Three-dimensional packaging technologies for highly integrated T/R modules

François DEBORGIES, Thierry Lemoine, Yves Mancuso*

Thomson-CSF LCR, Domaine de Corbeville, 91404 ORSAY Cedex, FRANCE
Tel: +33 (0)1 69 33 09 32, Fax: +33 1 69 33 08 62, E-mail: deborgies@lcr.thomson-csf.com
* Thomson-CSF Detexis, 1 boulevard Jean-Moulin, 78852 ELANCOURT Cedex, FRANCE

ABSTRACT

Future generations of avionic systems will be based on conformal antennas spread over the body of the aircraft. Smart skin systems will need highly integrated T/R modules (size below 2 cm^2 at 10 GHz). To realise these modules, 3D integration of MMICs and control circuits is proposed.

INTRODUCTION AND STATE-OF-THE-ART

The evolution of microwave technologies, over the next twenty years, will lead to the use of conformal antennas for airborne systems. This evolution is the direct consequence of the technical and economical benefits brought by smart skin concepts:

- simultaneous reduction of weight, volume and cost by using more integrated technologies and by sharing apertures between EW, CNI and radar functions,
- reduction of aerodynamic drags by suppression of blade antennas,
- low cost aircraft retrofit by integrating ultra thin antennas,
- improvement of performances such as better hemispherical coverage and detection [1].

Radar functions could benefit of such advantages providing that X-band conformal active arrays are available. Major bricks of such antennas are small (less than $\lambda/2$, i.e. 1.5 cm at 10 GHz, in all dimensions) highly integrated "tile" T/R modules. Although conformal active X-band antennas are still one or two generation away, "tile" T/R modules are of immediate interest because they require collective manufacturing processes, and they are expected to be low cost.

On the other hand, the manufacturing of 'tile' modules affords major benefits for the integration of 'flat' phased-array antennas, for applications where small size and weight are mandatory : for example, spatial applications (SAR, telecommunications), military systems such as missile seekers and more generally phased-arrays antennas working in millimetre frequency range, … Moreover, if a collective manufacturing approach is selected, decreasing the size of the module means decreasing proportionally the cost of the assembly and packaging process. Cost reduction using collective technologies is the major trend followed by Thomson-CSF.

The realisation of "tile" X-band modules have been investigated since 1990, both in the USA and in Japan. The HDMP [High Density Microwave Packaging] ARPA funded program was mainly dedicated to the cost reduction of 10 W T/R module. Amongst the various companies involved, Hughes Aircraft (Raytheon) proposed coplanar MMICs flip-chip assembly onto cofired AlN substrates, Westinghouse (Northrop-Grumman) proposed flip-chip assembly of microstrip MMICs into LTCC housing, and Lockheed Martin was supporting HDI process for packaging MMICs in SiC-Al housing. Basically, all these approaches had common a 3D architecture (stacking of HPA - low level MMICs - control circuits), fuzz buttons for vertical interconnects, quadrimodule packaging, circulator outside the module. Hughes and Westinghouse proposed hermetic ceramic packaging, Lockheed Martin was much in favour of plastic packaging [2]. In Japan, following the same trends, Toshiba and Mitsubishi presented original approaches for 1-2 W modules [3].

THOMSON-CSF APPROACH FOR TILE MODULES

For manufacturing low cost integrated T/R modules, the selected approach favours collective processes and has been named Collective Wiring. Every processing step is performed for several tens (and in the future several hundreds) of T/R modules simultaneously, as it is done in the semiconductor industry. Coplanar MMICs have not been selected because this standard is not yet fully accepted by the industry, and because it generates complex practical microwave, thermal and thermo-mechanical problems. The proposed technology has been demonstrated with microstrip MMICs, though it could be adapted to coplanar chips.

The principles of the technology are shown in Fig. 1. Some have already been described by Lockheed Martin [4] and by FhG-IZM [5]. The basics are the following:

- T/R modules are composed of 3 MMICs: HPA, LNA and multifunctional carrier (total GaAs area: 0.35 cm^2) and one control circuit (BiCMOS chip, 1 cm^2): Fig. 2
- large capacitors and circulator are outside the module,
- modules are non-hermetic,
- the level of integration is reached by assembling MMICs directly onto the silicon control circuit.

