MMICs for commercial satellite applications: from C and Ku to Ka band and millimeterwave

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Abstract

The application of MMIC technology to space hardware have seen a strong increase in the last years mainly to support the market demand for commercial satellite applications. Radiofrequency and microwave unit integrated in communication payloads for fixed (FSS), broadcasting (BSS) as well as mobile (MSS) services made extensively use of gallium arsenide MMIC designed and realised with european and american foundries. A new boundary will be the design and development of low cost, high production rate space hardware for satellite constellations like Celestri, Cyberstar, EuroSkyWay, SkyBridge, Spaceway, Teledesic. The paper will focus the application of MMIC technology in the Alenia Aerospazio on-board equipment engineering and production and will give a map of the present developments in conjunction with future trends.

Introduction

In the last years the satellite application have seen a strong increase in the space hardware demand as consequence of a broad offer of new commercial satellite services. As result of the fast evolution in the satellite commercial environment the payload complexity is growing with higher number of channels and units either in transparent and regenerative architectures. At the same time the required lead time is highly compressed, as consequence the technology solutions must address the miniaturisation issue, the design for production approach and the performance repeatability required for relative high volume productions. Only the massive use of MMIC technology allows to integrate complex microwave functions like LNAs, Front Ends, Receivers, Frequency converters, Channel amplifiers. The combination with advanced packaging techniques like MultiChip Module and Low Temp Ceramic Cofiring allows to achieve remarkable integration factors and impressive improvement with respect to the previous generation of space hardware. The definition and consolidation of MMICs screening flow including accelerated life test, burn in phases and lot acceptance tests has been very important in order to secure and assess, in the first application programs, satellite operating life of 15 years and more.

The modularity approach is another key feature of the MMIC application in the space equipment. Simple functions like Variable Gain Amplifiers, Flatness Correctors, Medium Power Amplifier, LNAs, Mixers and VCOs have been developed as building blocks and used in different configurations in the various modules and equipment. At present time low noise and power half micron MESFET and 0.25 μm PHEMT processes are used and are flying in space equipment produced by Alenia [1,2] and by other European companies [3]. Starting from 1996 a research and development effort is running to develop all the basic functions for next commercial system working at Ka band frequencies. The satellite payload configuration depends by the system requirements (transparent or regenerative architecture) but the basic function and modules can be easily reconfigured to build equipment for both configurations. At Ka band frequencies (30/20 GHz) the 0.25 μm PHEMT process is widely used [4] but some improvement can be achieved using the 0.13/0.15 μm gate lenght process. Ka band will be largely adopted in the future constellation systems where depending from the configuration and the amount of data to be transferred between the satellites, optical or V band Inter Satellite Link (ISL) will be used. For the millimeter wave ISL, receiver and transmitter modules working at 60 GHz will be needed and in this case the Indium Phosphide HEMT devices and MMICs have been identified and selected to obtain '*state of art*' performance.

Present MMIC Flight Hardware Applications

As mentioned in the introduction the market drivers in the design and production of space hardware in the last years can be summarized in the new paradigma: *better, faster and cheaper*. Having as reference a simplified transparent payload configuration (figure 1) can be easily understood that the Channel Amplifiers has been the first unit to see a massive use of GaAs MMIC. The MESFET process with half micron gate length has been used to realize a Voltage Gain Amplifier (VGA) circuit which is the basic building block of the microwave section and a MMIC flatness corrector to optimize the channel performance over 2 GHz bandwidth. The MMIC channel amplifier configuration in C and Ku band is exactly the same. The VGA MMIC provides the amplification function in conjunction with gain control capability. Figure 2 shows a C band VGA working in the bandwidth 3.7–4.2 GHz realised with the Alenia gallium arsenide foundry (Roma, Italy) with half micron MESFET process.

The corresponding function working in the bandwidth 10.7-12.7 GHz has been realised with Alenia foundry (figure 3) and in 1994 with Raytheon Advanced Device Center (Andover, USA) using a self aligned gate medium power low noise MESFET process (0.5 µm). The circuit (figure 4) is composed of three self-biased stages of amplification with an embedded analog attenuator. The analog attenuator is based on a broadband T design.. Each stage gives a typical gain of 14 dB over 2 GHz bandwidth (10.7-12.7 GHz) in combination with a gain control range of about 20 dB.

