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RF Radio Links and LMDS Communications - Module Technology, Status and Trends

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ABSTRACT

Broadband Wireless Access (BWA) systems and multi-media services, such as LMDS (Local Multipoint Distribution System) and MVDS (Microwave Video Distribution System) and related radio links are the main activities of the Business Unit “MicroWave Factory“ of EADS Deutschland GmbH (EADS: European Aeronautic Defence and Space Company). Based on a long term experience of modern active phased array radars and different sensor applications up to 100 GHz the communication module market for RF radio links and LMDS communications is still a big challenge for high volume production in our MicroWave Factory.

Covering a broad frequency range, our focal points are Point-to-Point radios within 20–38–64 GHz and Point-to-Multipoint radios with spectrum allocations at 26, 28, 31, 32 and 42 GHz.

Cost breakdown analysis for different EADS products, like Transmit/Receive (T/R) and RF radio modules give a clear identification of today´s cost drivers. The main results and recommendations will be discussed.

Advanced substrate technologies, based on PCB multilayers combined with RF layers, e.g. teflon materials, and the use of single packaged RF-MMICs with LGA (Land Grid Array) and MLC (Multi Layer Ceramic) macro modules in BGA (Ball Grid Array) technology will be compared with traditional module architectures based on the use of thin film ceramics and Chip&Wire technologies. The experience of a Micro Wave Unit (MWU) with a MCM-C (Multichip Module, based on

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ceramics) in LTCC (Low Temperature Cofired Ceramic) technology will be discussed.

Our technology strategy and packaging roadmap is mainly driven by long-term reliability, availability of basic materials and components and modularity. In combination with the idea and challenge of a Box-of-Bricks for a standard mm-wave transceiver radio, future trends of innovative module architectures and packaging technologies will be shown.

Topics/Keywords:

RF Radio Links, LMDS communications, Packaging, Technology Trends, Strategies

1. APPLICATIONS AND MARKET TRENDS

Broadband Wireless Access systems and multi-media services, such as LMDS and MVDS and up/down converters for VSAT applications have the potential to become very high volume markets for millimeter wave modules and radio units /1, 2/.

The EADS MicroWave Factory (MWF) is a leading supplier of microwave and millimeter wave modules and subsystems as building blocks for RF systems covering the frequency range between 5 and 94 GHz.

Products are used in:

• Point-to-Point radiolinks (PtP)

• Point-to-Multipoint radiolinks (PMP)

• VSAT terminals

• Active phased array T/R modules

• Industrial and automotive sensors

• Optical Transmission Units

MWF has a highly qualified and experienced team with key capabilities on:

• Design, simulation, fabrication and testing of RF modules

• Design, simulation and characterization of MICs and MMICs

• Innovative antenna and filter design

• Advanced substrate and module technologies, based on

- ceramics (alumina)

- Multichip Modules (MCM-D, MCM-C)

- FR4/PTFE multilayer (MCM-L)

• Micro- and optoelectronic assembly by Chip&Wire, Flip-Chip and SMT

An automatic assembly line with a full lot traceability via electronic lot tracking allows a low-cost high volume manufacturing.

Significant effort is spent on R&D projects to secure availability on next generation technologies.

Based on the world GaAs merchant market (Source: Strategy Analytics, 12/99) we see a clear diversion for accessible market segments for GaAs MMICs with an operating frequency > 6 GHz. Figure 1 indicates the growing fields of interest, e.g. VSAT, Automotive and Optics.

