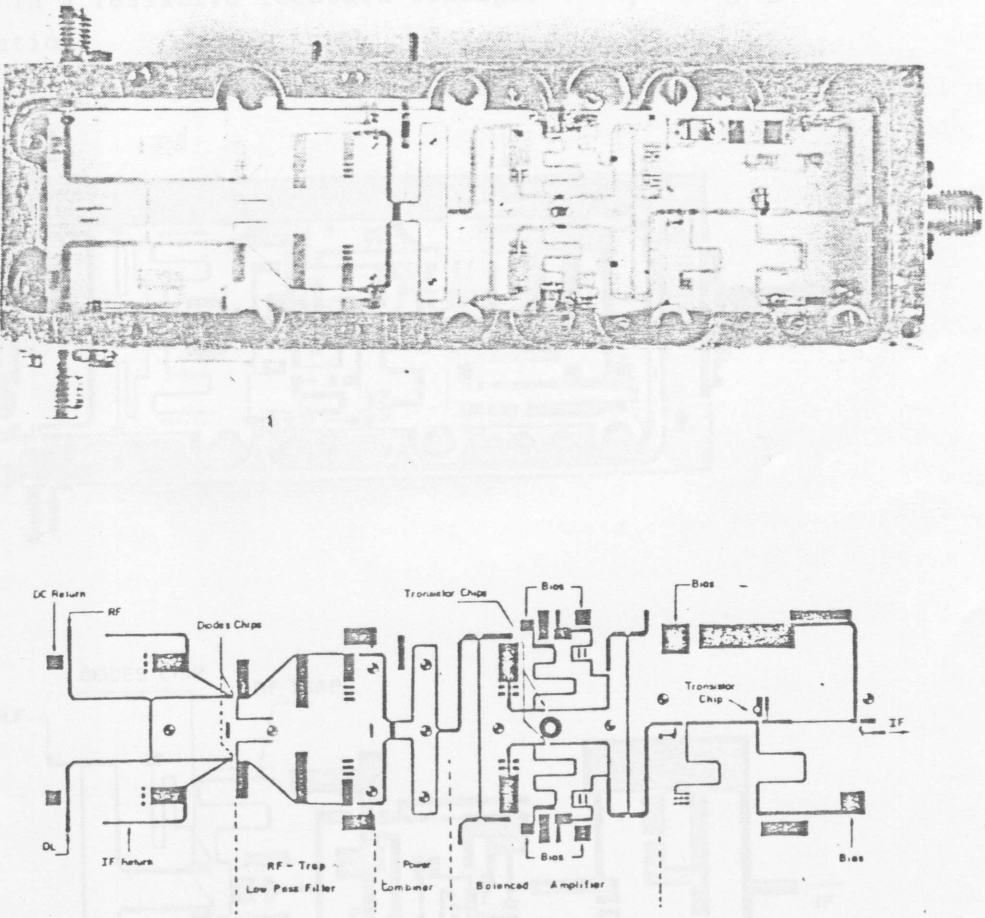


Fig. 10 - Photography and photomask of the Mixer-Preamplifier - I

Down - Converter Mixer-Preamplifier II

Figure 11 shows the 1.1 GHz mixer-preamp circuit photo-mask and photograph. The mixer beats the 1,112.5 MHz I.F. carrier with a L.O. in order to produce the 70 MHz baseband signal. The L.O. and I.F. traps were accomplished by means of 90° open-ended and short ended stubs, respectively.

The assembly includes a three-stage preamplifier with 30 dB gain and 4 dB noise figure. The transistor chips (HP HXTR-2001) were employed in a resistive feedback configuration, envisaging wide band amplification.