Low Noise Amplifiers, mixers and medium power amplifier have been used in the communication receivers. The FSS or BSS receivers provide low noise amplification and downconversion of signals in a portion of the frequency range 12.7-14.7 GHz or 17 - 18 GHz down to 10.7-12.7 GHz. A hybrid hermetic module mostly MMIC based has been designed to integrate the low noise, the mixer and the IF circuits. The LNA section uses as firts stage a hybrid MIC (HMIC) to achieve the best noise figure performances and two following stages based on GaAs PHEMT MMIC. Each stage is realised with a 0.25um pseudomorphic HEMT process. The design employs a self biased configuration with inductive source feedback on the first stage in order to achieve optimum noise figure associated to good input VSWR. A two-stage design is used at 14 GHz (figure 5) while three stages have been integrated in the 18 GHz MMIC (figure 6). Different hybrid mixers using beamlead GaAs Schottky diodes and MMIC designs (figure 7) convert the RF signal from the input frequency range down to the 10.7-12.7 GHz IF, the remaining part of the IF section is composed of a cascade of different MMIC circuits which provide the required gain, gain control dynamic (VGA) and linearity (MPA).

The best proof of the successful application of GaAs MMIC technology and of advanced microwave hybrid techniques is the production trend (figures 8, 9) in terms of used MMIC functions production and of complex microwave hybrids produced in the last years.

Present MMIC Flight Hardware Developments

New satellite services (as multimedia transmission) require communications in the frequency range from 20 to 30 GHz not only because of the amount of the transmitted data, but also to overcome the saturation of the channels in the Ku-band part of the spectrum. Moreover a huge amount of equipment having small dimension and weight is foreseen for the next future. In this frame the application of MMIC technology to Ka family circuits appears again the winning solution. As in Ku band the most attractive application for MMICs lies in the units which, depending on the payload complexity and configuration, are present in high quantities like receiver modules (Rx), frequency down and up converters (DWC, UPC), LNAs, channel amplifiers (CAMP) and linearisers (LIN). A conceptual block diagram of a regenerative payload is shown in figure 10[1]. It is adopted, with some differences, in all new programs for multimedia satellite services in the constellation systems as well as in GEO satellite.

A family of MMICs has been identified to be used in all the microwave modules and units [5]. A portion of this family has been developed (1996-1997) with Raytheon ADC using the standard 0.25 µm PHEMT process[2] and it has been completed with additional circuits designed and realised in cooperation with United Monolithic Semiconductors (Orsay, France; Ulm, Germany) in the frame of a development contract funded by European Space Agency. The MMICs are combined in different module configurations to build different units. In a transparent payload Ka band receivers (30/20 GHz), Ka band channel amplifiers and linearisers (20 GHz) are the basic electronic units[3].

The receiver hybrid module is a hermetic macrohybrid, integrating microwave open-carrier assemblies, and control multichip modules. The design makes extensive use of GaAs MMICs, embedded in passive circuitry realised on alumina. Low temperature cofiring ceramic is used for control circuitry. Circuits are mounted on copper-tungsten carriers or directly onto the kovar housing. The low noise amplifier front end is designed as a hybrid MIC using discrete 0.15 µm PHEMT device (1.2 dB NF @ 30 GHz). The MMIC building blocks are:

- a 20 to 30 GHz Low Noise Amplifier (KLNA)
- a 30/20 GHz Mixer (KMXR)
- a 20 to 30 GHz Variable Attenuator (KVA)
- a 9 to 12 GHz Voltage Controlled Oscillator (VCO)
- a 20 GHz Medium Power Amplifier (MPA)

[1] For transparent payload the basic architecture shown in figure1 is still applied at Ka band frequencies

[2] Typical process parameters are: Ft = 50 GHz , minimum noise figure of 0.8 dB at 15 GHz, Idss=120mA/mm; Gmp=375 mS/mm; Vp=-0.7 Volts; Vbgd=-10.

