Die & Package characterization of MMIC at Microwave Frequencies & its Analysis

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Abstract- **This article describes the characterization of Monolithic Microwave Integrated Circuit (MMIC) amplifier die before and after packaging. Die level characterization is performed using RF probe station. MMIC die is packaged in a connectorized aluminium housing for further characterization. Characterization of MMIC die using probe station at microwave frequencies involves utmost handling as both RF & DC measurements are carried out simultaneously. The measurement is performed by incorporation of die capacitors, and proper connections so as to have repeatable performance. Also, calibration aspects to be taken care. Further packaging of the die introduces parasitics mostly at launching and output side for which proper characterization to be carried out. In this article, MMIC Die at C-band is characterized both at die & package level. The result indicates package introduces losses. The packaging effects are simulated in standard software tools. Effects of packaging & assembly techniques on RF performance of the connectorized amplifier module are minimized. Interconnection wire-bond length between die and alumina substrates optimized for minimum loss. Gaps between the MMIC die and substrates & carrier plate and housing are reduced to avoid discontinuities in ground plane. The bare die is biased for 4 V drain voltage to draw 45 mA current. The characterized bare die using RF probe station has a gain of 17 dB, comparable to simulated data sheet specifications. Connectorized module after packaging has a gain of 16 dB. Comparison of the simulated and measured packaging effects with bare die is performed and analysis carried out. The packaging technique implemented in this article are to find out a working die for intended aerospace application. The connectorized amplifier module can be used for aerospace applications after screening tests.**

Keywords- Monolithic Microwave Integrated Circuit, Packaging, RF probe station, wire bond.

1. INTRODUCTION

Microwave modules developed using packaged active devices and discrete passive components assembled on a dielectric substrate are standard products used in aerospace systems for a long time. With increasing demand of wider frequency-bandwidth performance, size & weight reduction in subsystems, focus is shifted to use Monolithic Microwave Integrated Circuits (MMICs). Characterization of MMIC die is necessary, to know the RF response of the fabricated die is meeting the simulated response. RF probe station is used for characterization of MMIC die at wafer, carrier and package level. Some of the MMICs require large external lumped capacitor in the bias circuitry for low frequency gain reduction. On wafer characterization of some of these MMIC dice has limitations due to requirement of external lumped capacitor, higher power dissipation and fixturing issues. These MMIC dice are characterized using RF probe station after assembly on a heat sink carrier along with external lumber components. This article deals with such MMIC die characterization using probe station at carrier level and subsequent assembly in a connectorized aluminium housing. MMICs are packaged to meet electrical, thermal and environmental specifications of an aerospace subsystem. Packaging of MMICs provides mechanical support, environmental protection, and thermal dissipation path and connects the MMIC to other circuit elements in a system. Packaging of MMIC degrades the bare die performance. This work deals with characterization and validation of packaging effects arising due to wire bond interconnects at C-band frequencies. This article is arranged as follows. MMIC probing at carrier level, connectorized aluminium module realization and bond wire modelling & simulation are presented in section 2. Results of the bare die, simulated and measured packaging effects are analysed in section 3. Conclusions and further improvements are drawn in Section 4.

2. DESIGN METHODS

2.1 RF Probing:

RF probing of die is performed to verify, that the fabrication was completed satisfactorily, and for characterization of the bare die before packaging [1]. MMIC characterization at the die level is essential, since packaging affects performance. Knowing the MMIC performance before packaging allows the product designer to know how various packaging techniques affect device performance and to choose the optimum pacakaging technique meeting the intended application. RF characterization of the MMIC die in this article is carried out using 150 µm pitch, ACP type GSG probes. Assembled Kovar carrier containing MMIC die during RF & DC probing is shown in Fig.1.

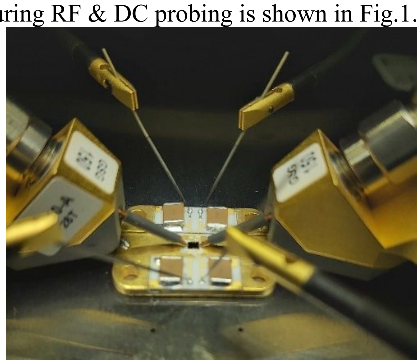

Fig. 1: MMIC Die Probing

DC bias voltages are applied thru DC probes on bond pads of the alumina substrate. During RF probing MMIC die is biased with 4 V drain voltage to draw 45 mA current. Before doing RF probing, planarity of the probe tips is checked using contact substrate [1]. Planarity adjustment is performed using micro positioners of the probe. Probe alignment to the die pads is adjusted using chuck adjustment. Calibration of the probes is the first step during characterization of MMIC die. Vector Network Analyzer (VNA) coaxial calibration will remove all errors to the end of the cables. For accurate MMIC die measurements, errors up to the probe tip must be removed. This includes internal VNA errors, cables and probe losses. For MMIC die measurements calibration at probe tips with known standards is necessary to bring the calibration plane to die pads. LRRM calibration method is chosen for better accuracy. WinCal XETM software application toll is used for calibration & validation of RF probe station measurement setup.