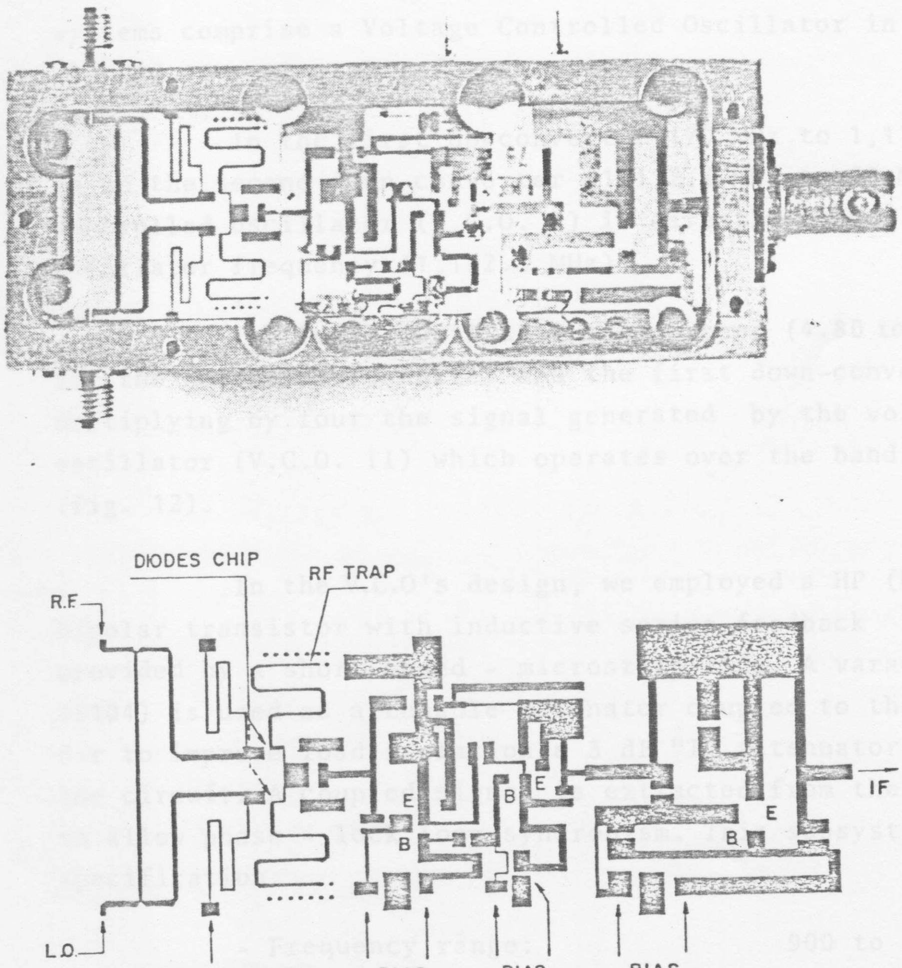


Fig. 11 - Photography and photomask of the Down-Converter Mixer Preamplifier II

The performance of this mixer-preamplifier II are listed below:

- Frequency: 1,112.5 ± 20 MHz
- L.O. Frequency: 1,182.5 MHz
- Lo.O. Power: + 10 dBm
- Conversion Gain: 20 dB
- Gain Flatness: 0.05 dB
- Noise Figure (SSB) 11 dB

III-4 - Local Oscillators

The local oscillators used in the reception and transmission systems comprise a Voltage Controlled Oscillator in the L-band, phase-locked to a crystal reference signal.

In the first up-converter (70 MHz to 1,112.5 MHz) as well as in the second down-converter (1,112.5 MHz to 70 MHz, the voltage controlled oscillator (V.C.O. I) is directly tuned to the local oscillator frequency (1,182.5 MHz).

The local oscillator tuning band (4.80 to 5.32 GHz) required for the second up-converter and the first down-converter is obtained, multiplying by four the signal generated by the voltage controlled oscillator (V.C.O. II) which operates over the band 1.20 to 1.33 GHz (Fig. 12).