[3] In some payload configurations the low noise amplifier sections and the frequency down converters are separated functions

The LNA MMIC working at 30 GHz (figure 11) is composed of three self-biased PHEMT stages. Self biased configuration has been used to allow compatibility with the other circuits at equipment level and source feedback was used in the first stage to get at the same time good input matching and noise figure. The LNA optimized at 20 GHz (figure 12) is based on the same configuration but integrates four stages to obtain the required performance. A circuit designed with UMS optimizes the lower bandedge performance providing wideband response in the frequency range 17.5 to 31.5 GHz (figure 13). The Ka band MMIC mixer (Figure 14) is a cold FET resistive mixer in a balanced configuration in order to effectively reject spurious outputs such as the 2nd LO harmonic and guarantee a good linearity performance. The analog attenuator (KVA, figure 15) is a wideband balanced shunt-FET attenuator where the FET drain to source resistance is used as a variable resistor. This approach was chosen because of its simplicity (no dual voltages are needed to drive the attenuator) and for its minimal VSWR variation and flat gain response over the attenuation range. The KVA chips are used within the module for thermal compensation of the gain. A 20 GHz Medium Power Amplifier (figure 16) has been designed to be used as last element of the RF chain, to enhance linearity. Four stages are used to achieve the required gain, power and bandwidth performances.

In the integrated receiver the local oscillator section, PLL based, receives a highly stable reference signal coming from external TCXO and makes use of a MMIC voltage dielectric resonator oscillator (VCDRO, figure 17) directly at a frequency in the range 9 to 12 GHz. The MMIC design is based on a GaAs FET device, the oscillator frequency depends on dielectric resonator characteristics, dimensions and its position with respect to the gate line while the varactor diode, coupled to the resonator, gives the capability to change the output frequency by means of the control voltage.

The channel amplifier [6] provides amplification of a Ka band signal (17.5 to 21.5 GHz) allowing selection of either linear gain or output power level in discrete steps, by means of an external command. If the Automatic Level Control mode is enabled the output level is limited by the ALC loop which compensates any input power variation within the loop's range (-30 to -55 dBm). ALC function may be inhibited for Fixed Gain (FG) operation depending on the application. Temperature compensation is implemented to guarantee gain stability in the fixed gain mode. The unit is designed around two basic MMIC functions: the 20 GHz low noise amplifier (LNA20) and the wideband 18-32 GHz Variable Attenuator. A linearized version provides a gain and phase response able to compensate the TWTs compression characteristics, causing the third order intermodulation products to be reduced. The equipment is designed as a predistortion linearizer, whose concept is to combine with proper amplitude and phase relationships the responses of two branches, one operating under compression and the other operating linearly. The linearizer is designed to provide a gain expansion above 6 dB and a phase expansion above 35 deg from 18 dB backoff to 3 db above TWT saturation input. A monolithic phase shifter has been designed (figure 18) in order to provide the phase shift function and constant group delay over the band.

The modules and function required in regenerative payloads are easily derived from the other configuration. As shown in figures 19 and 20 in the payload receiver section the integrated receiver usually is replaced by individual LNA functions and, through a redundancy ring, by a bench of frequency down converters. In the transmitter sections the channel amplifiers, standard or linearized, can be integrated with the up converter functions in a single module.

The number of satellites to be build for emerging satellite services and the payload complexity in terms of overall data throughput will support a remarkable trend in the number of modules and units to be produced with strongly reduced lead-times. The MMIC technology, as demonstrated in the consolidated Ku band payload applications, continues to be a key technology in the achievement of technical and industrial goals in the fast evolving commercial satellite world.

Millimeter Wave Applications

The development of broadband satellite systems will represents a revolution in the communication over the next few years [7]. The systems under development in Ka band will require intersatellite links to exchange information between the constellation spacecrafts or between GEO satellites in different orbital positions. Next generation systems[4] will exploit the V band not only for ISL but also for the communication with ground. Receiver modules will integrate a low noise front end working at 60 Ghz and a frequency conversion down to the regenerative payload IF (i.e. 5.5-7.5 GHz) while transmitter modules will integrate the up conversion function and the amplification to drive the power amplifier.

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[4] Motorola amended its original application to FCC for Celestri to request authorization for both V-band and Ka-band payloads. Expressway, a Hughes Communications Inc. constellation to provide global capacity, will use 3 GHz up and down link bandwidth in V band.

InP devices (HEMT and MMIC) are recognized to offer significant advantages in terms of noise figure, higher gain, power consumption and power added efficiency compared to GaAs based MMICs. With the growing maturity of the related processes, foundries [8, 9] are actively working in the InP devices application in the mmwave region. HRL Laboratories (Malibu, CA, USA) have proven the very good achievable performance mainly for low noise functions. Measured noise figure less than 2.5 dB have obtained in a two stage MMIC LNA while a V band mixer (60 GHz RF → 6-10 GHz IF) showing a conversion loss less than 10 dB has been realized [10]. On the other hand the transmitter function working at 60 GHz can benefit of very promising InP power device results showing an output power greater than 250 mW with PAE greater than 20% (HRL Laboratories). The maturity of InP devices, their very attractive performances and the trend to use mmwave systems to communicate identify a clear future, also in this application domain, for MMIC technology.

