Development of Multi-Layer Liquid Crystal Polymer *Ka*-band Receiver Downconverter Modules

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***Abstract*—We present the development of a Ka-band receiver downconverter module using liquid crystal polymer (LCP) thin-film surface mount packages. The packages are constructed using multi-layer LCP films and can be surface mounted on a printed circuit board (PCB). The package utilizes vias to connect the RF input from the PCB signal launch onto the package substrate. The use of an LCP enclosure provides hermetic capabilities in a compact structure. The receiver module consists of a low-noise amplifier (LNA), an image-rejection mixer and a driver amplifier. The surface mount package feed-through simulation predicts better than 20 dB return loss up to 40 GHz. We show the conversion gain measurement of the receiver and derive a chart that explains sources of loss in the module. From the chart we discern that the package feed-through loss is approximately 0.4 dB at 38.4 GHz.**

***Index Terms*—LCP, receiver module, *Ka*-band, surface mount package.**

I. Introduction

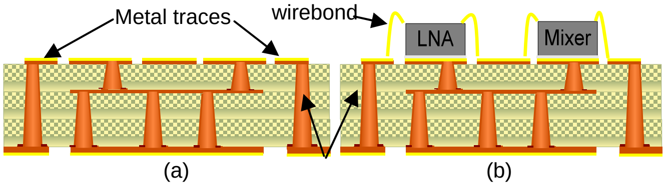
Emerging microwave and millimeter-wave applications require effective and low-cost approaches to high-frequency electronic packaging to fulfill the industry demand. At millimeter-wave frequencies, ceramic packages [1]-[3] are frequently used to provide low loss transitions and hermeticity. High cost and poor thermal dissipation are the disadvantages of ceramic packages. At lower frequency ranges, plastic packages [4]-[5] are used for cost effectiveness. However, their electrical performance is limited, and plastic does not serve as a moisture barrier.

In this work, we present the development of *Ka*-band receiver downconverter modules using thin-film LCP surface-mount packages. The LCP films have the ability to act as both the substrate and package for multilayer construction [6]-[7]. The use of multilayer LCP films provides added flexibility to design the package feed-through with smaller feature sizes. The height of the vertical transition can be altered through the use different film thicknesses starting from 1 mil. Furthermore, the multi-layer LCP structures will provide a hermetic environment for packaged MMICs [8] and embedded passive devices. Using our technology, a hermetic package can be constructed in a compact and light-weight format. Our packages are constructed using multilayer LCP films and can be surface mounted onto a PC board. The package uses vias to provide electrical connection between the PCB and the package substrate. Our via and surface mount concepts applied to the package using LCP demonstrate 6.9 dB of conversion gain and 0.4 dB of package feed-through loss at 38.4GHz in the down-converter module.

II. Design Of Package and Package Feed-Through

A. Package and Feed-through Design

Fig. 1 shows a schematic diagram of the thin-film LCP surface mount packages developed at the University of California at Davis [9]. The substrate layer can be as thin as 25.4 μm (1 mil) to shorten the vertical interconnect transition. Electrical signals enter the package through a bottom metal trace and connect to the top of the package substrate through a plated via. The LNA, mixer and driver amplifier are mounted on the top metal layer of the package substrate. Once proper electrical connections are provided to the MMICs by bond wires, a multi-layered LCP lid is laminated on top of the package to produce a near-hermetic cavity. Note that the ground pads from the top metal layer are connected to the bottom ground plane of the package by blind vias instead of through vias. The main purpose of using blind vias from above and below the package substrate and electrically connecting them at an intermediate ground metal layer is to prevent moisture from entering the package cavity through the ground vias. Also, the RF signal vias are through vias but are covered by the laminated LCP lid on the package surface, Fig 1d. Therefore, moisture will be blocked by the lid from entering the package.