In the V.C.O's design, we employed a HP (HXTR-2001) chip bipolar transistor with inductive series feedback in the base, provided by a short-ended - microstrip line. A varactor chip (MA - 45104) is used as a tunable resonator coupled to the emitter. In order to improve load isolation a 3 dB "T" attenuator is integrated to the circuit. A coupled signal is extracted from the resonant circuit to allow phase - lock loop syncronism. This subsystem has the following specification:

- Frequency range: 900 to 1500 MHz
- Tuning voltage range: 0 to 28 V
- Spurious output supression
  . harmonic: - 20 dBc
  . non-harmonic: - 60 dBc

- Frequency drift over temperature: 200 ppm/°C
- S:S.B. FM noise
  (10 KHz from the carrier in 1 KHz B.W.) - 55 dBc

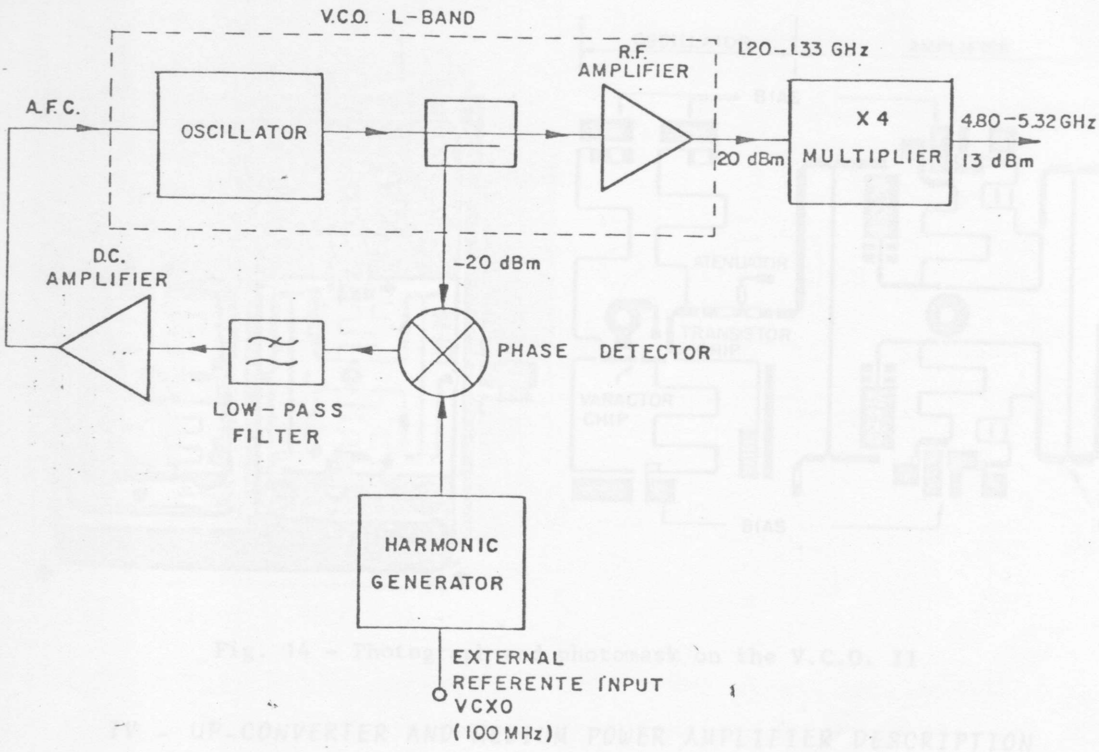


Fig. 12 - Functional diagram of the Phase-Locked-Oscillator

The voltage controlled, named V.C.O. I, is cascaded with an unbalanced bipolar transistor amplifier generating + 13 dBm output power (Fig.13).