Conclusions

MMIC technology for space has been consolidated in the last years and the applications continuously grow in terms of higher frequencies (Ka band, mmwave), new devices, improved processes and other semiconductor compounds. A number of MMIC families has been designed in the last years, covering all the frequencies and the required functions for payload and active antenna technologies. The paper summarizes some of the achieved results in the RF and Microwave engineering group at Alenia Aeropsazio showing a spread of applications and realizations done in cooperation with European as well as American foundries and laboratories.

Acknowledgments

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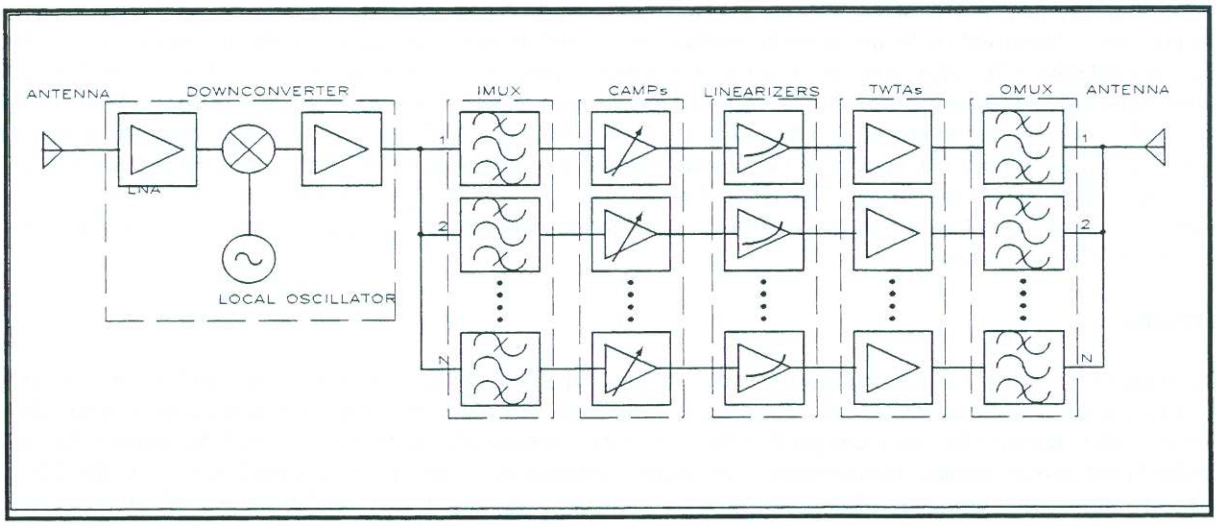

Figure 1 – Transparent Payload conceptual configuration

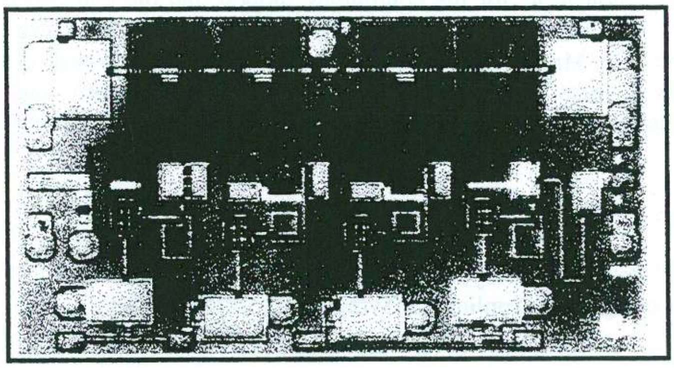

Figure 2 - C Band VGA (Alenia)

