Millimeter-wave SMT Low Cost Plastic Packages for Automotive RADAR at 77GHz and High Data Rate E-band Radios.

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***Abstract* —The cost of the millimeter-wave functions in the system overall price is today one of the main limiting factor for new high frequencies applications like wide band automotive RADARs or high data rate radios. A big difficulty for the new devices above 60GHz is to be intrinsically low cost, but also to comply with simple and standard assembly techniques at the module level. This very hard challenge has already been overcome for applications below 40GHz with low cost plastic Quad Flat No-Lead packages (QFN) in the last three years. This generation of plastic packages has strongly contributed to decrease the weight of packaging and assembly in the system's cost. It has also enabled the assembly of microwave devices on standard SMT lines achieving industrial and competitive microwave solutions. Today, the same demand exists for millimeter-wave applications. And plastic packaging solutions has to be pushed to their limits to fulfill these objectives. This paper will present new ultra-low cost packaging concepts involving plastic over-molding techniques. The realization of a 77GHz transmitter for automotive RADAR packaged in a plastic QFN will be detailed.**

***Index Terms* — Plastic packaging, Surface mounting, MMICs, Microstrip antennas, Rectangular wave guides, Millimeter wave devices, Millimeter wave RADAR, Quad Flat No-Lead Package (QFN).**

I. INTRODUCTION

This paper introduces a new concept of low cost packaging techniques for commercial millimeter-wave applications above 60GHz. The cost of the millimeter-wave devices is of course only one part of the system's price. The compatibility between the device and low cost assembly techniques like SMT lead free processes is also a key factor of success for new generations of millimeter-wave devices. Today, the E band (60 GHz -90 GHz) is more and more popular for new applications. It has been unoccupied during a long period due to very high technical difficulties and a strong duality between performances and cost. But the high occupancy of the lower frequency standards and the increase of performances required by the new applications are forcing to develop new generations of devices in this frequency band.

For example, in telecom the objective is 2 Mbits/s at least at the end-user's terminal in urban and dense areas. This very huge demand for data pushes the telecom system manufacturer to develop new equipments offering more than 1 Gbits/s for the last miles connections. Despite of breakthrough with new modem generations or new HPAs offering very high linearity (IP3 point) the frequency of millimeter-wave carrier has to increase consequently. Two frequency bands have been attributed for these applications: 71-76 GHz and 81-86 GHz.

Automotive RADARs applications are also requiring more and more functionalities in E band at very low cost [4]. Existing generations of RADARs for Long Range Applications (LRR) at 77 GHz (76 – 77 GHz) are being replaced by new generations offering more functions coupling long and short range detection capabilities like parking aid or pre-crash detection (Short Range Radars SRR). Today, these SRR functionalities are covered with 24GHz chip-sets packaged in plastic QFN. But the trend is to integrate them on one single chip-set covering an extended frequency band from 76-81GHz at the same cost. Since SMT plastic packages are considered to be the lowest cost solution, the new generations of devices in E band have to use these packaging techniques if they want to rise.

The work reported in this paper has been done in order to define a low cost millimeter-wave package based on the over molded plastic QFN technology usable in E-band for telecom and automotive applications. In a first paragraph, the solutions at the state of the art will be described and their limitations will be highlighted. A second paragraph will present the new concept developed by UMS. The last paragraph will report the performances obtained with a transmitter operating at 77GHz for automotive RADAR application packaged in a plastic QFN.