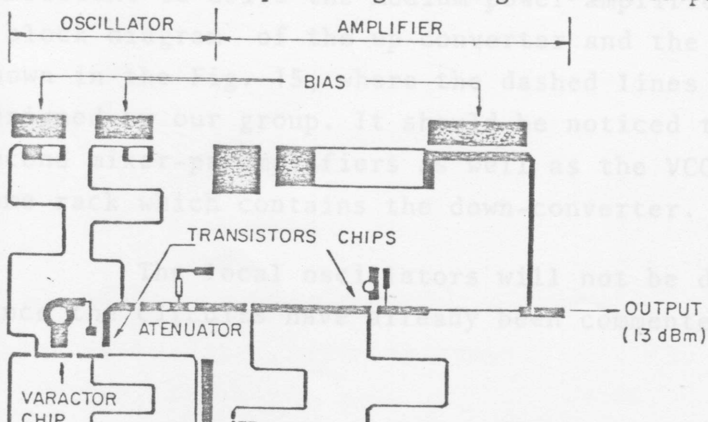


Fig. 13 - Photomask of the V.C.O. I

On the other hand the oscillator called V.C.O. II is followed by a balanced chip bipolar transistor amplifier (HXTR-2001), generating + 20 dBm output power (Fig. 14).

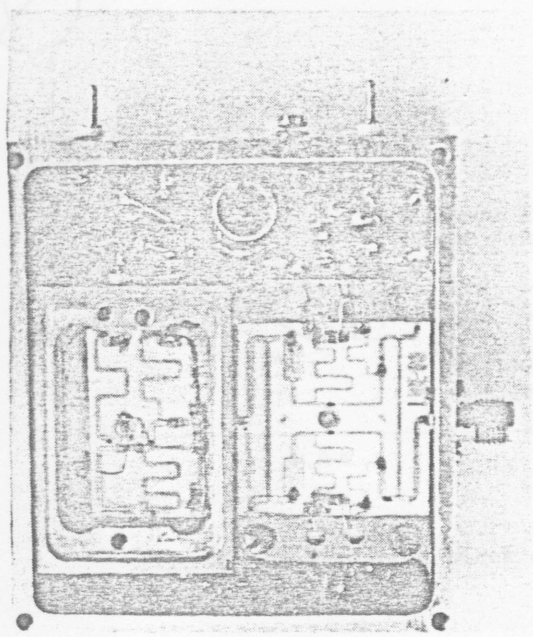
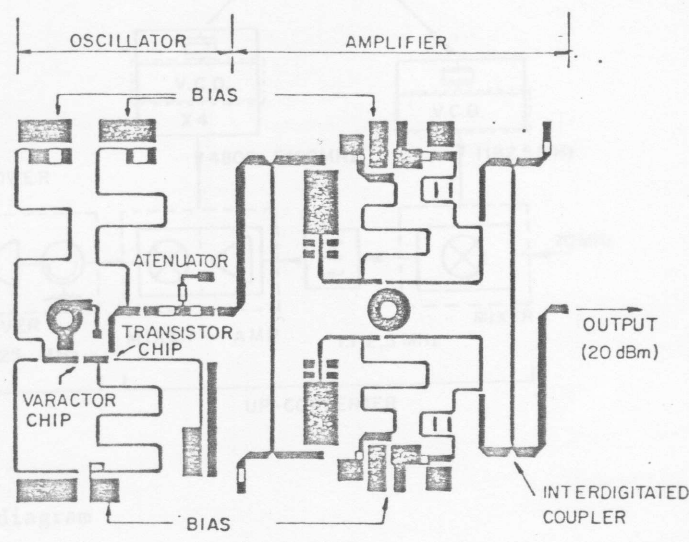



Fig. 14 - Photograph and photomask on the V.C.O. II

IV - UP-CONVERTER AND MEDIUM POWER AMPLIFIER DESCRIPTION

The transmit chain receives the 70 MHz I.F. from the based-band equipment and translates it into the 5,925 - 6,425 MHz link band, through a double convertion. The output power level (-2 dBm) is sufficient to drive the medium power amplifier located near the H.P.A. A block diagram of the up-converter and the high power amplifier shown in the Fig. 15, where the dashed lines indicate the circuits designed by our group. It should be noticed that the first and the second mixer-preamplifiers as well as the VCO's are located in the same rack which contains the down-converter.

The local oscillators will not be described in this section, since the circuits have already been commented in the last item.