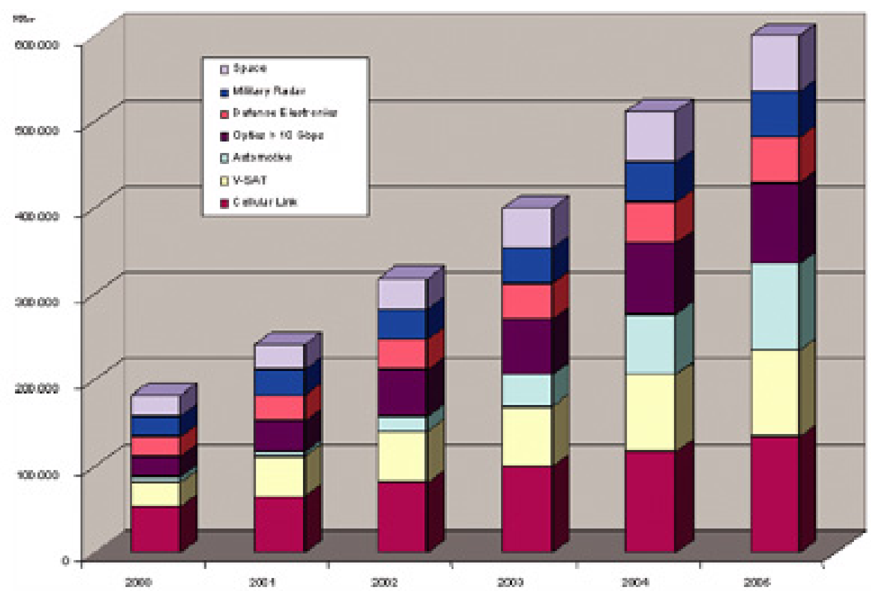

Fig. 1: Market Segments for MMICs > 6 GHz

2. RF MODULE TECHNOLOGY - TODAY

RF modules and frontends are normally realized with an architecture based on a Microwave Unit (MWU) with highly integrated MMICs (Monolithic Microwave Integrated Circuits) and interconnection substrates (ceramic and soft substrates) and an electronics unit for power supply, biasing and clock signals. The module electronics is usually designed and processed with SMD components and printed circuit board (PCB) technology like standard multilayers with FR4.

A typical MWU is completely assembled with automatic processes for dispensing, pick&place and wire bonding. All RF components (MMICs, filters in thin film technology on alumina and soft substrates and hybrid circuits) are combined in a Kovar metal package with glass seals. A CuMo (copper molybdenum) base plate serves for an optimized thermal heat transfer and offers a good CTE match (Coefficient of Thermal Expansion) with the GaAs semiconductors and the interconnection ceramic sub-units. All substrates as well as active and passive components are designed for an epoxy attach using a fully automatic pick&place process. The metal package can be hermetically sealed by resistance seam welding or laser welding.

Electrical interconnection between MWU and PCB is a standard reflow soldering process.

Electrical interconnection between MMICs and substrates are typical Chip&Wire bonding techniques. Figure 2 shows a detail of a MWU. Beside the MMICs (switch and two amplifiers) alumina substrats with a thickness of 127 µm are mounted with epoxy and bonds with 30 µm in diameter serve for interconnection.

