# Ku-Band MMIC's in Low-Cost, SMT Compatible Packages*

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*Abstract* — **mm-wave components are very expensive due to the high package and assembly cost. This paper describes a 0.25um PHEMT Ku-band 2-watt PA, and a 2.2dB NF LNA MMIC in a low-cost SMT package ($2.00). The package has excellent thermal resistance, 0.5C/W, return loss (20dB), and input/output isolation (40dB), from DC-40 GHz. We believe this is the first time such a package design is published.**

## I. INTRODUCTION

Microwave components for high frequency applications such as Ku-band VSAT, K-band LMDS, Ka-band point-to-point radio, Ka-band multi-media broadband satellite communication, 77GHz collision avoidance radar, and a host of millimeter-wave military applications are very expensive. A major reason for the high price is the high package cost and the subsequent (largely manual) assembly cost. This problem is especially difficult for high-power millimeter components, in which the package requires to have low thermal resistance, near 50-ohm RF input/output feed through, and high input/output isolation. In addition, to facilitate low-cost automatic assembly, the package needs to be SMT compatible, which complicates the design and manufacturing process. This is an area that continues to receive substantial attentions [1]-[5].

This paper describes two packaged MMICs: a 2-watt PA and a 2.2dB NF LNA MMIC covering the 14GHz to 18GHz band. The MMICs are assembled in low-cost, high-performance, SMT compatible package for affordable Tx and Rx automatic assembly production. We believe this is the first time such a package design is published. The package has low thermal resistance of less than 0.5C/W. It has RF input/output return loss better than 20dB and input to output isolation better than 40dB, from DC to 40GHz. It is compatible to automatic SMT assembly, and cost less than $2.00 for 1 million quantities. This approach can also apply to MCM (Multi Chip Module) for further reduction of the size and cost. This type of low-cost, high-frequency MMIC components will open up many millimeter wave applications, which were not affordable before.

## II. PACKAGE DESIGN AND TECHNOLOGY

Figure 1a shows the PA package. The package is first patterned on a 4"x4" ceramic substrate. The area on which the MMIC will be die-attached, is cut out by automatic laser scribing. This cut out is subsequently filled with Ag(95%)/Pd(5%) and sintered. This Ag/Pd pad serves as thermal conductive path, DC, and RF ground. Gold metalization patterns, which match to the MMIC RF and DC bonding pads, are fabricated on the ceramic, adjacent to the Ag/Pd pad for wire bonding from MMIC pads to the ceramic. Metallized Via holes are laser drilled in the ceramic to connect the RF input/out and the DC bias metalization patterns from the ceramic surface to the bottom side of the ceramic. Therefore, all the RF/DC pads and the RF/DC grounds are on the bottom surface of the ceramic to facilitate automatic SMT assembly. EM simulators are used to design the metalization pattern to achieve near 50-ohm input/output feed through and good input/output isolation. For the case of the LNA, the anticipated thermal dissipation is not significant. Hence, the package does not require a high-power heat sink. Thus, via holes can be used with filled Pd/Ag metal slug to reduce cost even further. Figure 1b shows the package used for the LNA MMIC.

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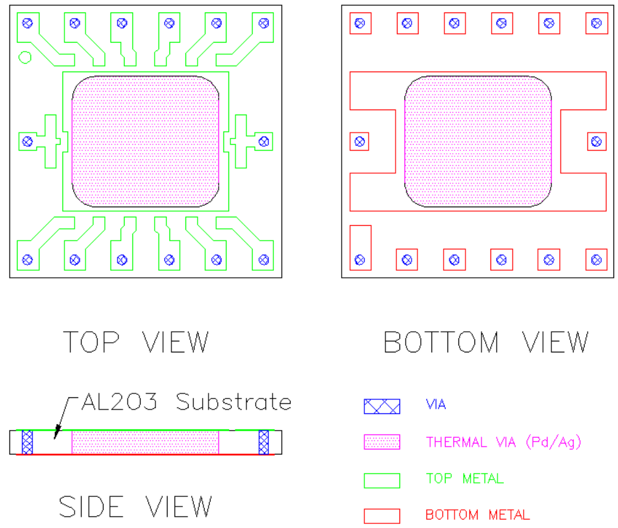


Fig. 1a. Package design for PA. The top, bottom, and side views are shown. The heat sink is a Pd/Ag filled metal slug.

