

Near-Hermetic High Power Package using Liquid Crystal Polymer for 4-Watt Ka-Band Amplifier with Sparse Thermal Vias for Cost Reduction.

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Abstract

This paper presents the design and development of a 10W power package at Ka-band with near a hermetic sealing cavity. The package has a 12x12x0.5 mm copper heat spreader on which Liquid Crystal Polymer films are laminated to form 50Ω feed-thru transition to a mother board. The experiment results demonstrate that a packaged GaAs power amplifier dissipating 10W DC power has the maximum channel temperature of 143.9°C. The T_{ch} temperature is obtained using infrared thermal mapping technique with baseplate temperature at 80°C. Also the effect of using sparse corner vias at the PCB level will be presented as well. By reducing the number of vias at the corners from 196 to 148, a 24.4% reduction, the channel temperature of the packaged amplifier maintains approximately the same temperature. This LCP package will be near-hermetic without extra adhesive and will provide enough power dissipation up to 10W to maintain GaAs device lifetime at Ka-band.

Key words: High power package, Liquid crystal polymer, Near-Hermetic, Ka-band, Sparse Thermal vias.

I. Introduction

With increasing demand for power in the wireless communication field, specifically for the base station towers, microwave power devices have improved tremendously. Even though GaAs is still the choice of many currently existing commercial devices, GaN is getting more attention as the next-generation power transistor and amplifiers. The output power for AlGaIn/GaN HEMT have now reached 110W for X-band [1] and 30W for Ku-band [2]. The thermal management for packaging these high power RF devices becomes even more critical.

In this paper, we present a high power package using Liquid Crystal Polymer (LCP) for a 4W Ka-band GaAs High Power Amplifier. By using LCP, the package does not require additional adhesive and obtains a near-hermetic property. We also investigate the effect of using sparse thermal via for cost reduction reasons.

II. ePhysics Thermal Simulation Setup

To simulate the thermal dissipation of the package, we use ePhysics from Ansoft. Figure 1 shows the cross-section of the simulation setup. The components from the top down are GaAs amplifier,

Diemat 6030 epoxy, copper heat spreader, Roger4350 and FR4. Dimensions are listed in Table 1.

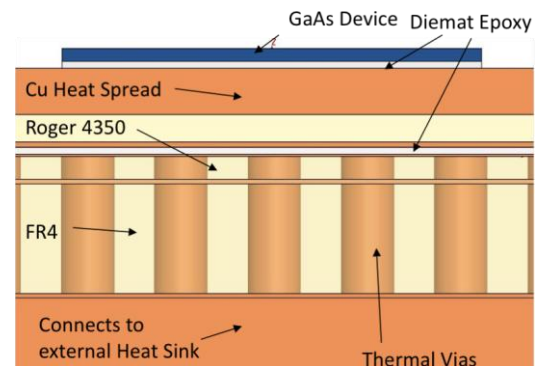


Figure 1 Cross-Section of Package ePhysics Simulation Setup

Table 1 Dimension of package components

	Width	Length	Height
GaAs Amp	4mm	4mm	100 μ m
Cu Spreader	12mm	12mm	508 μ m
Roger4350	36mm	36mm	168 μ m
FR4	36mm	36mm	508 μ m

The amplifier used in this simulation is a general Ka-band GaAs power amplifier with 4mmx4mm dimension. The heat sources are assumed to be the transistors of the last stage of amplification. 3 different types of sources are simulated in Figure 2.

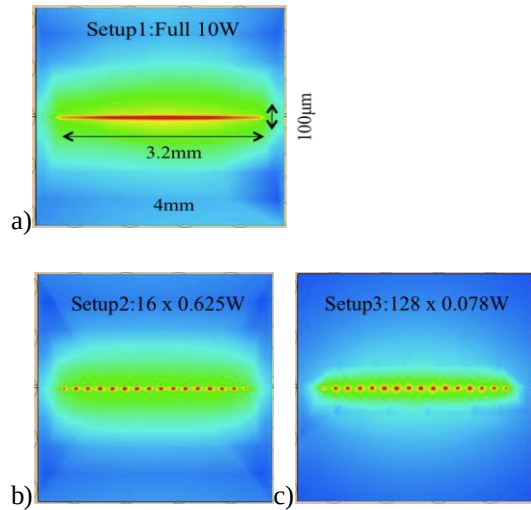


Figure 2 GaAs power amplifier heat source setups. a) heat source as the whole transistor stage, b) heat source as each individual transistor, c) heat source as each individual FET gate fingers.