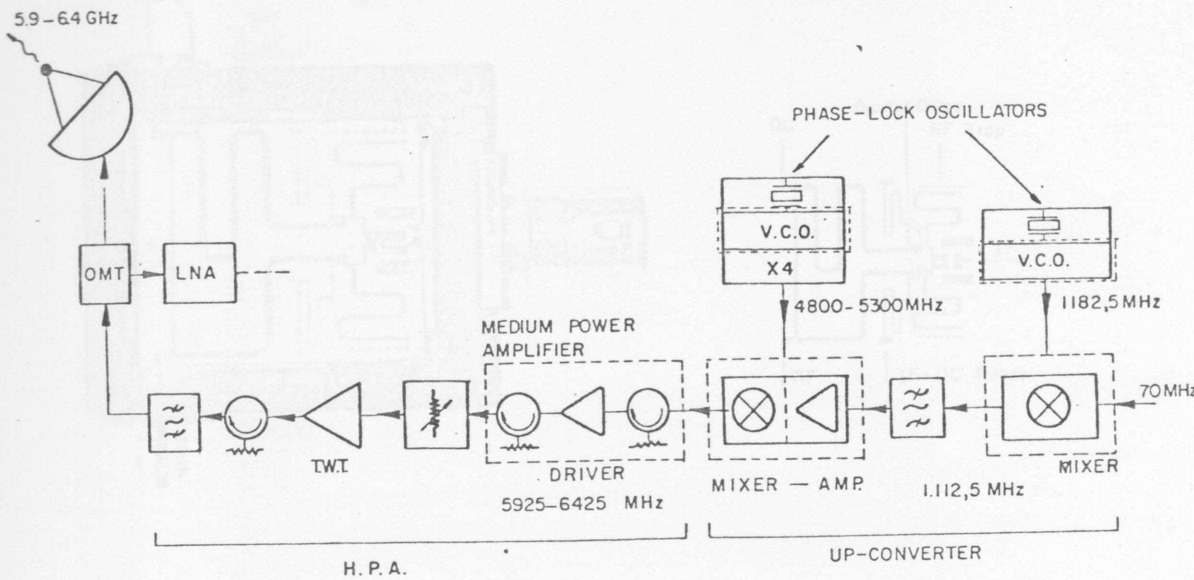


Fig. 15 - Transmitter block diagram

IV-1 - Mixer I

This mixer converts the 70 MHz signal into the 1,112.5 MHz I.F. The R.F. and O.L. traps were implemented by using the same stub structures as those employed in the second mixer down-converter. In order to improve L-R isolation, a 90° microstrip line was added at one of the coupled ports of the "Miley" hybrid to form a 180° hybrid. The wide band matching required at the I.F. port (75Ω) is provided by a series chip resistor. Fig. 16 shows the photomask and photography of this circuit.

The performance characteristics of the first mixer are given below:

- R.F. band:	1,112.5 ± 20 MHz
- L.O. frequency:	1,182.5 MHz
- I.F. band:	70 ± 20 MHz
- Conversion loss:	9.5 dB
- Third order intercept point:	+ 18 dBm
- L.R. isolation:	28 dB
- V.S.W.R. (I.F. port) L:	1.1

