MMIC's ARE NOW EFFECTIVE IN SPACE PROGRAMS

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Abstract

Since their first apparition, MMICs have been considered as very promising devices to allow miniaturization, increased reliability and cost reduction of space-borne equipment [1]. All actors, i.e. agencies, foundries and payload manufacturers have joined their efforts to promote the introduction of MMICs in space programs. The aim of this paper is to illustrate this evolution taking examples from the achievements accomplished at Alcatel-Espace.

Introduction

The main services of satellite systems using microwave circuits are:

- Fixed Satellite Service (FSS) for voice (telephone) or data transmission. They are on Geostationary orbits (GEO) for most conventional systems.. Some recently proposed satellite clusters for multimedia are using Low Earth Orbit (LEO).
- Broadcasting Satellite Service (BSS) from GEO. Applications are for radio or television, like Direct Broadcasting Satellite (DBS) for instance.
- Mobile Satellite Service (MSS) from GEO or LEO. Different applications exist whether the mobiles are on Land, Maritime or Aeronautical.
- Earth Observations mainly from space-borne radar in LEO.

Table 1: Allocated frequency bands for FSS links.

Band	Uplink	Downlink
C-Band	Around 6 GHz	Around 4 GHz
X-Band (Government Use)	Around 8 GHz	Around 7 GHz
Ku-Band	Around 14 GHz	Around 11-12 GHz
Ka-Band	Around 30 GHz	Around 20 GHz
EHF (Government Use)	Around 44 GHz	Around 20 GHz

The major part of the satellite commercial business is on telecommunications nowadays and, mainly, for GEO-FSS. The Table 1 indicates the allocated frequencies for this application.

A classical telecom payload includes several units were MMICs can be inserted:

- Receivers transposing the input frequencies down to the output frequencies.
- Channel Amplifiers (CAMP) adjusting the gain of each channel of the repeaters and operating at the output frequencies. The CAMP may include an ALC (Automatic Level Control).
  Also, the CAMP may be followed by a Linearizer in order to limit the effects of non-linearity.
- Solid State Power Amplifiers (SSPA) mostly up to C-Band were they fairly compete with Traveling Wave Tube Amplifiers (TWTA). The later is more used at Ku-Band and higher.
- TTC (Telemetry, Tracking and Command) Receivers which receive control signals from the ground and Transmitters which transmit information concerning the satellite.

CAMPs and Linearizers

As in others companies, MMICs have been first applied in CAMPs. This was prompted by the fact that this equipment is most commonly used in rather large numbers for commercial satellites. Another motivation for this choice is the use of simple low level circuits, mainly amplifiers and gain controllers (controllable attenuators).
Ku-Band CAMPs were the firsts to be designed and manufactured with MMICs. Three types of circuits were used: Low Level Amplifier, Variable Attenuator and Flatness Corrector [2]. At this occasion, an MMIC process has been formally space-qualified for the first time [3] following the methodology proposed by the French Administration [4].

Table 2: Summary of Satellites equipped with MMIC CAMPs.

Program	Band	Number of MMIC per CAMP	Number of CAMP per satellite
AMOS	Ku	7	9
ARABSAT 2	Ku	7	34
	C	14	24
TURKSAT 1C	Ku	7	24
TELECOM 2D	Ku	7	15
HOTBIRD 2 Plus, 3 and 4	Ku	10	3 x 28
MABUHAY	Ku	7	32
	C	6	38
SINOSAT	Ku	10	18
NILESAT	Ku	10	32

As an illustration, the Ku-Band CAMP on-board AMOS includes 7 MMICs. Its gain is adjustable from 51 dB to 16 dB, with 0.5 dB step resolution. The flatness is better than 0.5 dBpp from 10.9 to 11.7 GHz and the DC consumption is 2 W. This CAMP has permitted a mass and cost reduction by a factor 2.5 from the previously employed discrete FETs hybrid families in satellites EUTELSAT 2 while keeping the same performance rating.

AMOS will probably be the first to be launched within few weeks in 1996 and will be followed by numerous programs which, also, make use of Ku-Band MMIC CAMP. They are mentioned on Table 2.

C-Band CAMPs usually go along with pre-distortion linearizers to improve the power budget of the repeater. Then they need a typical number of 12 MMICs chips including a Phase-Shifter as supplementary function. ARABSAT 2 has been the first program to incorporate such a sub-system. Its launch date is planned for 1996.