Since for a FET device, the heat is generated from the gate area, the third setup would represent the most accurate simulation. For a 4W power amplifier at Ka-band with 40% Power Added Efficiency (PAE), the

total DC power dissipation would be 10W, therefore 10W is chosen as the power outputted by these heat sources.

After simulating multiple variation of the heat spreader size, we conclude that 12mm x 12mm is the most optimal geometry. Beyond this dimension, the decrease of channel temperature is not sufficient in proportional to the increase in size anymore.

III. Sparse Thermal Vias

In the PCB design, the number of via holes on a board dominate the cost of the actual board production. By examining the application of sparse thermal via at the corner, we showed that the channel temperature of the device does not degrade with the reduction of corner vias. Figure 3 shows the 3 different configurations used for simulations and measurements.

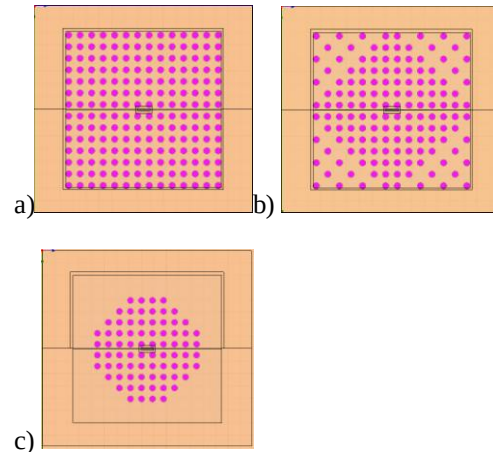


Figure 3 Sparse via configurations a) full via configuration (196 vias), b) sparse via (148 vias), c) no corner vias (76 vias).

Table 2 Sparse via simulation and measurement comparison obtained from TTC.

Part	Full Via	Full Via Simulation	Sparse Corner Via	Sparse Corner Via Simulation	No Corner Via	No Corner Via Simulation
Thermal Resistance θ_{package} ($^{\circ}\text{C}/\text{W}$)	6.99	6.85	6.09	6.79	7.86	6.86
Avg T_{channel} ($^{\circ}\text{C}$)	124.68	101.6	107.6	101	127.55	101.7
Dissipating Power (W)	10.34	10	9.89	10	10.11	10

The channel temperature measurement in this part is done using a Thermal Test Chip (TTC) from Thermal Engineering Associates, Inc. It is a Si chip embedded with resistors for heating and temperature sensitive diode for measuring the temperature. The sparse via simulation and measurement are both done in room temperature of 23°C with only natural convection. Results are tabulated in Table 2. Both measurement and simulation results prove that even with 24.4% reduction, the sparse via package does not perform any worse than full via configuration, unlike no corner via package.

However since the material of the TTC is Si, the thermal conductivity of it is different than GaAs. We need to back out the TTC thermal resistance θ_{Device} from the whole system and add in GaAs thermal resistance. The extrapolated measurement data is plotted in Figure 4. At 10W dissipating power, the sparse via data shows the channel temperature at 150°C, the safe operating region for GaAs devices. This shows that for our 4W Ka-band power amplifier can be use with a sparse via PCB board to greatly reduce the production cost.

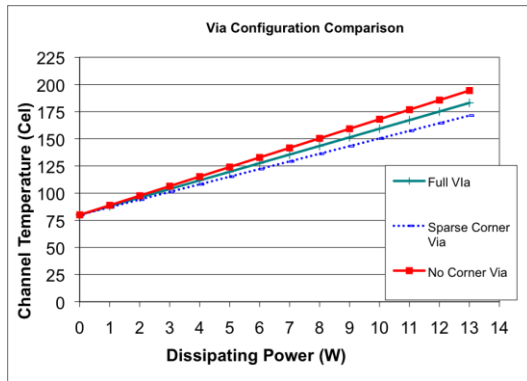


Figure 4 Sparse via extrapolation for GaAs device at 80°C ambient temperature.

IV. Package Feedthru Design

The package feedthru is designed based on Ka-band feedthru by Aihara [3]. The difference is that in this paper, the package is not a QFN type, but instead has extended lead as show in Figure 5.