(a) (b)

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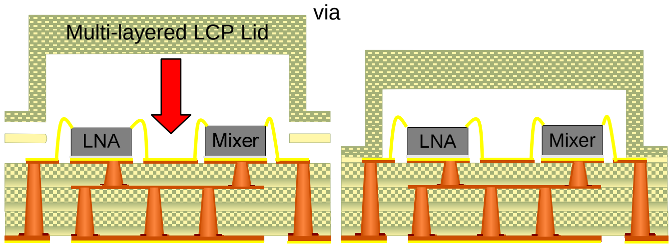

(c) (d)

Fig. 1. Schematic diagram of the multi-layer thin-film LCP package: (a) cross section view, (b) after MMICs are mounted, (c) before lid lamination and (d) after lid lamination.

We have designed the vertical feed-through transition of the thin-film LCP surface-mount packages with the aid of an Ansoft HFSS (High Frequency Structure Simulator) and Q3D Extractor. Our design starts out with a 228.6 µm (9 mils) thick LCP multilayer substrate with a 254 µm (10 mils) diameter via process. We have chosen the via diameter to be 254 µm, which is mechanically drillable, to minimize the production cost by avoiding laser machining. The via and via pad dimensions were designed using a first-level approximation of dividing the inductance of the via by the capacitance of the via pads, taking the square root of the quotient and setting it to equal approximately 50 Ω. Since the height of the via is fixed at 9 mils, the sizes of the via pads were varied to achieve 50 Ω. This design was performed using the Q3D Extractor that calculates the inductance and capacitance of the via. Then, the complete feed-through was simulated and optimized on HFSS. Fig. 2 shows the simulated S-parameters of the complete package feed-through design. The simulation shows a return loss of better than 20 dB and an insertion loss of less than 0.45 dB up to 40 GHz.

B. *Package Fabrication*

The fabrication starts with six layers of LCP film with thicknesses alternating between 50.8 µm (2mils) and 25.4 µm were laminated to produce a total substrate thickness of 228.6 µm. High- and low-melting-temperature LCP layers were staggered to allow lamination by sandwiching the melted low-melting-temperature LCP layers with the high-melting-temperature LCP layers. The metal traces are located above, below, and in two layers within the multi-layer LCP stack to allow blind vias to electrically connect the ground planes on the package substrate surface to the bottom ground of the package while preventing moisture from entering the package cavity, as well as to route DC input and IF signal traces. The bottom ground metal has a thickness of 36 µm to provide mechanical support, and all visible copper traces and planes are gold plated to prevent oxidation.

III. CONVERSION GAIN MEASUREMENT

A. *Downconverter Module Layout*

The schematic diagram of the *Ka*-band receiver module is shown below in Fig 3. The package requires two *Ka*-band signal inputs, for RF and LO ports, and two IF outputs from the mixer. There are three DC inputs for powering the LNA and the driver amplifier. Fig 4 shows an image of the receiver downconverter module. As can be seen the RF signal enters the package on the left hand side and is amplified through the LNA. The amplified signal then enters the mixer to be downconverted to two IF signals, which exit at the right side of the package. The LO signal enters the package from the bottom, is amplified through a driver amplifier, and enters the mixer.

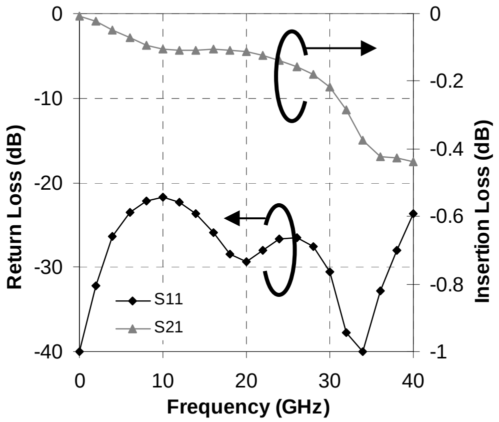

Fig. 2. Simulated result of the thin-film LCP package feedthrough transition design on HFSS

