New Trends for Microwave Packaging into Space-Borne Equipment

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This paper focuses on the most promising evolutions which are emerging in the packaging of microwave functions for space applications. Starting from the former micropackage solution, continuing with the current MCM technology, new routes are then reviewed. Those include flip-chip which has the huge advantage of short and reproducible connections, glob-top and other non-hermetic approaches. All of them are major departures from the present situation if not a complete revolution. Finally, a special attention is given to MEMS as these new devices can also bring their own intrinsic packaging solution. This is one of the most intriguing and captivating outcome of their apparition : at last, the convergence of electrical and mechanical expertise.

INTRODUCTION

Miniaturising modules and increasing the frequency while maintaining manufacturing cost at minimum, has been the continuous trend for microwave space equipment ; as well as in many other industrial sectors. However, space always had a special flavour due to stringent environment requirements. Compliance with space qualification has always been compulsory and hermeticity is so far an inviolate rule.

This paper focuses on the most promising evolutions which are emerging in the packaging of microwave functions for space applications. Starting from the existing technologies, several new routes are going to be reviewed which are in some cases major departures from the present situation if not a complete revolution.

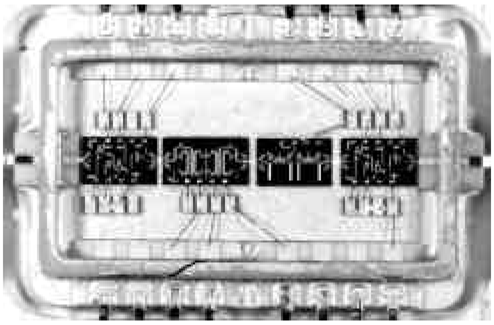
FROM MICROPACKAGES TO MCM

In the 80s, most of RF hybrids were based on a monolithic Kovar® body with glass sealed feedthroughs for both LF and RF in/outs. The different parts of the RF functions (discrete transistors, passives, thin film alumina substrates) were soldered on metallic carriers; then those carriers screwed into the package.

At the beginning of 90s, the microwave industries saw the blossoming of GaAs MMICs. To accommodate them, we had to develop a new microwave packaging system able to :

- preserve the high intrinsic reliability of GaAs dice, notably by providing a contamination-free environment,
- provide a low loss interconnection system, both within the module and to the outside world, for keeping the MMIC performance,

The selected solution has been micropackage made of metallic parts for bottom and walls and 50Ω cofired ceramic feedthroughs. Together, the use of MMICs and micropackages drastically reduced the weight – and the cost - of equipment by 50%.

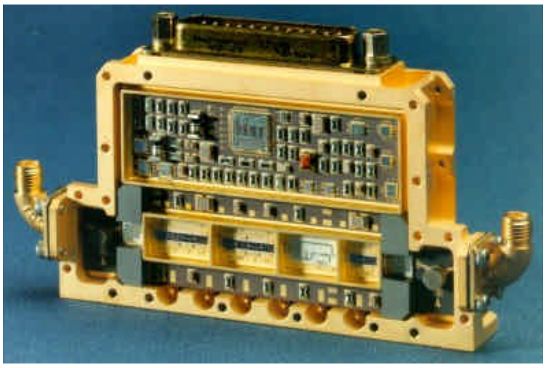


A micropackage containing 4 MMICs

Later, it appeared that not only the high frequency parts but also the commands and biasing circuitry had to be miniaturised to further cut weight and size. Associating this idea with the rallying of several RF cavities, the concept of multichip module (MCM) came out naturally.

Among the various types of MCMs, the choice was made of HTCC (High Temperature Cofired Ceramic) where buried metallization is an integral part of the alumina ceramic structure. This technology is intrinsically one of the most reliable one because multilayer ceramics have been used for a long time to build packages like LCC, CQFP or PGA.

Based on the experience acquired by Alcatel Space in the field of microwave micropackages up to 45 GHz, mixed LF/RF MCMs were designed. They could include lead-frames, heat sinks and/or seal rings soldered with a silver-copper eutectic. All the exposed surfaces are plated. On both sides of the substrate, components, MMICs, ASICs, etc., can be bonded either inside or outside the walls defining hermetic areas[1].



Channel Amplifier (CAMP) with a LF/RF MCM
(size : 88 x 52 x 14 mm)

As far as future evolution is concerned, AlN could be a good substitute for substrate when an efficient power dissipation is needed. The thermal conductivity of raw material for multilayer substrates is around 150 W/m°C, about 5 times that of alumina. Its drawbacks are its price and its low coefficient of thermal expansion, better matched with silicon than with GaAs.

FLIP-CHIP MOUNTING

One of the main advantages of flip-chip is certainly the short and reproducible interconnection length. This is a key point for better electrical performance and lower cost since less tuning is necessary. Some particularities for RF purposes have to be taken into account :

- GaAs components are relatively fragile,
- There are few bumps : 10 to 20 per chip only,
- Chips have Au pads with size about 50 to 100 µm,
- The hosting substrate has an influence on the circuit performance.