A 6 inch Si wafer is used as an active substrate where about 150 control circuits are integrated at a 1 cm pitch. The wafer is metallized (NiCr - Au), and the metallization is etched in order to insulate decoupling capacitors, resistors and microwave ground plane. A 100 µm polyimide film is glued onto the wafer, and is locally removed where the MMICs are to be placed and above the pad of the control circuits, using a CO_2 ablation process. The polyimide is then metallized (NiCr-Au) and the metallization is locally etched. MMICs are glued or brazed into the cavities, directly on the silicon: a 10 µm positioning accuracy is necessary in the three axis. A second polymer film is glued onto the wafer, so the MMICs are totally surrounded by organic materials. This second layer will support 50 Ω connections between MMICs and low frequency connections to the control circuit. Finally a third polymer layer will give a final protection to the module and will support SnPb bumps. After testing and dicing, the module will be mounted onto a multilayer PCB by solder reflow. Thermal management will be provided by gluing the silicon onto a heat sink (Fig. 3).

RESULTS

The S-band module shown figure 4 has been manufactured using off-the-shelf active components : LNA, attenuator, and phase shifter. The upper surface of the MMICs has been coated with a BCB resin (thickness : 10µm) in order to protect air bridges before gluing the polymer film. BCB also limits RF extra losses, because this resin offers better RF characteristics than epoxy-based resins used to glue the polymer film. The Noise Factor of this module is 4.5dB, a figure close to the Noise Factor we got with the same MMICs assembled by wire bonding. Therefore Collective Wiring doesn't degrade significantly the RF performances of S-band standard microstrip devices. Such assertion is of course less valid at higher frequencies.

Figure 5 shows measurement results for a GaAs 50 Ω line packaged this way: return losses are kept below 20 dB up to 20 GHz for the whole transmission line (Fig. 6) and one can see that this technology could be used up to Ka-band and possibly in the millimetre-wave spectrum.

Assembly of MMICs digital phase shifters (X-band) onto their control circuit (bipolar HF2C Thomson-CSF technology) has been realised to demonstrate the active silicon carrier concept (Fig. 7 and 8). Simulations and measurements show that the parasitic capacitances brought by the RF ground onto the Silicon transistors doesn't affect significantly the circuit's switching time. An estimation of the temperature increase of the RF transistors junction has been simulated, due to a 1W/cm^2 thermal dissipation inside the silicon chip. We demonstrates that this temperature increase is keep at a very reasonable level (3°C). Ultimately, this technology allows to suppress both assembly substrate and heat sink, and therefore is a very attractive alternative for reducing the cost of T/R Modules.

Assembly of HPA onto silicon using AuSn brazing or gluing has also been demonstrated. Silicon offers a good thermal substrate for pulsed mode HPA (with pulse duration below 100µs). When quasi-CW devices are to be used, reducing the thermal resistance will require substrates with larger thermal conductivity such as AlN or SiC, and perhaps alternative mounting approaches. In this case, the module will be split in two parts: the LNA and multifunction MMICs hybridised onto the control circuit, and the HPA in a separate package, the whole T/R module remaining smaller than 2 cm^2.

CONCLUSION

We have demonstrated the interest of Collective Wiring technology for manufacturing low cost T/R modules which constitutes a step towards future smart skins. This technology could be envisaged in a nearer term for reducing the cost of active antennas. It also offers an interesting opportunity for packaging millimetre-wave devices at low cost. Manufacturing of receiving module demonstrators using this technology is underway ; packaging of HPA will be the next step.

ACKNOWLEDGEMENTS

This work has been partly supported by the DGA-STTC of the French MOD, and by the CNES (Centre National d'Etudes Spatiales, Toulouse, France). The simulation results of IEMN are also acknowledged.

REFERENCES

[1] A.J. Lockyer et al, "Development of a Conformal Load-Carrying Smart-Skin Antenna for Military Aircraft", SPIE vol 2448, pp. 53-62.

[2] E.D. Cohen ,"High Density Microwave Packaging Program", 1995 IEEE MTT-S Digest, pp. 169-172.

[3] T. Sakai et al,"Ultra Small Size X-band MMIC T/R Module for Active Phased Array", 1992 IEEE MTT-S Digest, pp. 1531-1534.

[4] J.D. Kennedy et al, "GHz Packaging", *Advanced Packaging*, November-December 1996, pp. 24-26.

[5] M. Töpper et al, "Embedding Technology - A Chip-First Approach Using BCB", *Advanced Microelectronics*, July-August 1997, pp. 18-21.