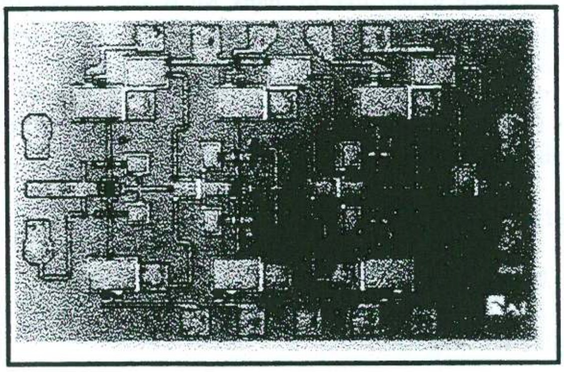

Figure 3 - Ku Band VGA (Alenia)

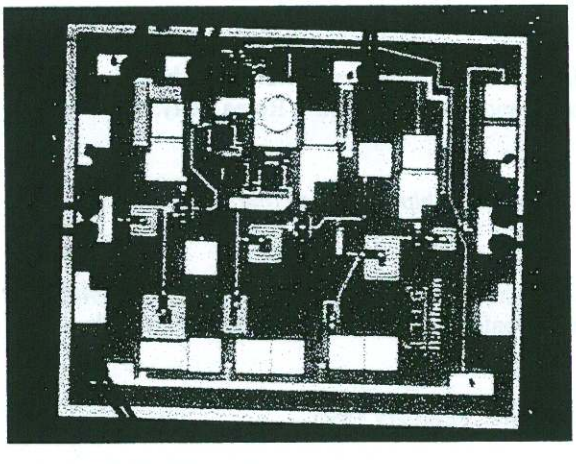

Figure 4 - Ku Band VGA (Raytheon)

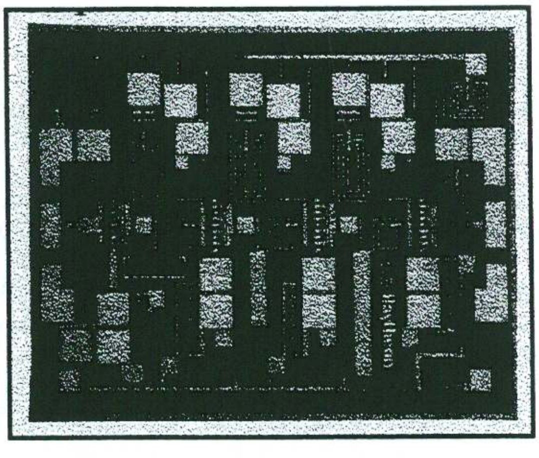

Figure 5 - K Band LNA (Raytheon Foundry)