The RF performance of the package is improved by compensating for the inductance of the bond wire through the use of two open stubs immediately next to the MMIC input/output. In addition, the ground plane metal pattern is selected to reduce any discontinuity caused by the input/output via holes of the package.

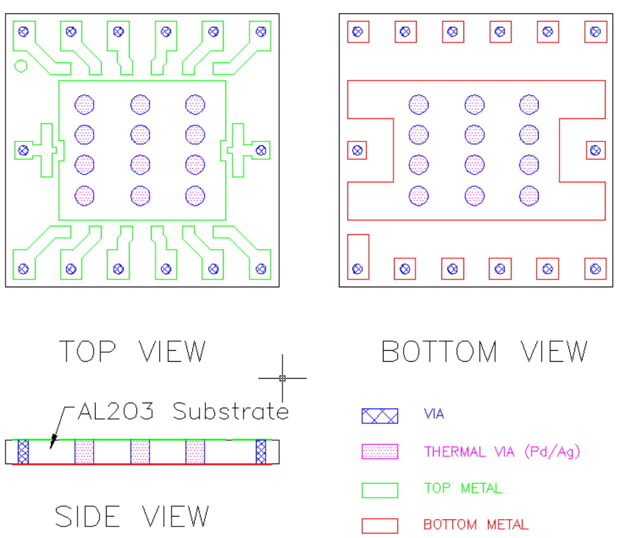


Fig. 1b. Package design for LNA. The top, bottom, and side views are shown. Via holes replace the heat sink since little thermal dissipation is needed.

Figure 2 shows the simulation results of this package, which match very well with measurements in the lab. In all cases, the performance of the package was calculated using full wave analysis (*AWR's Microwave office* and *Ansoft's HFSS*).

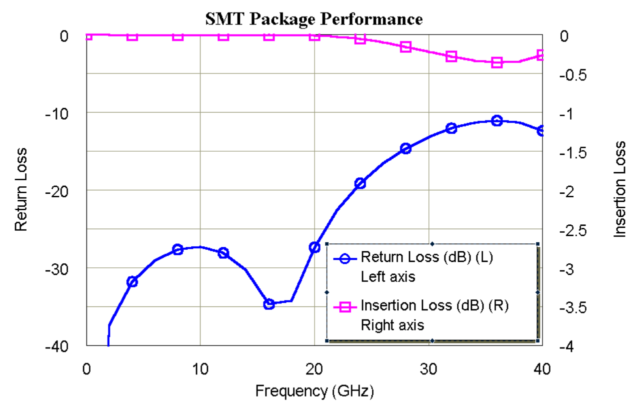


Fig. 2. Package performance from DC to 40 GHz. The worst case for insertion loss is –0.4 dB (right scale) and for return loss is –11 dB (left scale).

After all the package patterns are fabricated, the 4"x4" ceramic substrate is diced to be individual package. The MMIC is Au-Su eutectic die attached to the Ag/Pd pad for good thermal conductivity and high reliability. A ceramic lid is attached to the ceramic package by non-conductive epoxy to cover the MMIC as protection (The EM simulator design includes the effect of this ceramic lid). This completes the MMIC assembly process. Figure 3 is the finished assembly (without lid or bias lines for clarity).