II. STATE OF THE ART PACKAGING TECHNIQUES

Packages at high frequency introduce generally very important parasitic elements causing un-matching or detuning of the MMICs enclosed. The package's dimensions have to be down-scaled in respect of the signal wave-length, causing incompatibilities with mechanical fabrication techniques, and chip assembly processes at low cost. One of the main limitations in the MMIC connection to the package is the wire-bonding length used to link the chip to the package's accesses. Despite of manual or very accurate new automatic wire-bonding equipments it is difficult to achieve shorter wire connections below than 0.3 mm chip to chip or chip to package's bond pad. The self-inductance equivalent to the wire can not be easily decreased below 0.2nH with a good repeatability and yield in production. At 77GHz, a wire equivalent to 0.2nH comes in resonance with a capacitance of

21 fF. This is typically the capacitance equivalent to bonding pad. These figures help to understand the difficulty to match a MMIC in E-band and explain why the package's leads or contact pads act as real low pass filters. Furthermore, with leaded packages, the motherboard where is assembled the device has also to be designed in respect of the millimeter-wave signals, causing design complexities and high costs at the module level. In order to over-come these difficulties at the package's interfaces, UMS has developed some years ago [1] a SMT package at 77GHz for automotive RADARs (LRR) including a radiating element (see Fig. 1). The packaged device is attached on a low cost PCB mother-board made of FR4 by using a standard SMT reflow process. The radiating element acts as an electromagnetic probe converting a microstrip propagation mode at the GaAs chip output into a TEM01 rectangular wave-guide mode at the package interface. The main advantage of this technique is to enable the coupling of the packaged device to a rectangular wave-guide managed in the system without any direct mechanical contact at the operating frequency. This configuration solves the low-pass filtering effects observed with standard leaded solutions, and complies for the fist time at millimeter-wave frequencies with surface mount low cost assembly techniques (SMT) on standard PCB materials which are normally not compatible with 77GHz signals. The MMIC internal matching is also simplified, improving the device fabrication yield.

Despite of the strong cost decrease obtained at the system level by using surface mount techniques (SMT), the metal-ceramic package used was too much expensive in comparison to the objectives of the new commercial millimeter-wave applications.

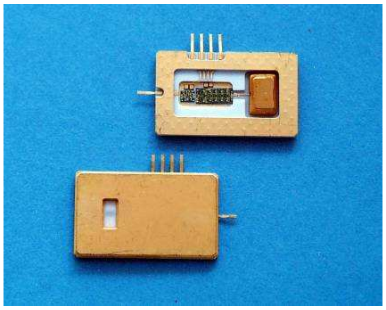
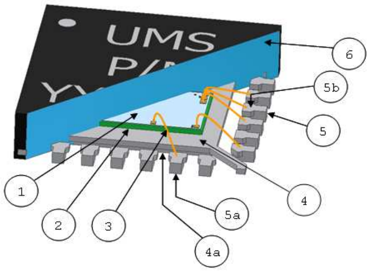


Fig. 1. Ceramic-Metal transmitter module at 77GHz compatible with SMT assembly processes.

III. NEW CONCEPT OF PLASTIC PACKAGES FOR E BAND FUNCTIONS

The key advantage of the over-molded plastic packages is the capability to perform the assembly of the MMIC on mass production equipments at low cost. These equipments originally developed for digital or RF devices for consumer markets, have been optimized and refined in order to increase the devices density with very short connections inside the package. In the family of the plastic over-molded packages, the Quad Flat No-Lead package (QFN) answers perfectly to applications up to 30GHz or 40GHz [2] [3] with very short connections from the chip's bond pads to the packages leads (see Fig. 2). But the QFN is still limited by the bonding wire length for applications above 40GHz and it has to be soldered on a PCB compatible with the high frequency signals.

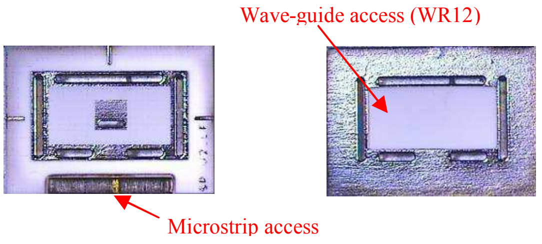
In order to define an optimal package for millimeter-wave applications, it has been decided to take advantage of the QFN topology for cost aspects and to integrate inside a contact less transition as developed for the ceramic package presented in the paragraph above.