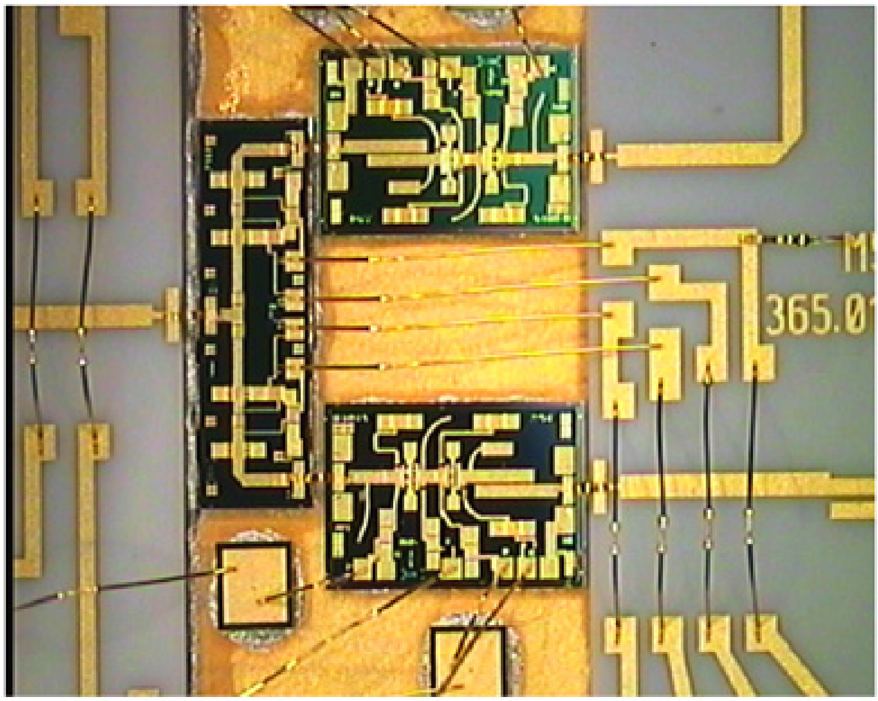

Fig. 2: Electrical interconnects

Bond-compensated interconnection from chip to chip at 60 GHz is done with ribbon bonds (see Figure 3).

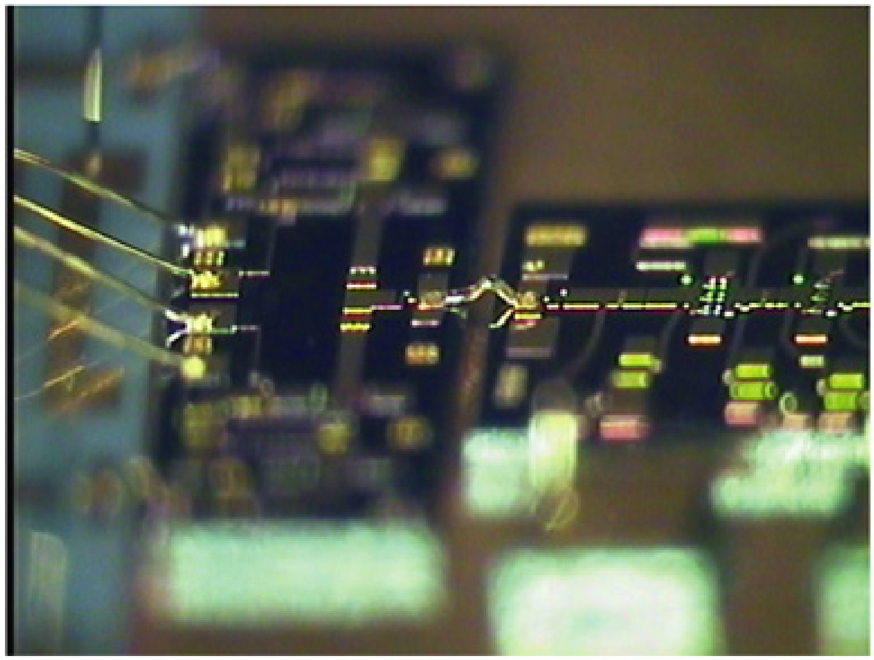

Fig. 3: Typical RF ribbon bonds (sideview)

Another approach for high volume production of millimeter wave units is based on multilayer ceramics technology. As a result of an internal qualification programme concerning ceramic multichip modules (MCM-C) and a broad experience with different products manufactured in Low Temperature Cofired Ceramics (LTCC), the basic test structures and a demonstrator for the 38 GHz MWU radio was made together with a strategic partnership to the ceramic supplier.

Figure 4 shows a LTCC integrated package with 4 layers. Filled vias serve for local electrical shielding and as thermal vias. A high resolution patterning with printed structures down to a local width of 70 µm allows the integration of millimeter wave functions, e.g., planar filters, waveguide and triplate feedthroughs /3/. The package is soldered onto a CuWo baseplate. A Kovar frame on top serves for final shielding with a planar lid.