Telecom Receivers

The next step was to introduce MMICs in Telecom Receivers.

The receiver is a more complicated RF sub-system and it can be considered as the core of the repeater. It consists of:

- a low noise amplifier (LNA) at the uplink frequency,
- a frequency converter which is a microwave mixer,
- a local oscillator (LO) generating a reference frequency. It is generally stabilized by a phase-locked loop (PLL)
- an amplification chain at the downlink frequency.

Due to very demanding performance, not all microwave functions use MMIC technology. First stage of LNA, for instance, is still based on discrete PHEMT hybrid. However the situation is changing rapidly with the progress of monolithic technology and MMIC have already conquered functions as frequency conversion and linear output amplifier. Uplink frequency amplification will undoubtedly be in MMIC within few years.

An MMIC receiver incorporates about 10 MMIC chips. Its typical performance is summarized on Table 3.

The needed MMIC chips are : LNA and/or Low Level Amplifiers at input frequency, Balanced Mixers for frequency conversion [5], so-called « Negatrons » (Negative resistance circuit for the VCO), Multipliers when necessary for the LO [6], Attenuators, Low Level, Medium Level and High Linearity Amplifiers at output frequency. Two or three different foundries or processes might be used in order to optimize every function:

- Standard low level 0.5 um MESFET process (same as for CAMPs),
- High level process: 0.5 um Power MESFET or HFET, (or PHEMT or HBT in future)
- Very low noise process if necessary like 0.25 um PHEMT.

Some MMICs have been already inserted in receivers for programs like TELECOM 2D, MABUHAY and NILESAT in Ku-Band, and receiver with complete set of MMICs are now proposed in coming programs in C, Ku and, also, Ku+ (18/12 GHz) for DBS application.

Table 3: Typical main performance of MMIC Ku-Band telecom receiver

Performance	Receiver
Gain	60 dB
NF	2 dB
Linearity (IP3)	28 dBm
In-Band Spurious	60 dBc
DC Consumption	7 W
Weight	500 g

SSPAs

There is still a tough competition between SSPA and TWTA for RF power generation on satellite payloads. The first has the obvious advantage of compactness and a more discussed edge for reliability. However TWTAs are still improving and present power added efficiency larger than 60% which put them ahead of SSPAs. This fact is less pronounced when frequency decreases, and, today, the limit for SSPA use is at C-Band (except for active antennas where, for size limitation, SSPAs are preferred at Ku or higher).

C-Band SSPAs present up to 25 W of output power with about 70 dB of gain around 4 GHz. Therefore they perform also the role of the CAMP and need several kind of amplifiers from low level to high power. In addition to the power amplification, there are other functions which are needed like gain control or pre-distortion linearizer. In Alcatel-Espace designs, about 18 MMICs are employed up to a power level of 2W approximately, the rest being achieved under discrete form with our naked chips power hybrid fabrication line.
Programs like INTELSAT 9 in C-Band or Mobile communication payloads in L or S Bands will assuredly use MMIC SSPAs in near future.

Satellite Constellations

The telecommunication satellite market is quite exploding with spectacular announcements of several satellite clusters for the end of the century. LEO constellations like Iridium, 66 satellites and GLOBALSTAR, 48 satellites (plus 8 spares) represent a first « generation » devoted to worldwide cellular personal communication services. Both programs are expected to start their services in 1998.
Each Iridium satellite will use more than 1600 MMIC chips [7].
For GLOBALSTAR, Alcatel-Espace has manufactured C/S downconverters (16 per payload), 2 telemetry transmitters and 2 telemetry receivers which give a total of 94 MMICs per satellite (Low level amps, Mixers, VCOs, Multipliers and Power amps). The total number of MMICs assembled in this program by Alcatel-Espace comes to 5264. (See Table 4).
Such high numbers represent a real break in the work organization of space-borne equipment.
With sub-systems from other partners, the count part number of MMICs will exceed 800 per GLOBALSTAR satellite [1]. The total number of chips necessary for those two major mobile telephone programs exceed 150 000 chips.