No.	Name	Material	Note
1	MMIC	GaAs	
2	Die attach	Epoxy resin with silver filler	
3	Bonding Wire	Gold	
4	Frame	Copper (C194) with Sn external finish	Sn finish on back side, see 4a
4a	Frame external Sn finish	Matte tin (Sn), thickness 400 µinch	Package's exposed surfaces only
5	Lead	Copper (C194) with Sn external finish	Sn finish on back side, see 5a Ag finish on top side, see 5b
5a	Lead external Sn finish	Matte tin (Sn), thickness 400 µinch	Package's exposed surfaces only
5b	Lead bond pad Ag finish	Silver spots (Ag), thickness <40 µinch max.	Lead's internal bond area
6	Mold Resin	Multi-Aromatic Resin (Br/Sb free)	

Fig. 2. Example of plastic QFN build-up structure.

The main challenge has been to integrate a low cost radiating element into the package (see Chip#2 at Fig. 7) able to connect the device to the system without any mechanical contact. As explained previously this element has to convert a microstrip propagation mode at the MMIC's output (see Chip#1 at Fig. 7) into a TEM01 rectangular wave-guide propagation mode (WR12 flange). This wave-guide transition (see Fig. 3) has been designed and fabricated by using a PCB technique based on a low cost organic material and integrates a microstrip patch antenna.



Top-side view Bottom-side view

Fig. 3. Picture of the organic microstrip to wave-guide transition.

Two of these transitions have been realized on one chip and measured back to back in order to estimate the transmission losses of one single transition. The two transitions are connected on chip through a 50Ω transmission line. The chip is measured on a test jig designed to be connected to two

WR12 wave-guides. The scattering parameters measured with this chip are given at Fig. 4. Less than 3.5dB of transmission losses corresponding to the two transitions and the 50Ω line connecting them together have been measured. After de-embedding, one single transition presents about 1.2dB of losses at 77GHz.

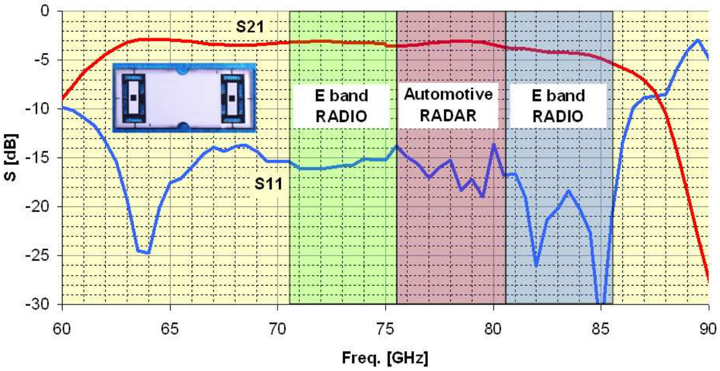


Fig. 4. Scattering parameters measured for two microstrip to rectangular wave-guide transitions connected back to back on chip.

In order to define a very low cost device, the wave-guide transition has to be handled like a standard MMIC on the QFN assembly line. So, it is conditioned and delivered to the assembler in a wafer format (see Fig. 5).

Fig. 5. Wave-guide transition conditioned as a 6 inches wafer.

This conditioning enables to use a very standard QFN fabrication flow for the assembly of the millimeter-wave packaged device. This flow is described on the Fig. 6. The two chips (see Fig.7), Chip#1 which can be a GaAs or SiGe MMIC, and Chip#2 which is the wave-guide transition made of organic material are die-attached in one step on the copper lead-frame constituting the package's base.

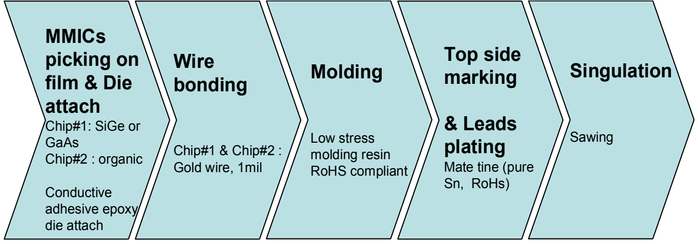


Fig. 6. Millimeter-wave plastic package assembly flow.