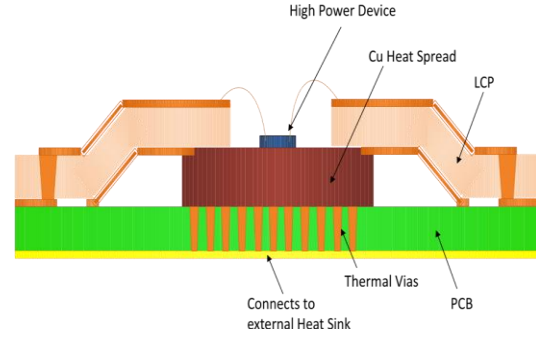


Figure 5 Cross-section schematic of the package with extended feed-thru.

The electrical design of the package feedthru is done using HFSS from Ansoft. Figure 6 is the simulation structure based on the stackup in Figure 1 with a 4mil thick LCP as the substrate. The feedthru has a total length of 6.1mm from end of wirebond to the beginning of the CPW probe pad. This long line is designed to accommodate the 12mmx12mm copper heat spread with 4mmx4mm amplifier in the center.

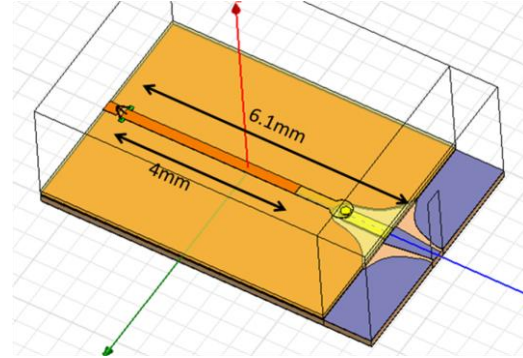


Figure 6 HFSS simulation structure for package feed-thru on 4 mil LCP.

Figure 7 shows the insertion and return losses of the feed-thru. The dotted line shows that S21 insertion loss at 0.32dB at the end of Ka-band, which is 40GHz. Solid line represents the return loss and has a below -20dB performance across the whole Ka-band.

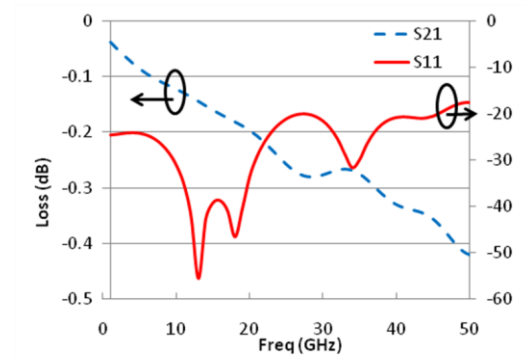


Figure 7 Package feed-thru simulation S-parameter results.

V. Measurements

Triquint TGA4505 Ka-band high power amplifier (HPA) is used as the power device to measure the actual thermal resistance of proposed package. The test setup has the package, shown in Figure 8, mounted on a hotplate with constant temperature of 80°C. This is done to prevent ambient temperature noise from affecting Infrared imaging and to emulate a harsh operating environment for the package. The package was left open for the purpose of taking channel temperature using IR camera. The enclosed LCP package's hermeticity has been demonstrated by Chen in [4]

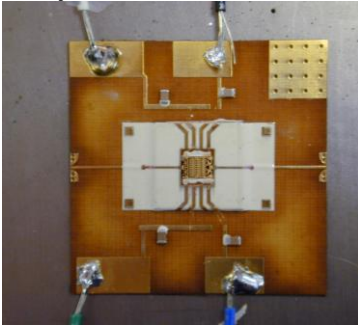


Figure 8 Open LCP high power with Triquint power amplifier for IR imaging.

Figure 9 shows the IR result of the thermal mapping of the power amplifier. Images are from two different units of package tested (b and c are the same device). More details are listed in Table 3.

Table 3 Package thermal resistance and IR temperature measurement results.

	a (A1)	b (B2)	c (B3)
V_D (V)	6	4.2, 6 *	6
I_D (A)	1.3	1, 0.9	1.9
Dissipating Power (W)	7.8	9.6	11.4
Highest T (°C)	137.4	143.9	184
Lowest T (°C)**	84.5	88.2	88.9
Average Heat Source T (°C)	126.43	131.65	152.1
Thermal Resistance θ_{package} (°C/W)	5.95	5.38	6.33

* Unit B has problem with balanced DC biasing at the last stage as can be seen from IR image.