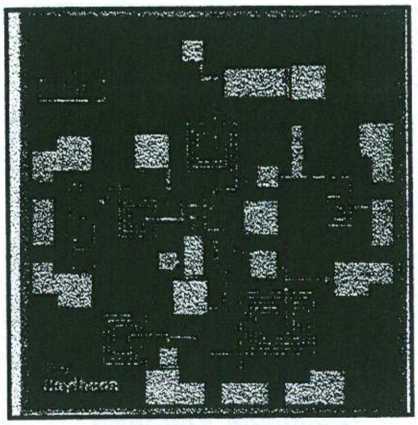

Figure 6 - Ku Band Mixer

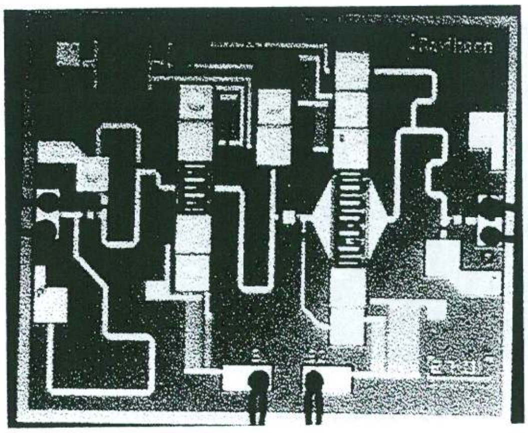

Figure 7 - Ku Band Medium Power Amplifier

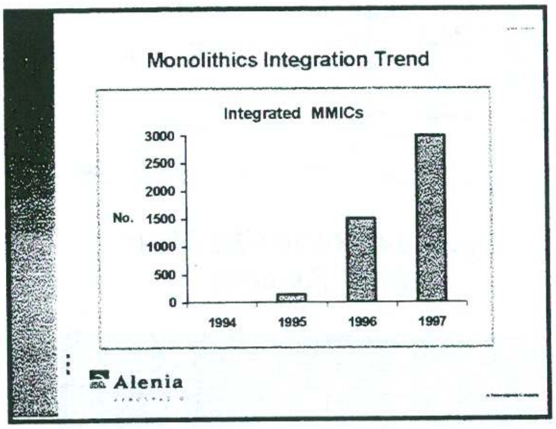

Figure 8 - Flight MMICs Integration Trend

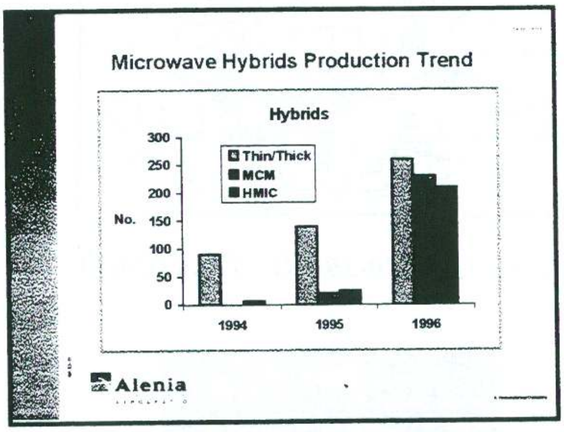

Figure 9 - Flight HMIC Hybrid Integration Trend

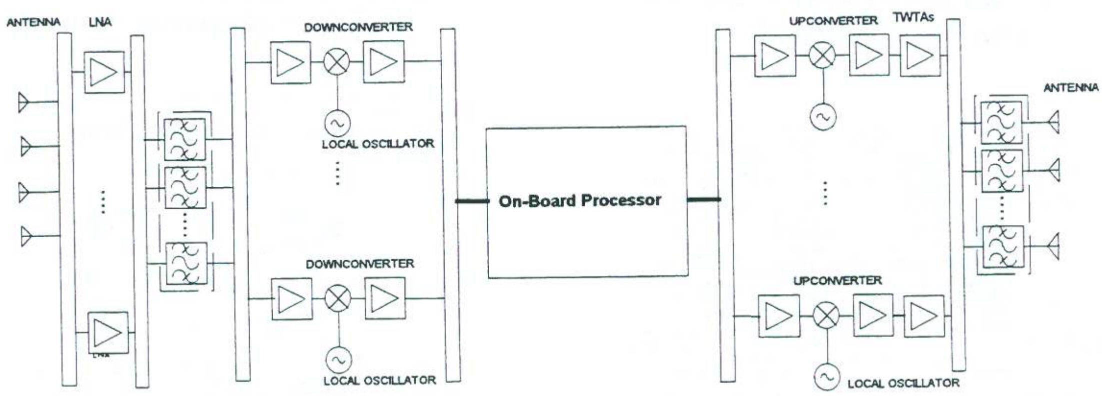

Figure 10 – Regenerative Payload Conceptual Block Diagram

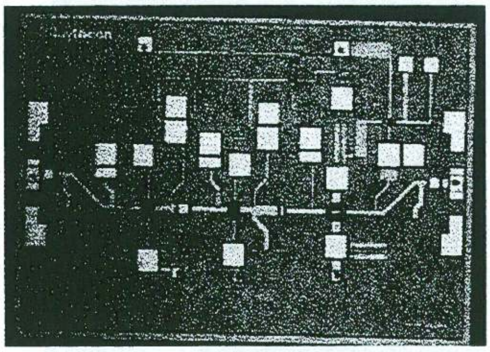

Figure 11 – 30 GHz LNA (Raytheon)

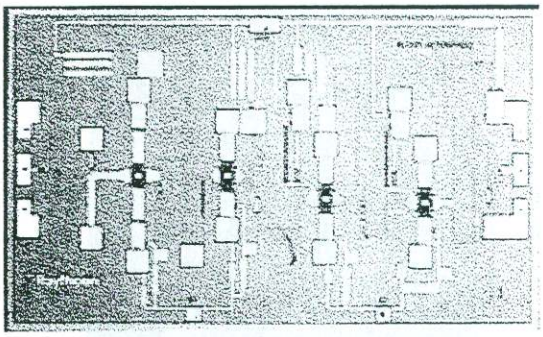

Figure 12 – Ka Band 20 GHz LNA (Raytheon Foundry)