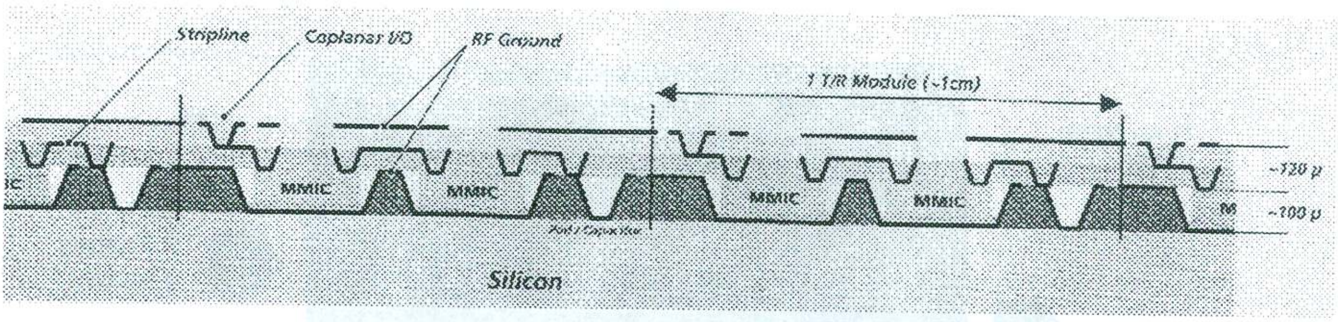

Fig.1 : Collective Wiring Technology

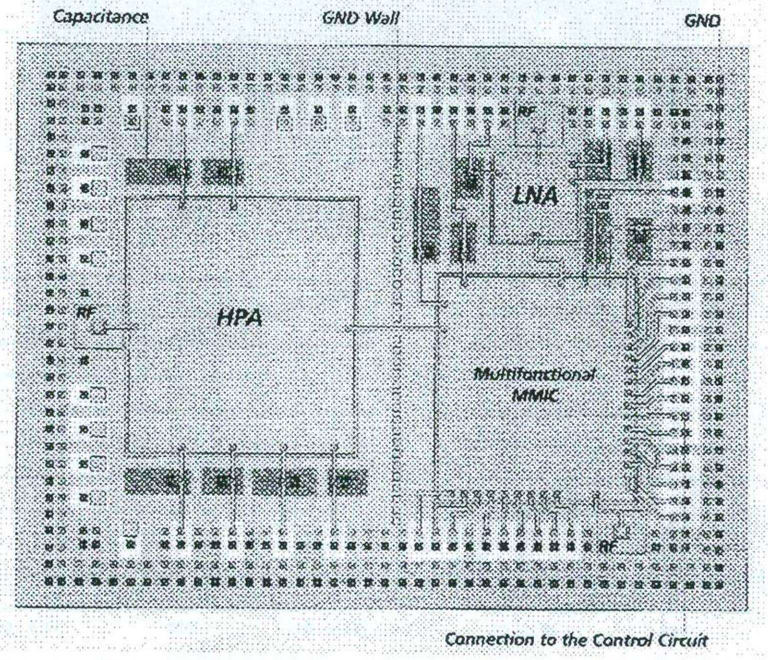

Fig.2 : T/R Module Design with 3 MMICs

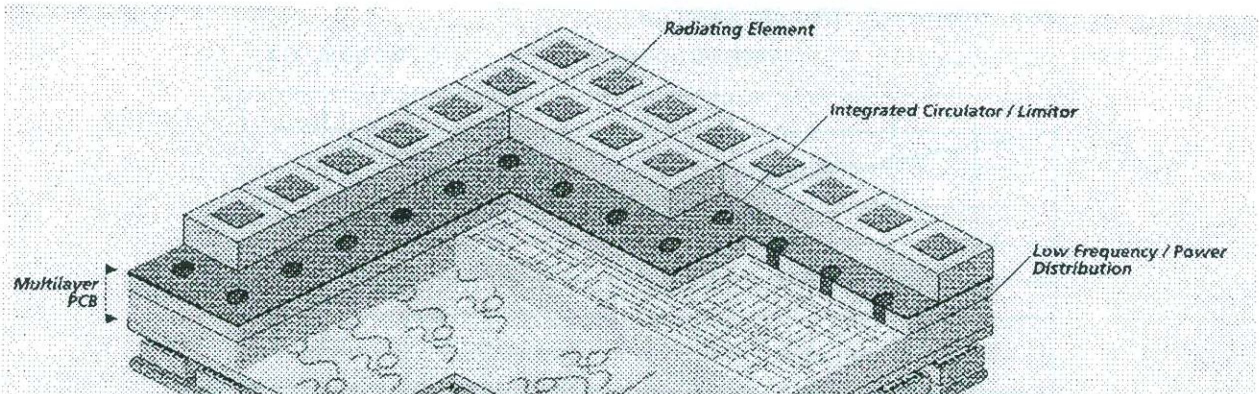

Fig.3 : Integration of Tile Modules into a Smart Skin

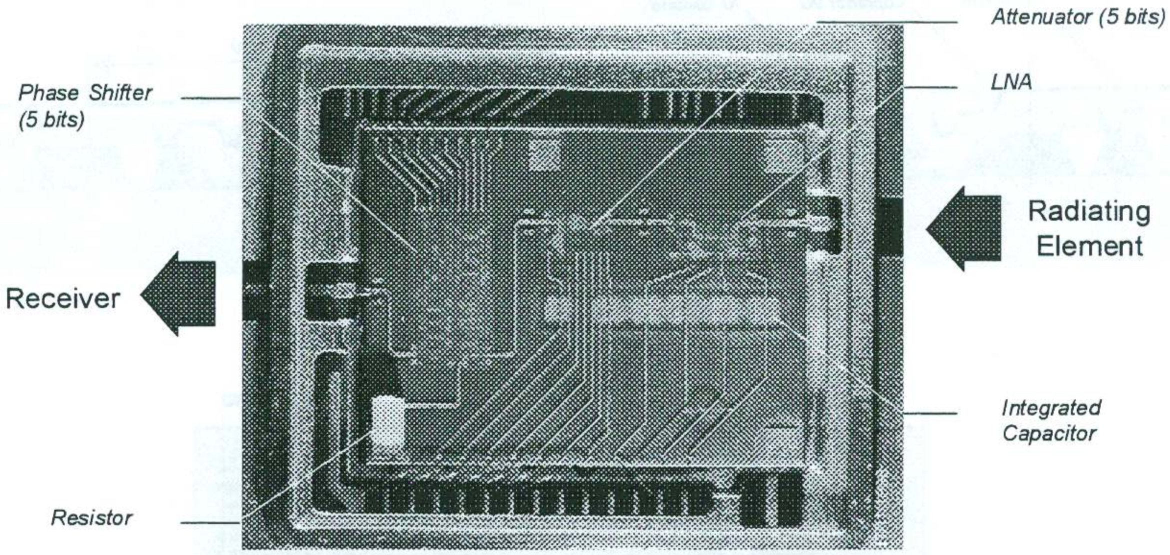