2.2 Fabrication of Connectorized Module:

Connectorized MMIC amplifier module is realized using Aluminium housing. Assembly processes sequence of module is shown in Figure 2 below.

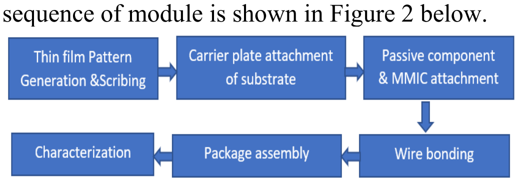

Fig. 2: Assembly Process Sequence

Aluminium package is custom designed. Module thus assembled is shown in Figure 3.

Standard assembly process as mentioned in [2] are used. The amplifier module is realized using 10 mil thick alumina substrates for 50-ohm microstrip lines and bias circuitry. Thin film patter generation and laser scribing techniques are used for alumina substate fabrication. The alumina substates along with MMIC die are soldered on metal carrier. Gold plated Kovar carrier is used as interface to take care of coefficient of thermal expansions between GaAs /Alumina and Aluminium. The amplifier circuit is divided into three separate alumina substrates for ease of fabrication & assembly. Input & Output substrates contain 50-ohm microstrip RF line. Bias substrates on both sides of the MMIC die accommodate the 0.01 µF supply-bypass capacitors required for biasing the MMIC die. 100 pF die capacitors are attached very adjacent to MMIC die to supress instabilities arising due to bond wire inductances. Bare MMIC die requires a capacitors of 100 pF & 0.01 µF in drain and gate paths for MMIC stability and to supress leakage of RF signal into DC path. MMIC die attachment and interconnecting the die using wire bonds is the last step in realization of the module. This is done at the end to avoid any failures while handling due to ESD. Wire interconnect length is reduced by minimising the gap between alumina substrates and GaAs MMIC die. The achieved gap after MMIC die is measured. It is less than 0.5 mil (shown in Figure 4).

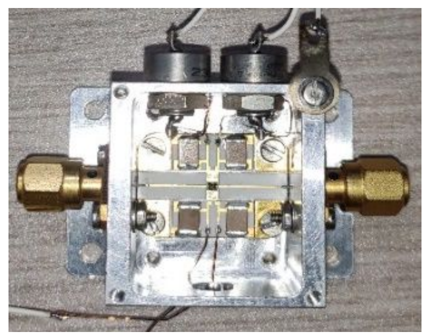

Fig. 3: Assembled Module

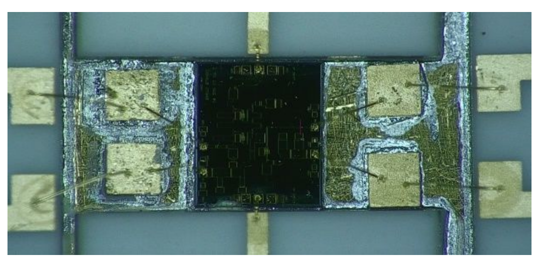

Fig. 4: Wire bonded MMIC Die

With this gap the achieved wire bond length including loop height is 12 mil. The assembled carrier is mounted inside the aluminium housing. SMA type RF connectors are soldered to 50-ohm microstrip alumina substrates. Gap between the Kovar carrier and aluminium housing is minimised by tight mechanical tolerances of hardware to avoid ground loops. The packaging process carried out are qualified, thus making the packaged MMIC suitable for aerospace applications. The packed MMIC module performance is meeting the application requirements. The fabricated MMIC amplifier module after subjecting to standard screening tests, can be used in aerospace systems

2.3 Wire bond Model:

The low pass filter model as presented in [3] is used in this article for wire bonds below 8 GHz is shown in Figure 5.

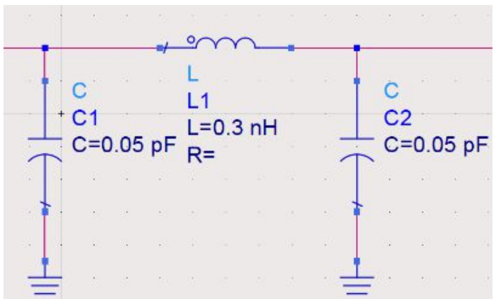

Fig. 5: Wire bond Low pass Filter model

It is a shunt-series-shunt C-L-C structure. The bond wire inductance is dependent on the length of the bond wire and its cross-sectional profile [4]. For frequencies up to 8 GHz bond wire inductance is independent on frequency and for a single wire the 1nH/mm formula can be used as a rule. The wire bond length achieved in packaged module is 0.3 mm. This gives a series inductance of 0.3 nH. Shunt capacitances in the π-network represent bond pad capacitances and for interested frequency range can be considered a constant value of ~30 fF. Wideband effects are simulated using these parameters. Later, shunt capacitance is adjusted to 50 fF based on alumina substrate parameters to match the measure module performance. The obtained L, C values for wire bonds of this work are 0.3 nH and 50 fF. Simulation of the connectorized module in standard software is shown in Figure 6.