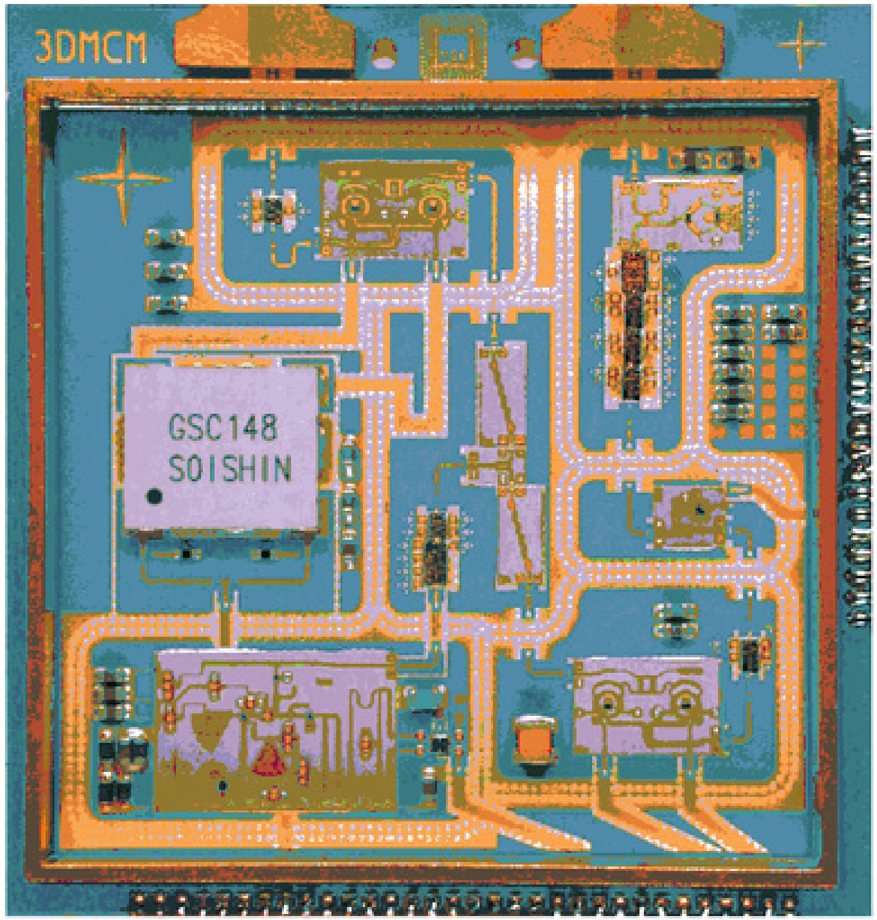

Fig. 4: MWU with LTCC, populated

3. MODULE MANUFACTURING AND COST ANALYSIS

Actually different types of module architectures are discussed in the literature. Two very popular manufacturing versions can be described, as:

Sub unit based modules

MMICs and passive functions (e.g. filters, couplers) are assembled on the base plate of a metal package. All sub units are connected via gluing/soldering and bonding.

Common substrate based module

RF components and DC functions are assembled on a common substrate. For an optimised heat transfer, devices like power amplifiers are placed in cut-outs for a direct attachement on a metal plate. The assembly techniques are similar to the sub unit based modules.

A critical look on the overall and specific module costs, based on EADS experience with Transmit/ Receive (T/R) modules for active phased array radars with an operating frequency of 6 – 10 GHz and a point-to-point mm-wave transceiver unit at 58 GHz show the following situation /4/:

MMICs	35 - 50 %
Package/Assembly	25 - 35 %
Testing/Tuning	10 - 20 %

(Values are depending on complexity and chip area.) These cost drivers have to be taken into account with target costs per module and the volumes in annual quantities.