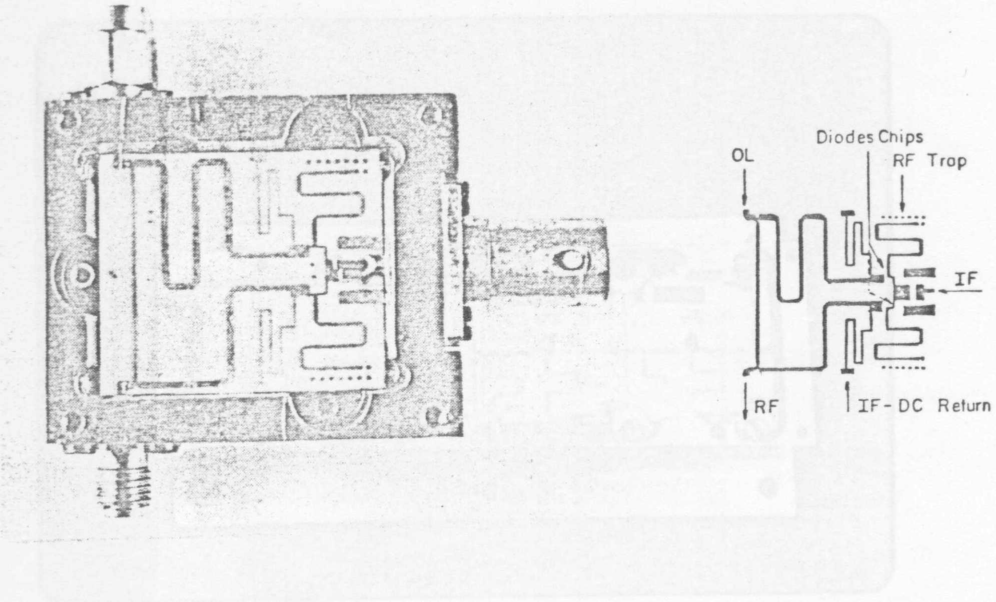


Fig. 16 - Photography of the Mixer I

IV-2 - Mixer-Preamplifier II

This module amplifies and converts the 1,112.5 MHz I.F. into the transmission frequency band, (5.9 to 6.4 GHz). The preamplifier increases the carrier level (-30 dBm) so that nominal level at the up-converter input may be attained (-8 dBm). It also employs two stages (22 dB total gain) as the preamp used in the down-converter. Apart from the L.O. traps and low-pass filters, now tuned to their respective frequency bands, the mixer circuit was built in the same structure used in the down-converter mixer.

This subsystem features the following characteristics:

- R.F. band:	5,925 - 6,425 MHz
- L.O. band:	4,800 - 5,300 MHz
- I.F. band:	1,112.5 MHz
- Conversion Gain:	15.0 ± 0.5 dB
- Flatness:	± 0.1 dB
- Noise Figure:	3.7 dB
- Output power: (at 1 dB compression)	0.0 dBm

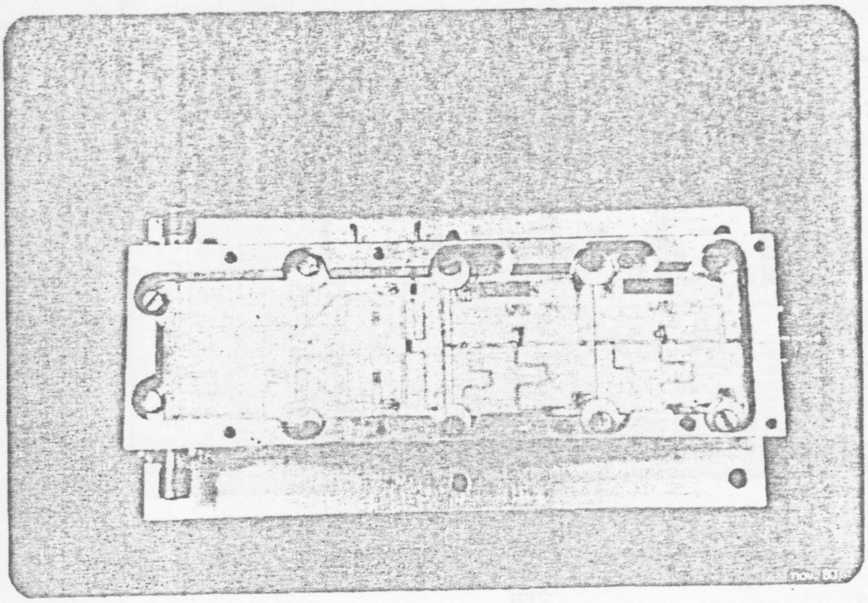


Fig. 17 - Mixer-Preamplifier II

IV-3 - Medium Power Amplifier

A medium power amplifier was developed in order to drive a standard bought-in TWT power amplifier. The MPA employs C band MSC power GaAs FET's and was made on alumina substrate, using thin film technology. The input and output ports include integrated ferrite isolators. The photograph and a schematic of the 3 stage amplifier with cover and bias removed are shown in Fig. 18.