Table 4: Count part numbers of MMICs and sub-systems for GLOBALSTAR Alcatel-Espace equipment (56 Satellites)

Sub-system	Number of MMIC per equipment	Number of equipment per satellite	Number of equipment fabricated
C/S Converter	5	16	896
TTC Transmitter	3	2	112
TTC-Receiver	4	2	112

A second « generation » of satellite constellations is making the headlines nowadays. They are FSS systems which plan to offer interactive video and multimedia communications services beginning in 2001 or 2002.
First to be announced is the astonishing system of TELEDESIC with 924 satellites whose 840 are active in orbit (700 km) ! The frequency used is Ka-Band (30/20 GHz). With the emerging of 0.25 um PHEMT foundry, MMICs are the unavoidable technology for this application. Alcatel-Espace has developed a set of MMIC chips with the PML D02AH process [8]. This process is currently under a space-qualification program managed by the French Administration (CNET/CNES/DGA).
An other approach has been recently proposed by Alcatel-Telecom with the program named SATIVOD. It consists in a 60-satellite constellation operating at Ku-Band (14/12 GHz) [9].
Both concepts will be based on steerable active antennas having very large numbers of microwave modules. It is most likely that those will be extremely compact, demanding a lot of efforts for higher integration at MMIC design and, above all, at packaging level.

All these programs impose severe cost restraints and, therefore, give a real opportunity for MMIC technology.

T/R Modules

Another area of concern for MMICs space application is Earth observation. MMIC technology with increasing manufacturing yield has made possible to consider active antennas with large number of Transmit/Receive modules for synthetic aperture radar (SAR).

Three main programs have been recently conducted at Alcatel-Espace: the SPOT RADAR demonstrator in X-Band supported by the CNES [10], a military radar program and ASAR. The later is the second generation of SAR instrument promoted by ESA. The first generation was ERS1 (launched in 1991) and ERS2 (launched in 1995). Offering additional advantages (as dual polarization, wide swath capability , greater coverage,...). ASAR will be the C-Band (5.331 GHz) radar of the ENVISAT payload of ESA. It will be launched in 2000 and will be the first space-borne SAR with active T/R modules in Europe.
The ASAR active antenna will incorporate 320 T/R modules (TRM) which make use of 15 MMICs each, designed by either Alcatel-Espace or Matra Marconi Space. The microwave component technologies are discrete PHEMTs for the LNAs, power MESFETs for the SSPAs and MESFET MMICs for all other functions. All manufacturer sources are European.
Each TRM weights 170 gr. Their main performance is about 10 W Output Power with 0 to 40 dB Transmit Gain and about 3 dB Noise Figure with -10 to 30 dB Receive Gain. The mean consumption (with 6% Tx and 60% Rx duty factors) is 3.2 W.

After the completion of a B phase in 1993 with the test of 40 DM (Demonstration Model) TRM, the program continues with Alcatel as Design Authority for the TRM and the manufacturing of 80 EM (Engineering Model) in 1995/96 and 320 FM (Flight Model) in 1997 at both Alcatel-Espace and Matra-Marconi Space [11].

Prospective and Conclusion

MMIC's are now clearly unavoidable for space-borne equipment design. When used on classical equipment they have demonstrated that mass and cost can be divided by a factor 2.5. As an illustration, the Ku-Band CAMP of Telecom 2D weights 200g where the one of EUTELSAT 2 was about 550g for a comparable performance. The miniaturization is continuing, the next generation will be the 3D MCM (Multi Chip Module) technology which employs multilayer RF substrates to interconnect ASICs and MMICs into a single housing. An MCM CAMP has been developed and is under industrialization. Its weight has been reduced to 95g for the same functionality.
Also of importance is the fact that MMICs have allowed the emerging of new concepts which require very large numbers of compact, reproducible and reliable circuits at the least cost. This type of production is already a reality with satellite constellation for mobile communication as for GLOBALSTAR or radar active antenna as for ENVISAT/ASAR. In telecommunication also, active antennas represent the natural evolution to respond to the increasing demand of operational flexibility. Power-sharing among the beams, reconfigurability, steerability, beam-hopping, beam-scanning are some of the new possibilities offered with the active antennas. An experimental program is on-going in France with STENTOR which will employ a Ku-Band active transmit antenna using 48 5W-SSPAs. Multimedia projects like TELEDESIC or SATIVOD will marry large number of satellites and active antenna leading to the need of a tremendous number of MMIC modules. For those, it is clear that demonstrate and produce very advanced high density packaging is certainly one of the most important challenge of the coming years.
Then, we are convinced that MMICs have just entered the world of space electronics and that their future is undoubtedly bright in this field.

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