Three main routes could be used for flip-chip assembly : soldering, adhesive joining or thermocompression. The first two present important drawbacks in term of compatibility with RF chips. Soldering is best avoided because of the risk of covering all the chip surface with AuSn which is the best brazing alloy for Au pads. Adhesive joining with anisotropic glue may spread conductive particles all over the surface of the dice which can drastically affect the electrical performances. For isotropic adhesives, it is not possible to get the right size of dots with a ratio 1:1 in diameter and height.

The thermocompression flip-chip assembly needs gold bumps. However, component suppliers are still reluctant to propose bumped devices unless there is a large volume market demonstrated. Up to now, this limits the development of flip-chip bonding for low or medium quantities. As an alternative, stud ball bumps made on the substrate allow the use of MMICs without any extra process at wafer level. Moreover, this can be available on all types of substrates: alumina, AlN, HTCC...

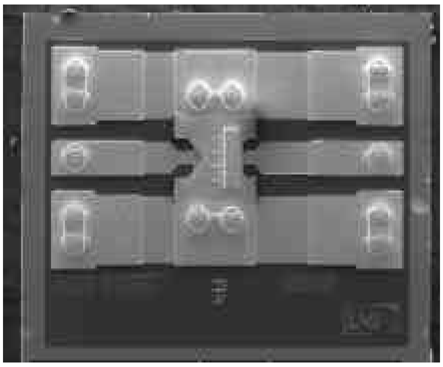
The bonding height is imposed to avoid propagation disturbance. It has been shown that a gap of 35 µm ± 5 µm is enough for both microstrip or coplanar circuits. This can be realised with double stacked bumps using ∅20µm gold wire[2].

Double stacked bump

Flip-chip needs only one step for the assembly process: attaching and connecting are performed in the same time. This could be a strong advantage for cost reduction but, on the other hand, using the same point for mechanical attachment and electrical connection is not usual for space application. A first level of reliability tests have been performed through thermal cycles to assess the validity of the assembly.

These measurements, up to 500 thermal cycles, have clearly shown the compatibility of our flip-chip process for GaAs MMIC on alumina substrate. Nevertheless, underfill has been found necessary for the flip-chip assembly of large GaAs dice onto an AlN substrate.

Some trials have already been made by GaAs MMIC foundries to implement RF gold bumps on the wafer. This is the route to be used for mass production as well as for thermal management where thermal bumps could be associated to bumps for electrical connections. Location and shape of the thermal bumps have been optimised using 3D models. In best configuration, a 30-40% decrease of the thermal resistance compared to standard face-up mounting (with 100 µm GaAs thickness) is expected with gold-gold thermocompression assembly on gold coated AlN[3]. Because of the small size on the transistor, the thermo-mechanical simulation shows that underfill is not necessary to prevent from damage during thermal cycling.



Bumped transistor in CPW topology (Photograph of UMS)

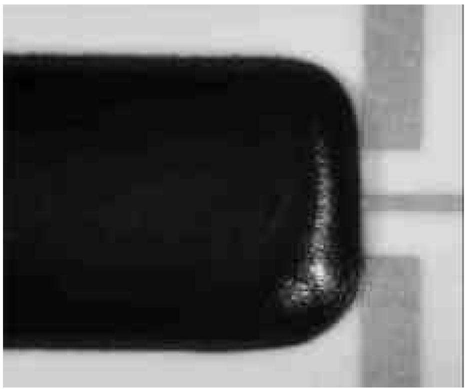
NON-HERMETIC PACKAGING

Glob-top (encapsulation of bare dice with a resin) associated with RWOH (Reliability With Out Hermeticity) is a very promising technology for miniaturised space equipment.

Even if the process for glob-top on microwave devices seems very similar to the process used for conventional ICs, some major constraints have to be taken into account for the resin :

- compliance – w.r.t chemical composition, thermo-mechanical characteristics and electrical properties - with both the dice and the lines on the substrate,
- severe accuracy for the dispensing onto the substrate which should not affect the microwave performance.

The choice of "dam and fill" has been made because of its precision on the dam positioning (around ± 20 µm).



"Dam and fill" glob-top which requires accurate positioning.

Electrical tests based on a Ku-Band (10-14 GHz) MMIC Low Level Amplifier have been performed. This circuit has been designed to be used conventionally, i.e. with ε_r=1 (air) above. The best epoxy resins have ε_r about 3.5 with losses around 6 to 10.10^{-3} (tg δ at 12 GHz and at room temperature). The results showed a slight modification of the responses which could easily be reworked taken into account the resin impact.

In term of reliability, thermal cycling could have highlighted some defects. As a matter of fact, no major variation of the RF characteristics have been seen after 200 thermal cycles in the range –55/+125°C. These results indicated that glob-top is compatible with GaAs MMICs, with some specific design rules and assuming the right topping material and associated process[4].