A listing of products/applications, quantities and target costs /5/ referred to the beginning of this century is given in Table 1:

Product for	Quantity in k units	Unit Sales Price in US k $
Space	1 - 5	25
Point-to-Point	10 - 50	1.5
Point-to-Multipoint	100 - 500	0.6
LMDS/MVDS Consumers	> 1000	0.2

Table 1: Target costs for high volume products

To reach the desired and market driven cost levels makes it necessary to create basic assumptions for:

- High volume/yield production
- Well known technologies for substrates, housing and assembly
- Reduction of testing and tuning effort

4. SINGLE PACKAGED MMICs FOR SMT

Since 1999 single packaged MMICs for application up to 40 GHz are on the market. Typical RF functions like Low Noise and Medium Power Amplifiers (LNA, MPA) and mixers are catalogue products from major suppliers like Hittite Microwave Corp., Alpha Industries and others.

Chip and MMIC suppliers are pushing these products very strongly with the scope to realise completely packaged chip sets for various frequencies for the assembly on modern SMD compatible assembly lines.

Figure 5 shows typical Hittite single packages for operating frequencies up to 40 GHz.

The Ball Grid Array (BGA) package in the upper part is a ceramic package with a ceramic lid. The baseplate is a double side structured thin film alumina with filled vias. The MMIC is mounted by Chip&Wire.

The newest package type is a Land Grid Array

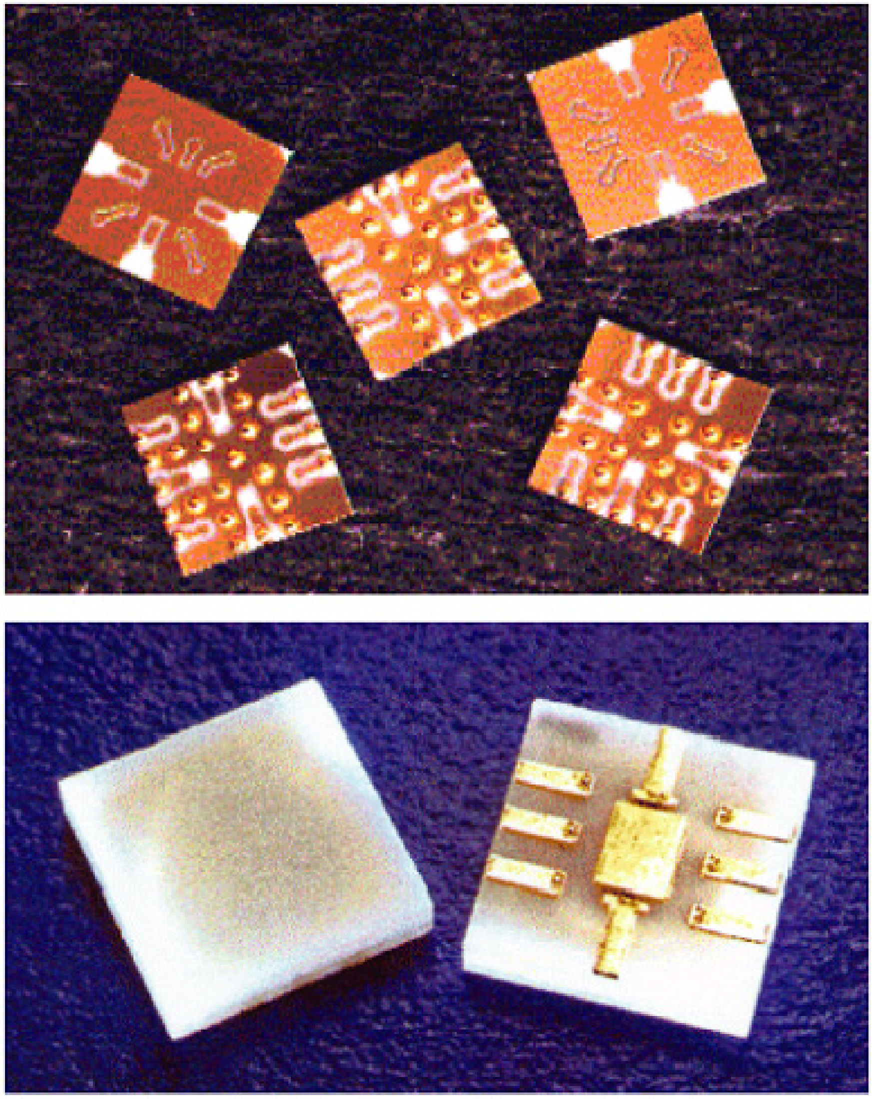

Fig. 5: SingleRF Packages (www.bittite.com)

(LGA) package (lower part of Fig 5). Package material is a soft substrate as well as the lid. RF and DC contact pads are designed for assembly on matched soft substrates.