Fig.4 : S-band Receiver Module

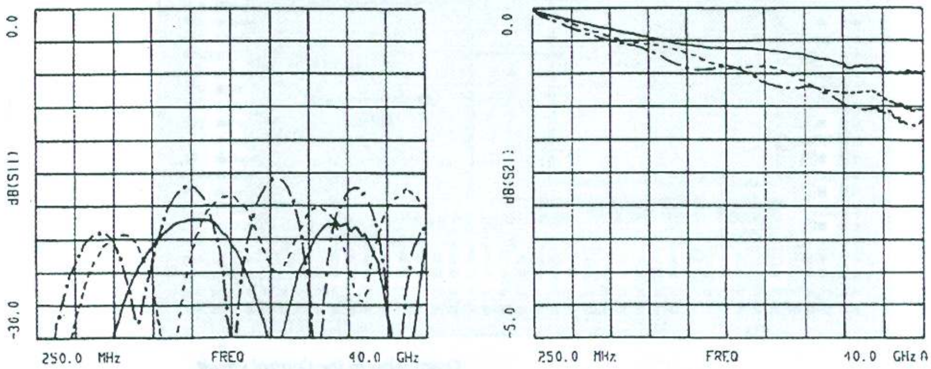

Fig.5 : Measurement of the Tile Module before assembly. MMICs have been replaced by a 50Ω line.

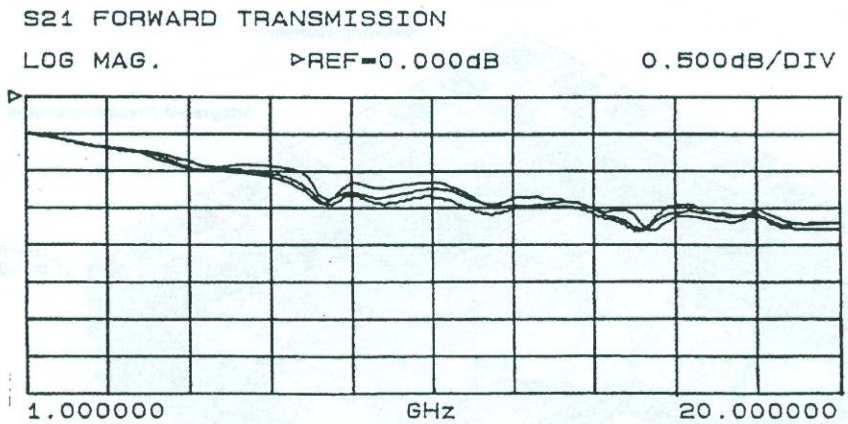

Fig.6 : Measurement of a Tile Module Using Stripline Technology Inside the Module