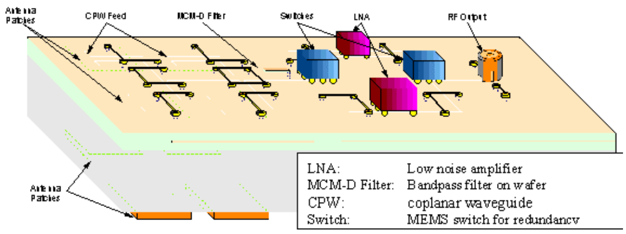
The glob-top protection opens the road towards the System-In-Package (SIP) concept which allows heterogeneous mixes. SIP is certainly not so integrated than SOC (System-On-Chip) which full process is generally complex. The latter is associated with a very high development cost not compatible with the low volume series requested for space applications.

A SIP design is defined by its substrate (MCM-D for example) which may feature interconnect lines and passives elements (resistors, capacitors, inductors). On this support, the active devices are bonded, conventionally or by flip-chip. Those are selected regardless of the semiconductor technology. Moreover, this concept can be associated with an intelligent chips/package partitioning and co-design approach saving time in the development cycle[5].

MEMS STEP INTO THE GAME

It is expected that the advantage of MEMS (Micro Electro-Mechanical System) technologies, demonstrated already in areas such as automotive, medicine, etc., will also benefit space applications. A bright future can certainly be predicted for MEMS aboard space-borne payload, following the same route that MMIC experienced 15 years ago.

The demand for more bandwidth in interactive multimedia services could be reached using new satellite systems which are widely based on active antennas whose array elements are feeding the electronics composed of amplifiers and other functions. In the case of receive antennas, each radiating cell is connected to a self-redunded module composed of an input filter, a single pole-double throw (SPDT) switch, a nominal and a spare low noise amplifiers (LNA).



Self redunded front-end module

Here, the switch needs to operate at the downlink frequencies (30 or 50 GHz), to present negligible insertion loss and to fit into a very small size compatible with the mesh of the radiating array. Electromechanical waveguide switch is too bulky, ferrite switch is costly and needs a cumbersome current driver, PIN diode and MMIC switches are too much lossy. MEMS switch is a providential solution.

MEMS technology not only offers performing switches but the micro-machining process can be used to fabricate high-quality novel integrated filter banks, tunable matching networks or tunable LC tanks. Thus improved functionality is offered and practical solutions for implementing novel re-configurable transponder architectures are allowed(6).

The fantastic promises of MEMS technology should not hide that a rather large bunch of matters are still an issue. Among the anticipated difficulties, there is the need of reliability. This is a major concern, if not THE major concern, indeed. The problem covers a very wide domain. Failure mechanisms and their activation energy are still not well known. Their nature is very application-dependent. Talking about the reliability of a switch which will endures billions of cycle for a beam forming application or for a redundancy switch which may be used only once in 15 years from now, is not the same thing at all ! It is probable that accelerated tests will have to be performed. How to define them is a pending question ?

So far, MEMS need to be packaged in inert atmosphere(7). This results in a search of hermetic packages, which could be in contradiction with the trends announced just above in this paper. Another difficulty is that those packages usually present some insertion losses at their in/out feedthrough transitions. At millimetric frequencies, these can even exceed the low loss of the MEMS device, then spoiling all its advantage. The solution is to avoid an excessive number of transitions, then to integrate the MEMS with the active devices and all the rest of microwave electronics in a SIP-like module. Micro-machining can advantageously be employed for the package itself : it has been imagined to manufacture a silicon wafer of etched covers, then hermetically bond that wafer onto the SIP wafer and, finally, dice the stacked wafers into “nano-hybrids”.

From that discussion, it comes clear that the packaging is an issue per-se. It will require a special attention and the selected packaging solutions will be decisive. Going even further, many people think that the design of MEMS is somewhat limited nowadays just because it was done by microwave engineers. The emergence of a new race of engineers with both mechanical and electrical knowledge will certainly change our views of what those devices are able to do and will open unexpected doors for future space systems.

CONCLUSION

In the satellite communication arena, the need of reducing costs and weight of satellite payload is now more than ever a critical issue. The answer to the very specific space requirements has been given successively by hybrid technology with discrete naked die, then with MMIC encapsulated in hermetic micropackage and currently with MCMs.

The evolution is now turning to more collective approaches, requiring less human operation. Flip-chip is a promising solution to decrease manufacturing cost while improving performances such as higher frequencies and better thermal dissipation. The glob-top and other coating solutions are opening the path towards non-hermetic Systems-In-Package. That concept is very cost effective since it can be fully automated and is always favouring the best device technology for a given performance.

One these device technology is preparing a revolution : the MEMS. The main advantages offered by this technology are mainly associated with the everlasting less-dB and more-Q trend. However, fundamental issues have to be resolved – priority must be given to reliability and packaging – and this constitutes very exciting challenges for space engineers and scientists.

All these issues contribute to reach our target : simpler and cheaper system architectures resulting from higher integration of components and extensive use of batch processes.

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