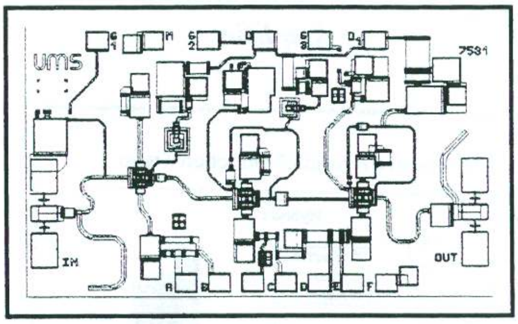

Figure 13 – 20-30 GHz LNA (UMS)

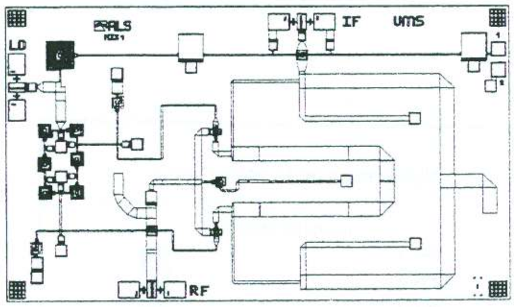

Figure 14 - 30/20 GHz Mixer (UMS Foundry)

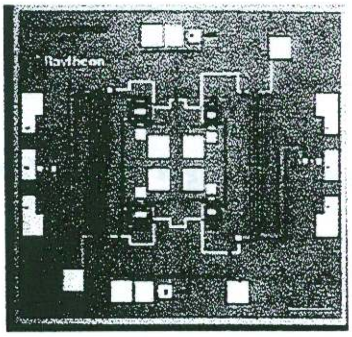

Figure 15 – Ka Band Variable Attenuator (Raytheon Foundry)

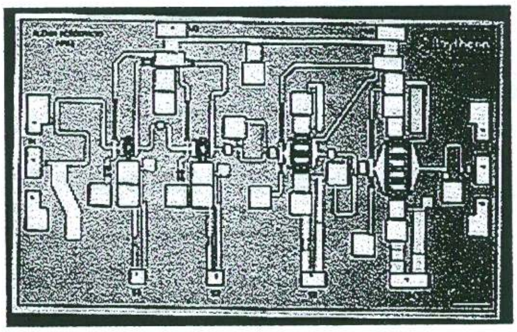

Figure 16 – Ka Band Medium Power Amplifier (Raytheon Foundry)

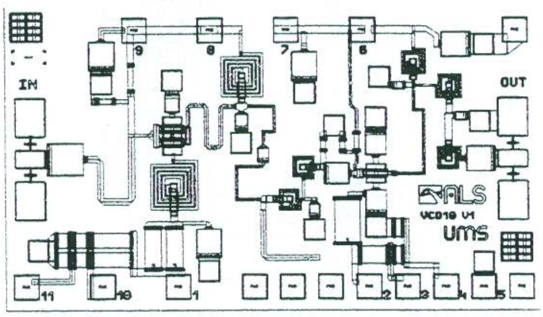

Figure 17 - 9-12 GHz MMIC VCO (UMS Foundry)

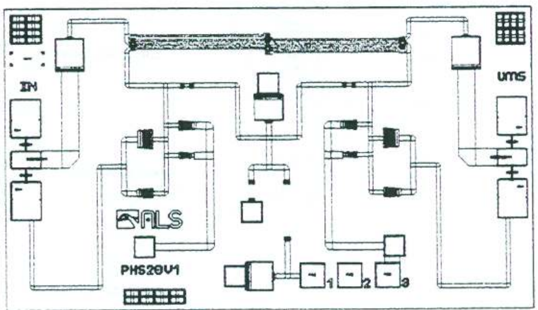

Figure 18 - Ka Band Phase Shifter (UMS Foundry)