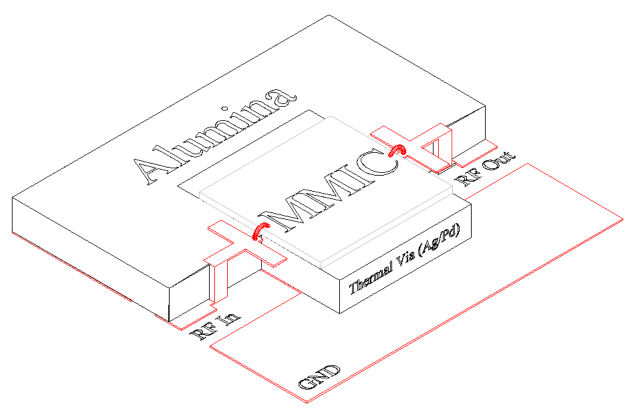


Fig. 3. 3D view of finished package with MMIC assembly. The MMIC sits on a Pd/Ag heat sink.

Our simulation shows that this package works from DC to beyond 40GHz, and it can handle more than 8 watts of DC dissipation. Because this package is fabricated by batch process, the price of this package is below $2.00 for a quantity of over 1 million. In addition, this approach can also apply to MCM (Multi Chip Module) for further reduction of the size and cost.

## III. PA, AND LNA DESIGN AND TECHNOLOGY

Both PA and LNA MMICs use 0.25um gate power PHEMT process to take advantage of volume purchase to reduce cost. The same process is used for the PA and the LNA circuits. The process yields 0.6W/mm and a noise figure < 1.5dB under optimum matching conditions at 18GHz. The PA (Fig. 4) consists of 3 stages with FET sizes: 400µm, 1200µm & 4000µm respectively. To achieve a minimum of 2W output power, the last stage has four FETs, with 1mm periphery each, which are directly combined to achieve the required power target. A small amount of resistive feedback is used in each of the output FETs to improve the output return loss. This feedback is kept to a minimum to avoid affecting the output power. The size of the chip (Fig. 5) is 3.5 x 2.4mm.

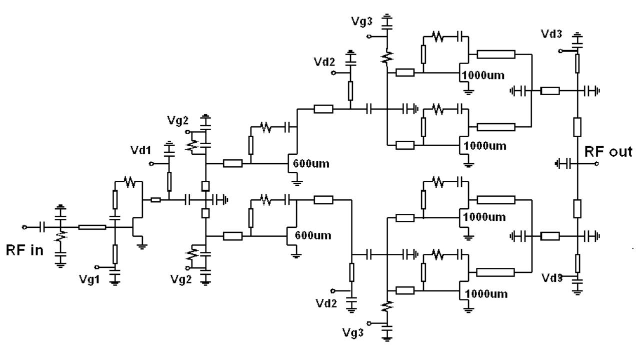


Fig. 4. PA MMIC schematic.

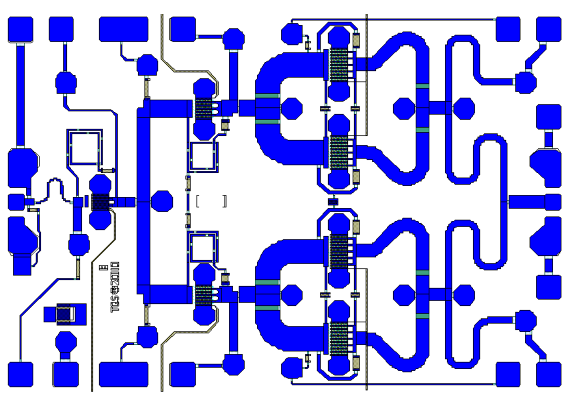

Fig. 5. PA MMIC layout.

The packaged 3-stage PA achieves over 2-watt P1dB with 25dB gain and 35% efficiency (Fig. 6). The input return loss is > 10dB and the output return loss is around 10dB over most of the band. The results shown in Fig. 6 are almost identical to measured chip performance (output power, Pout, is the P1dB power measured over the band of interest).