In between 1 year (time frame was in 2000) a price erosion for a typical packaged device was obvious: a 50 % reduction in price, mainly driven by exchanging the packaging material and the step from BGA to LGA. Actually the price for the LGA package is given by the bare die price plus 40% for the package, including assembly and testing.

A future packaging step will be the integration of blocking capacitors into the single package very close to the MMIC DC pads.

Alpha Ind. offers its Alpha-2 surface-mounted packages specifically designed for high-frequency, high speed ICs used to implement PtP microwave links, LMDS and fiber optic systems. This package family currently includes low-noise amplifiers, driver amplifiers, single- and double-balanced mixers, variable attenuators and a SPDT switch.

First electrical results of 28 and 31 GHz LMDS transmitter modules with RF packages on a 200 µm Rogers base material (RO4003, most in use) and with a total semiconductor cost less than $ 100 US have already been published /6, 7/.

Actually, the main US packaging companies (Hittite, Alpha, Dielectric Laboratories) are working on SMT power chip solutions up to 60 GHz. First SMT power packages will be available at the end of 2001.

5. PCB BASED RF MODULES - TRENDS

A visionary mm-wave module architecture based on a Polytetrafluoroethylene (PTFE, Teflon) multilayer and SMD compatible packages is shown in Figure 6.

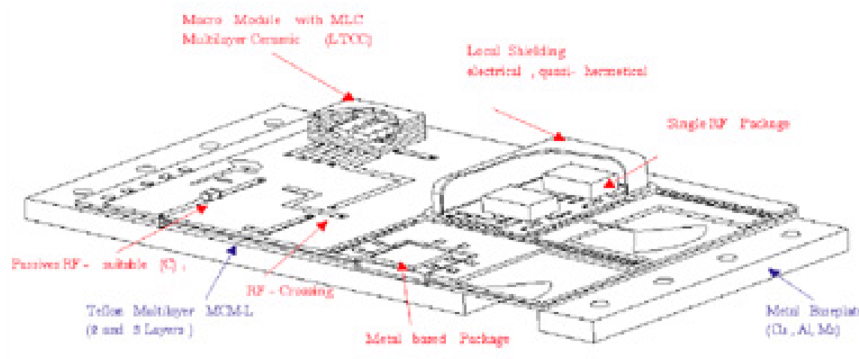

Fig. 6: RF PCB with SMT components

Macromodules and single RF packages are mounted on a dielectric multilayer substrate that is laminated on a metal core for mechanical stability and for an optimized thermal management.

Board materials for PTFE multilayer

Typical board materials used for microwave applications are:

- Ceramic filled plastics (e.g. Rogers)
- Ceramic filled PTFE (e.g. Taconic)
- PTFE/Glass (e.g. Taconic)

Different substrate thicknesses are available (>125 µm) and most of these materials are available as metal based laminates. Metal baseplates of Copper (Cu), Aluminum (Al) and Brass (Ms) are suitable for a range of board layer finishes that can be used making use of materials such as Gold, Nickel and Tin. Up to 3 RF layers can be necessary for individual functions:

2 layers: for local electrical shielding, RF and DC lines need buried routing

3 layers: RF crossing of two microstrip lines (RF and ground)

Single RF packages

The first generation of this type of package shows SMD compatible balls for reflow soldering or gluing on the carrier board. Actually the second generation is on the market: LGA packages based on soft materials (e.g. Rogers, Taconic) and LGA designed interconnection patterns.