The general concept of the E band SMD plastic package applying the new approach reported in this paper is given at the Fig. 7. On this cross-section view, the device is represented soldered on a PCB mother-board. In this configuration, the Chip#2 transfers the millimeter-wave signal from the MMIC (Chip#1) to the rectangular wave-guide which is aligned with the package's output access below the PCB.

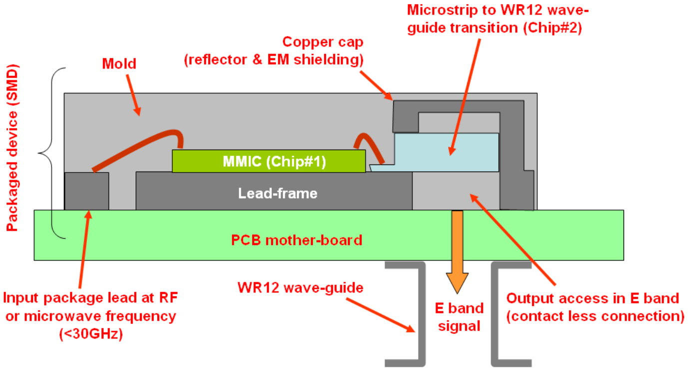
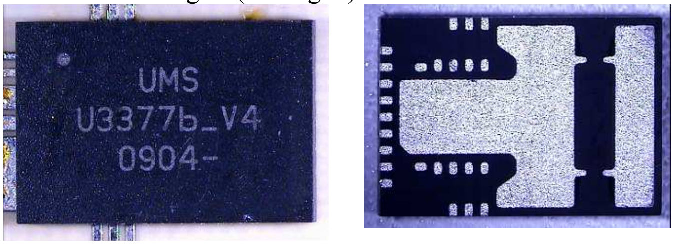


Fig. 7. Cross section view of the plastic millimeter-wave package.

IV. 77GHz TRANSMITTER DEMONSTRATOR

A first demonstrator has been developed targeting the long range automotive RADAR application at 77GHz. The existing 77GHz transmitter chip CHU3377b based on the UMS GaAs technology PH15 (PHEMT 0.15µm) has been assembled inside an over-molded plastic package following the concept described at the Fig. 7. The outlines of this device packaged in a 9x6 mm² QFN are given at the Fig. 8. This transmitter operates as a frequency multiplier and is driven by an input signal at 12.83GHz (Fout/6). The bare die delivers about 14.5dBm at its output at 77GHz (Fout) when measured on probes station. The die is packaged using a production assembly line normally dedicated to standard QFN products without modification. This demonstrator highlights the capability to fabricate millimeter-wave devices at low cost. The cost objective for package and assembly is extremely low in production and has been already divided by ~40 if it is compared with those of previous versions based on metal ceramic technologies (see Fig. 1).



Top-side view Bottom-side view

Fig. 8. Photograph of a 9x6 plastic QFN embedding a 77GHz transmitter GaAs MMIC.

This packaged device has been assembled by soldering on a low cost microwave PCB from Rogers (Ro4003, h=203µm, copper cladding 17µm) using a standard RoHS SMT process. A photograph of the QFN's land pattern on PCB is given in Fig 11. The device has been measured on test fixture (see Fig. 10) and 11dBm of output power have been obtained at the test fixture output at 77GHz. The output power of the packaged device measured on test fixture is 3dB lower at 77GHz than typically obtained with the bare die when it is measured on probes station (see Fig 9). This difference is mainly due to the wire-bonding connection inside the packages between the GaAs chip and the wave guide transition. The test fixture contributes also for about 0.3dB. For this first prototype, the wire length between the two devices has not been optimized (wire length ~0.5mm) and a standard ball bonding process has been applied. A strong improvement on the output power can be expected with a second iteration when this wired connection will be optimized. A gain between 1.5 to 2dB can be expected by decreasing the wire length by 0.15mm.