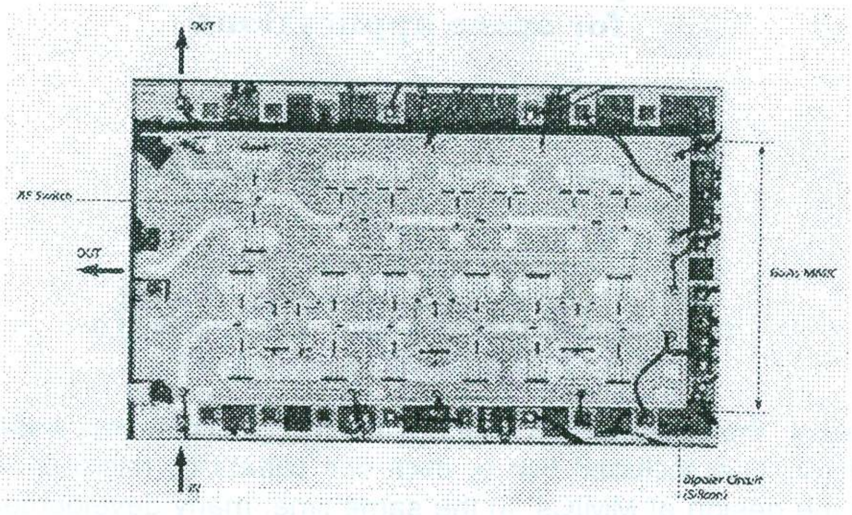

Fig. 7 : MMIC Phase shifter Hybridized on its Control Circuit

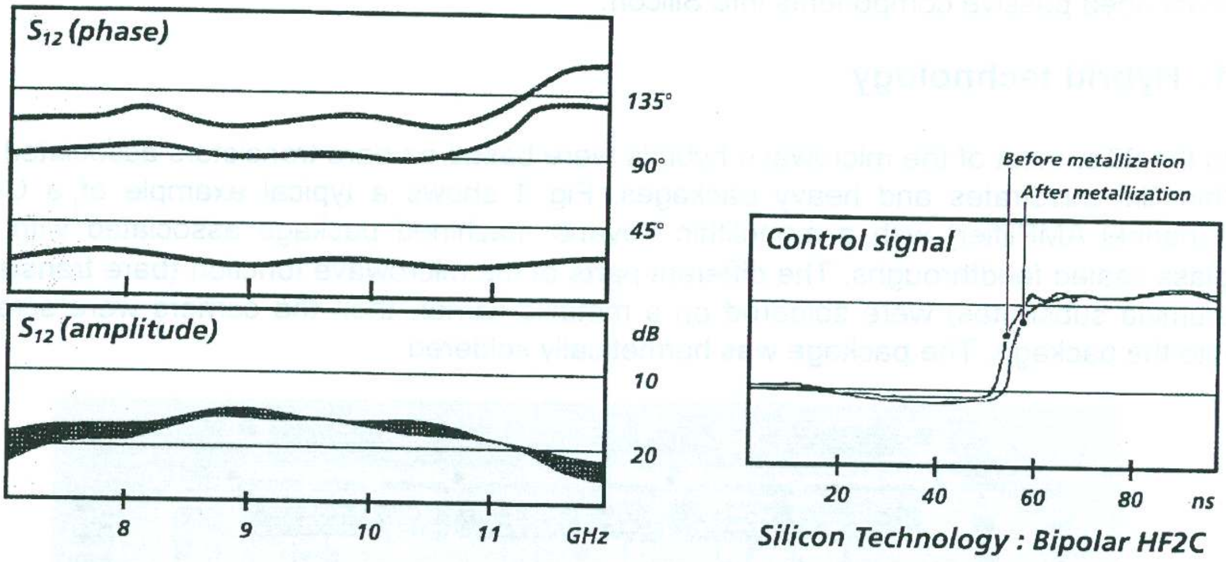

Fig. 8 : MMIC Phase shifter Hybridized on its Control Circuit – Measurement Results