** Lowest T is the lowest temperature on device, not the lowest package temperature.

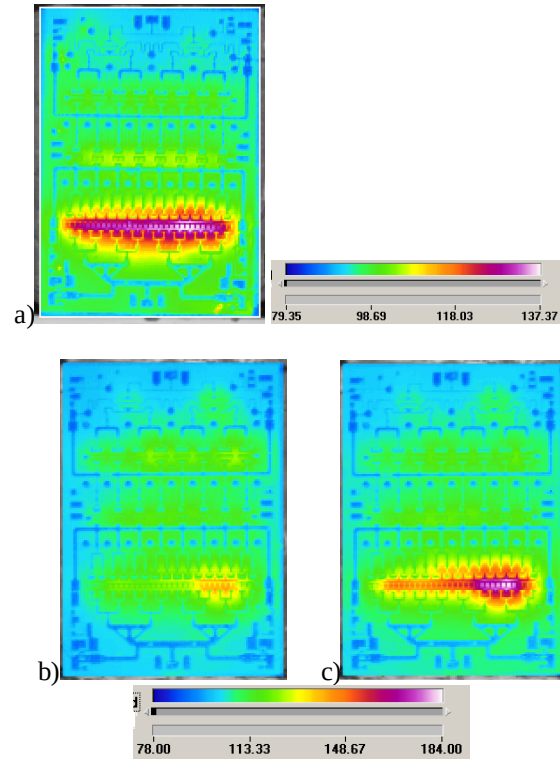


Figure 9 IR image of power amplifier a) test unit A, b,c) test unit B.

From Table 3, we have 9.6W DC dissipation for B2, which is the closest to our 10W goal. The highest temperatures are plotted in Figure 10.

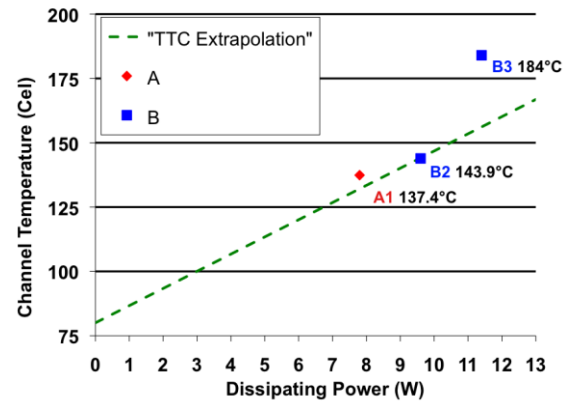


Figure 10 Measured channel temperature vs. dissipating power.

Both A1 and B2 show that the amplifier is operating below the 150°C maximum operating temperature specified by Triquint. Also by plotting the sparse via extrapolation line from Figure 4 here, we can see that the TTC extrapolation data agrees with HPA measurements below 10W power dissipation. Above 10W, the difference is possibly caused by the much higher power density of the power amplifier. The

heat source area is much bigger and spreaded out in the test chip than the HPA, where it is basically confined to the last stage transistors. Therefore, for the power dissipation over 10W, the relationship between power and channel temperature is not linear as predicted from extrapolation.

In Table 3, package thermal resistance is also calculated for each dissipating power level. For the thermal resistance calculation to be more consistent, instead of the highest temperature recorded by the IR image, we have to use the average temperature of the whole heating area. Then thermal resistance is a very simple calculation from

$$\theta_{th} = \frac{(T_{high} - T_{low})}{P}$$

T_{high} : High temperature of the package.

T_{low} : Low temperature of the package.

P: power dissipated by the package.

One thing worth noting is that the T_{low} in the equation is not the lowest temperature in Table 3 but the 80°C mounting plate temperature. The thermal resistances are pretty consistent around 6 °C/W. B2 is a bit lower because its T_{high} might be lower than what it's supposed to be due to the unbalanced heating of the transistors. If we raise the temperature of B2 by 5° (both the average and highest channel temperatures), $\theta_{package}$ becomes 5.9°C/W, while the device still operate below 150°C.

VI. Conclusion

In this paper, we have demonstrated a high power package capable of handling a 4W Ka-band high power amplifier. While dissipating close to 10W DC, the amplifier still operates under the maximum allowed temperature as shown by the IR measurements. The sparse thermal via technique is a very viable cost reduction option without sacrificing thermal performance. The package feedthru has insertion loss of 0.32dB at 40GHz with return loss below -20dB across the whole Ka-band.

Acknowledgement

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