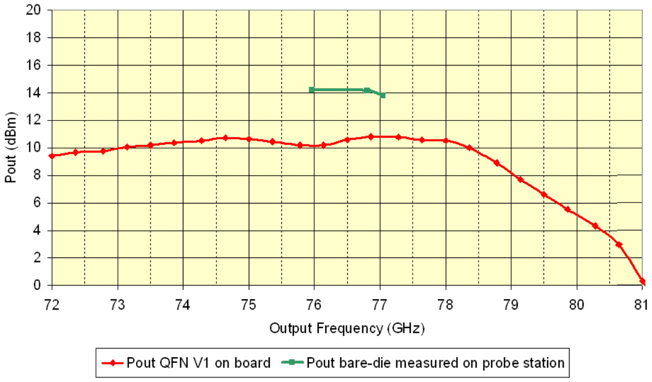


Fig. 9. Output power of the 77GHz transmitter in plastic QFN 9x6 (output power measured at the test fixture output).

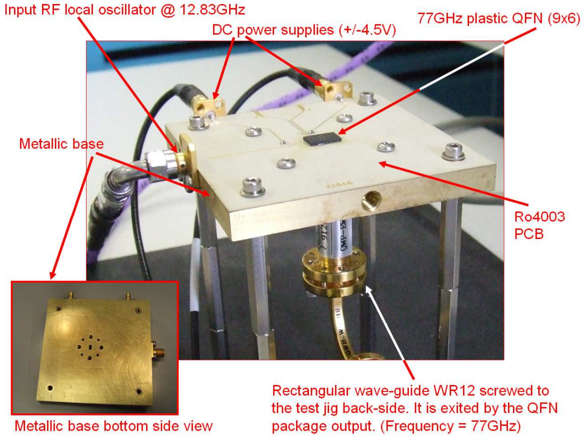


Fig. 10. Photograph of the 77GHz transmitter packaged in plastic QFN 9x6 assembled on test fixture.

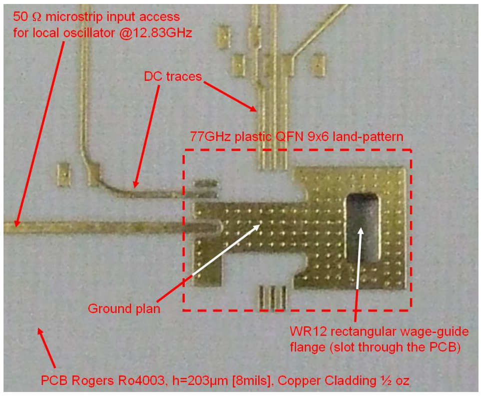


Fig. 11. Photograph of the PCB used for the evaluation of the 77GHz transmitter in plastic QFN 9x6.

V. CONCLUSION

A new concept of packaging for millimeter-wave devices beyond 60GHz has been developed. A first generation of 77GHz transmitter packaged in plastic QFN has been designed, fabricated and tested on test fixture. It takes advantages of the lower cost packaging techniques available for mass production with plastic QFNs. Furthermore, the contact-less transition included into the package enable to assemble this millimeter-wave SMD device on low cost motherboards made of laminated organic PCB like FR4 or Ro4003 despite of the 77GHz output frequency. The rectangular wave-guide transition is very tolerant and can accept placement errors generally observed with fully automatic SMT assembly equipments (~+/-50µm) applying solder paste screen printing processes. With this new approach, only low cost solutions are used from the packaged device to the system architecture.

In production, the testability of such millimeter-wave devices will be also very simplified since there is no direct contact between the package and the test socket. Measurements repeatability issues generally observed with leaded packages at high frequency will be solved with this contact-less transition.

The first 77GHz packaged transmitter presented in this paper demonstrates the capability to assemble on standard QFN fabrication lines the new generations of SMD millimeter-devices.

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