The main characteristics presented by this system are:

- Frequency range:	5,925 to 6,425 MHz
- Power Gain:	24.5 ± 0.2 dB
- Output Power (at 1 dB compression):	22 dBm
- Third Order Intercept Point:	+ 33 dBm
- AM/PM Conversion (at 22 dBm)	<0,8°/dB
- Noise Figure	<8 dB
- V.S.W.R. in/out	<1,2

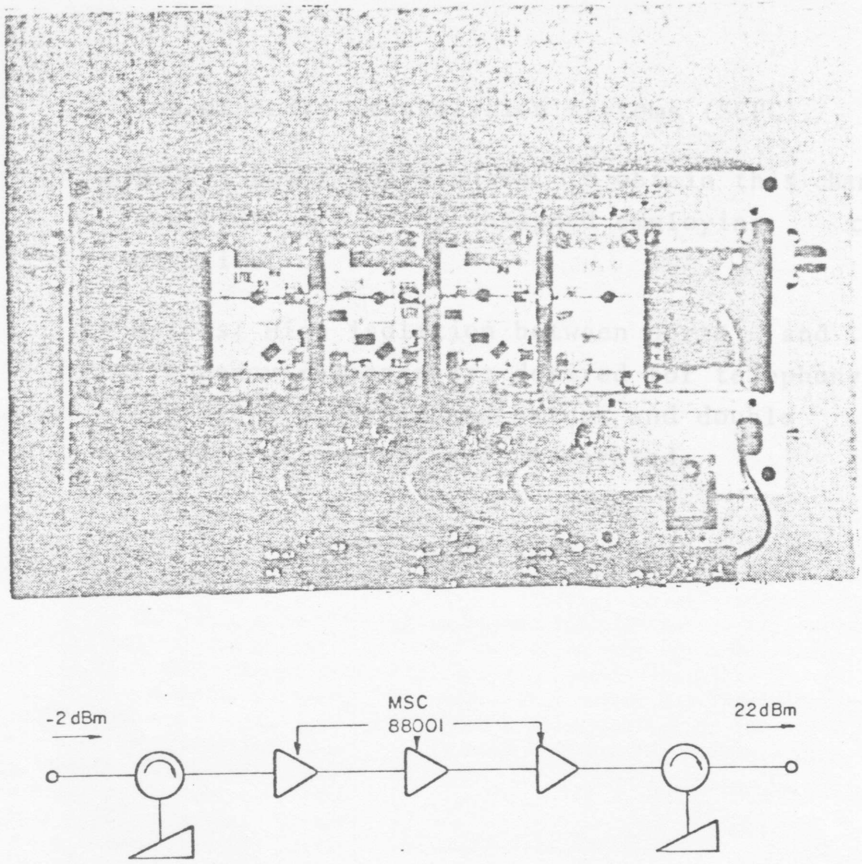


Fig. 18 - Photograph and schematic os 3 stage amplifier with cover and bias removed.

V - CONCLUSION

The earth station for TV signal reception (3.7 to 4.2 GHz) and transmission (5.9 to 6.4 GHz) has been assembled and tested using locally designed and constructed subsystems. It has been operating since 1981 presenting a good performance. At present, the Microwave Group at Escola Politécnica is mainly concerned with the optimization of the microwave modules, aiming at their utilization in a Front-End system for telephony.

The main goals to be reached in the near future are depicted as follows:

- Low noise amplifier: Noise temperature lower than 100°K over the reception frequency band.
- Medium Power Amplifier: Otuput power in the order of 5 watts, so that the module will be able to replace TWTs in some terrestrial links, as well as used in

low capacity transmission systems (SCPC).

- VCOs: Lower phase noise. To obtain this characteristic new VCOs are being designed employing coaxial cavities.

- Mixers: High isolation between ports and flatter frequency response are desired for telephony signals- The usage of broadband baluns and double balanced structures are being investigated.