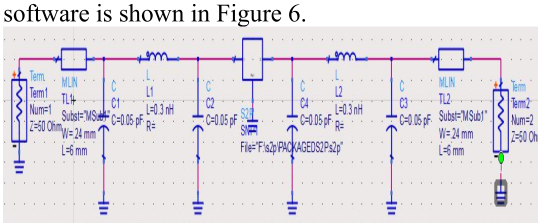

Fig. 6: simulated connectorized module

While simulation S-parameters of the die are used. Impotrted S-parametes of die, wire bond model and 10 mil thick alumina substrates are used for connectorized module simulation.

3. RESULTS & DISCUSSION

The MMIC amplifier is tested at die level using FormFactor EPS 150 RF manual probe station and ZNB40 Vector Network Analyzer. The characterized MMIC die offered a gain of 17 dB over the operating band of 1-10 GHz. The measured results of the bare die are comparable to data sheet specifications. The same Kovar carrier containing with MMIC die is attached with input & output 50-ohm microstrip launchers to realize the connectorized module. The connectorized module with 1 mil dia wire interconnection is characterized using VNA. S-parameters of the bare die and connectorized module are compared in Figure 7.

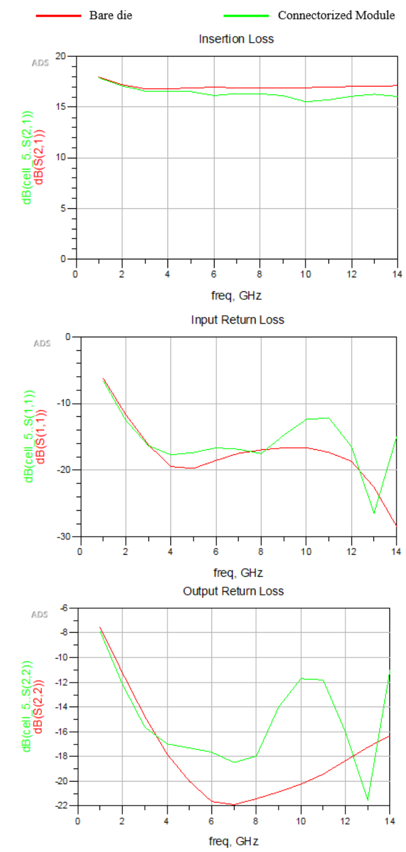

Fig. 7: S-parameters of bare die & connetorized module

Results indicate wire interconnections and packaging effects has not degraded the die performance significantly. However, a 1dB degradation in gain at 6 GHz is observed. Measured gain of bare die and connectorized module at various frequencies is mentioned in Table 1.

Table 1: Measured gain of bare die & Connectorized Module

Frequency (GHz)	Gain (dB)	
	Bare Die	Connetorized Module
2	17.2	17.0
4	16.7	16.5
6	16.9	16.1
8	16.8	16.3
10	16.9	15.5
12	17.0	16.0

This degradation is due to wire interconnection between MMIC die and alumina substrate. Further improvement in gain of the MMIC module is possible using multiple wire bonds as suggested in [5]. Also, wire bond effects on connectorized amplifier module are simulated in standard software tool utilizing the model presented in Section 2. Comparison between simulated and measured amplifier module are presented in Figure 8.

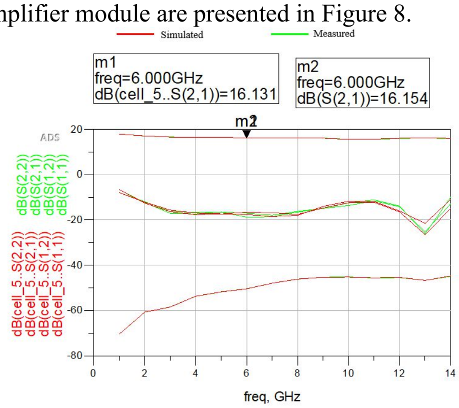

Fig. 8: Simulated and Measured amplifier module

The simulated results are closely matched the actual measured performance. This indicates the model parameters predicted for wire bonds of this assembly are accurate and can be used during design of any other module.

4. CONCLUSION

This article has demonstrated the characterization of MMIC amplifier die using RF probe station. MMIC interconnection and packaging aspects of the connectorized module are covered. Ball Wire bonding process is used for MMIC interconnection. S-parameters of the bare die, connectorized module are compared. Wire bonding and packaging effects on connectorized module are minimized using controlled process techniques. Wire bonding effects are simulated and validated using equivalent low pass (C-L-C) circuit model of the wire bond. Simulated and measured results of the connectorized module are matching. Further improvement in RF performance can be achieved using double bond wires/ribbon interconnections.

5. ACKNOWLEDGEMENT

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