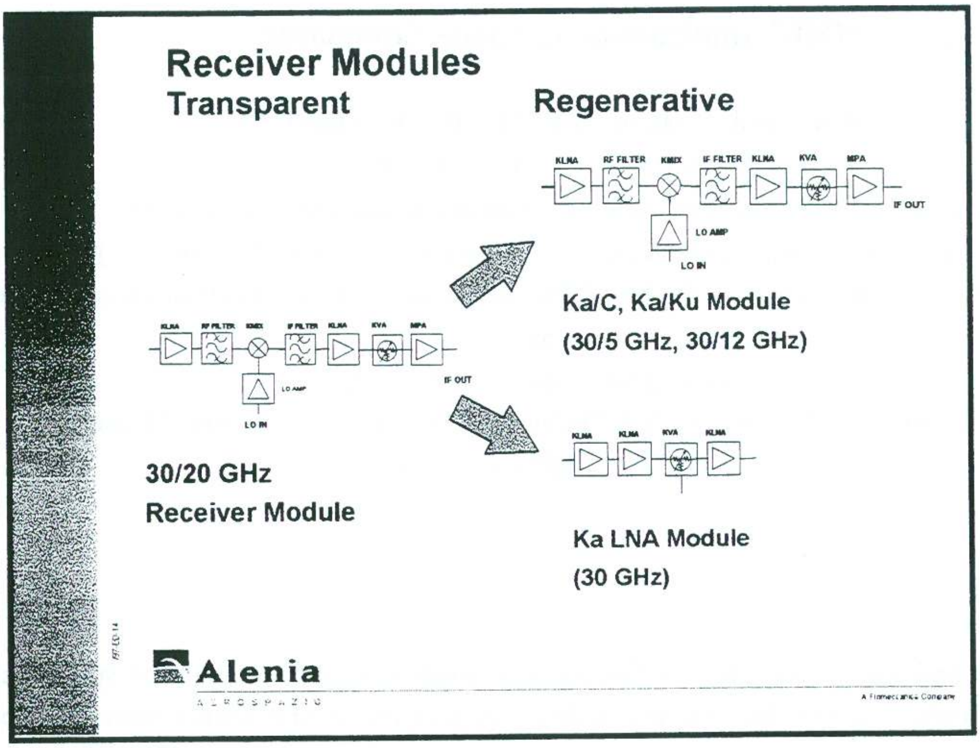

Figure 19 - Ka Band receiver modules for transparent and regenerative configurations

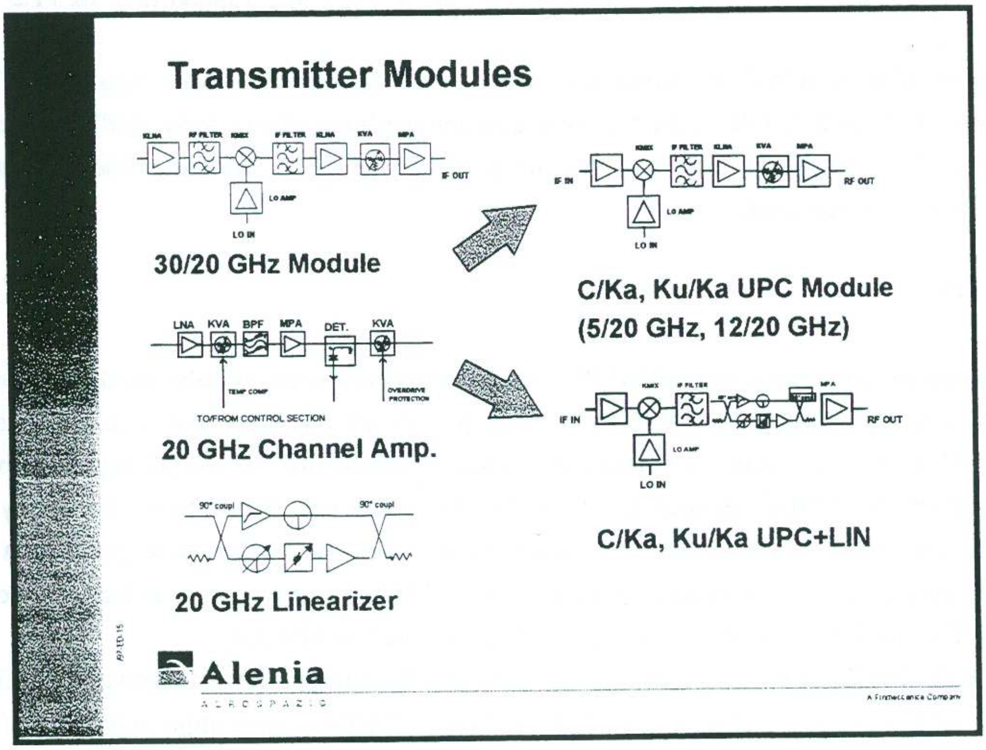

Figure 20 - Ka Band Transmitter modules for transparent and regenerative configurations