Up to now, only a small number of packaged MMICs is available but the chip supplier´s roadmaps announce completely packaged chip sets for various RF radio frequencies.

Metal based packages

Power amplifiers with dissipation power >1 W need a direct backside contact to the metal core or heatsink. Suppliers, e.g., Dielectric Laboratories, Kyocera and Stratedge offer packages with excellent RF performance up to 40 GHz and more. The top surface conductors are designed and metallised for soldering and bonding.

Macro Modules with Multilayer Ceramic (MLC)

Multifunctional MMICs or RF macro functional units can be realized in SMD compatible MLC modules (e.g. based on LTCC technology). The close arrangement of e.g. oscillator, mixer and filters allows modular functions consisting of different types of MMICs and Si/SiGe chips and integrated passives. Various assembly technologies inside the macro module can be used: Chip&Wire bonding, Flip Chip mounting by ball or stud bumping.

This visionary module architecture could be one base line for the challenge of a Standard mm-Wave Module.

Macro modules and single packages with a manufacturing-friendly surface-mount solution, combined with an optimized electrical module partitioning, could result in a Box of Bricks that can be used for different product demands. Finally, only the PCB layout with frequency specific filters, waveguides and mechanics will be customer specific.

Module visions based on LTCC

Different suppliers, e.g. C-MAC, Dielectric Laboratories, show their capabilities in LTCC technology. Cavities and cut-outs with minimum tolerances, integration of RF passives and WG-MSL (wave guide to microstrip line) transitions.

With the LTCC-M technology the ceramic layers are cofired with a CuMoCu baseplate.

This module vision deals with a big advantage in thermal management capabilities.

Actually, a unique module in LTCC-M with an area of about 4 cm x 4 cm would be a ´show stopper´ for cheap radio solutions because of its overall dimensions and a low fabrication yield.

Improved materials and manufacturing processes and well known libraries for integrated passives and RF functions up to

40 GHz (+) are a must to reach the goals.

6. SUMMARY AND OUTLOOK

Microwave and millimeter wave modules in different architectures and assembly technologies have been shown. Today´s complex RF products are based on ´traditional´ and proven Chip&Wire technology on single layer structured ceramics and soft substrates, assembled in a metal package.

The rapidly growing demand for MWUs and transceivers for LMDS and VSAT applications will address to

- An overall low product price
- Modular designs
- Engineered packaging and substrate materials

A clear signal to module designs based on PTFE multilayers is driven by the modern single packaged MMICs. A combination of single RF packages and macro modules suitable for high volume SMD processes will result in a near future box-of-bricks for standard mm-wave transceiver radios and innovative module designs.

Based on a clear technology strategy and roadmap together with the experience in our MicroWave Factory we are on the way to realize the challenge to win the future module demands.

7. ACKNOWLEDGMENT

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Dr. Martin Oppermann is a physicist and holds a diploma degree in applied physics of the Eberhard-Karls University in Tuebingen and and a doctor's degree of the Natural Science and Medical Institute of the University of Tuebingen. Directly after his study time he was with the Bosch company in the field of wafer processing and micromachining for automotive sensor applications.

In 1993, Oppermann came to the EADS (European Aeronautic Defence and Space Company) in Ulm/Germany and started in the department of thin film technologies. He developped Multichip Modules in Thin Film Technology for usage in Transmit/Receive Modules, combining RF and DC on one substrate. In 1998 he changed to the R&D department for Microwave and mm-Wave Technologies inside the MicroWave Factory.

He is an expert in 'Module Technologies' and is responsible for the technology management, market monitoring and Technology Strategy.

Dr. Oppermann is a member of the German Physical Society (Deutsche Physikalische Gesellschaft, DPG) and since 1994 he is an international member of IMAPS. He gave several papers in cenferences and actually in 2000 he became a member of the Technical Committee of the High Density Packaging conferences.

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