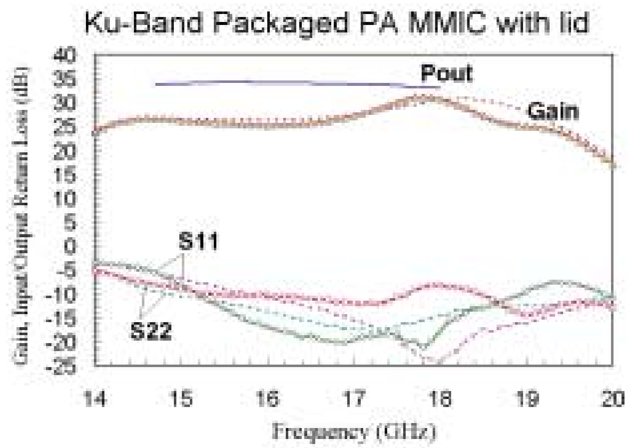


Fig. 6. Package performance of PA. Left axis is in dB for Gain, Input/Output return loss, and in dBm for Pout. MMIC chip performance is shown as dashed line.

The LNA consists of 3 stages with FET sizes: 200µm, 400µm & 400µm respectively. Resistive feedback is used in the output stage to broadband the design and to achieve good output return loss (Fig. 7). The chip size is 2.8 x 1.4mm (Fig. 8). The packaged 3-stage LNA achieves 2.2dB noise figure with 20dB gain (Fig. 9).

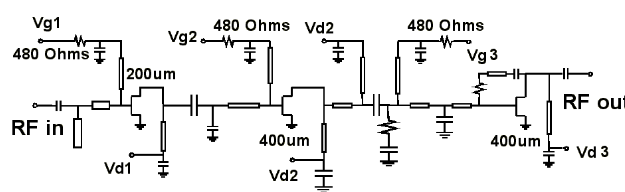


Fig. 7. LNA MMIC schematic.

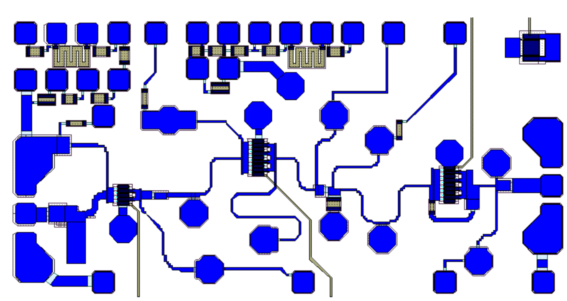

Fig. 8. LNA MMIC layout.

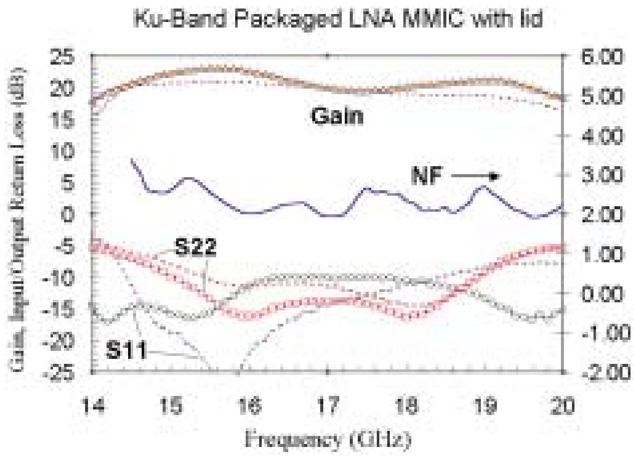


Fig. 9. Performance of Packaged LNA. Right axes is for NF curve (in dB). . MMIC chip performance is shown as dashed line.

The performance of the MMIC bare die and the packaged one are nearly identical for the PA & the LNA designs, which illustrates the excellent performance of the package. This performance is obtained with first pass success, without iteration. Therefore, the design of the package and MMICs were done independently. This necessitates ensuring excellent 50-ohm match from the package and MMIC and makes both of them useful independent of each other.

## V. Conclusion

We have designed, built and tested Ku-band PA and LNA MMIC in a low-cost automatic SMT assembly package. This package, although it is currently used at Ku-band, is suitable for mm-wave applications. We used the package with two Ku-band MMICs with great success. The package demonstrates that many of the mm-wave applications can be brought to market affordably given the proper package design.

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