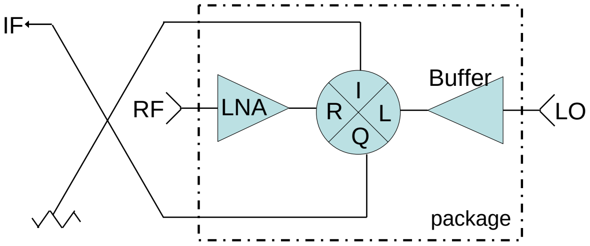

Fig. 3. Block diagram of the Ka-band receiver module

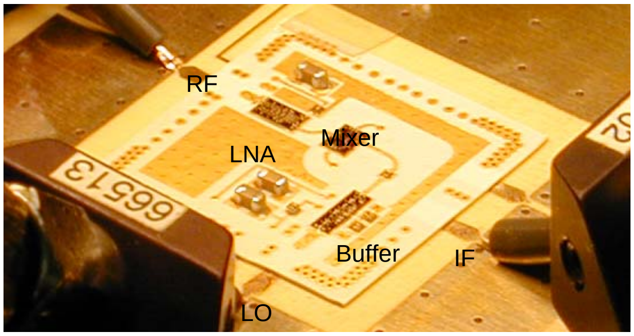

Fig. 4. Thin film LCP surface-mount receiver downconverter package module mounted on the PCB test board

B. *Measurement Setup*

The package was mounted onto a 508 µm thick Rogers RO4350B printed circuit board using epoxy. The CPW launches on the PCB test board were probed for measurement. The receiver RF input power was varied from -39 dBm to -12 dBm, the RF frequency was varied from 37 to 39.4 GHz, the LO frequency was varied from 35.8 to 38.2 GHz, and the IF output power was measured at 1.2 GHz. The RF signal was generated by Agilent's Performance Network Analyzer 8364B, the LO was supplied by an HP8350A Sweep Oscillator, and the IF output was picked up by the E4440A PSA Series Spectrµm Analyzer. The LO input power entering the package was 2 dBm, and the driver amplifier provided enough gain, ~24 dB, to supply the mixer with greater than 17 dBm of power.

C. *Measurement Results*

Fig. 5 shows the conversion gain of the packaged receiver. The *x*-axis gives the input RF signal frequency, and the *y*-axis gives the conversion gain achieved at 1.2 GHz. The legend shows the input RF power. As can be seen, at high end of *Ka*-band, the conversion gain is maintained at 6 to 8 dB. The conversion gain above 37 GHz drops off due to gain roll-off of the LNA, not from package feed-through performance. Table I shows the gain/loss distribution seen throughout the package by the 38.4 GHz RF input signal until it leaves the package after being downconverted. Also, the chart assumes a power level of -18 dBm presented to the RF input of the package. From the table it can be seen that the package feed-through loss was approximately 0.4 dB. Fig 5 shows the assembled receiver module on the LCP package mounted on the PCB board for measurement.

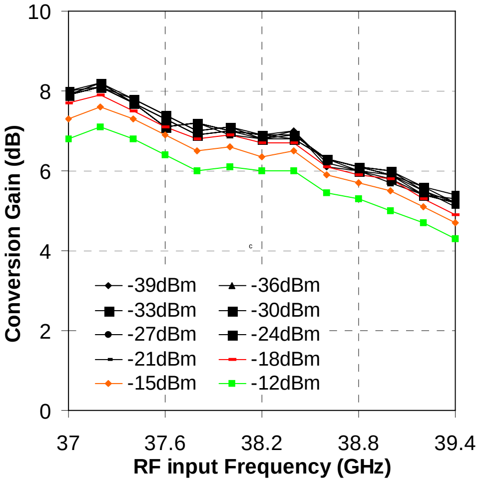

Fig. 5. Conversion gain measurement of the Ka-band receiver module

Table I Loss distribution throughout the package at 38 GHz

Description	Loss (dB)	Gain (dB)	Power (dBm)
Receiver Package RF Input			-18dBm
Package feed-through	0.4dB		-18.4dBm
LNA Gain		17.6dB	-0.8dBm
Bond wires connecting LNA and microstrip on package	0.05dB		-0.85dBm
Microstrip between LNA and Mixer (~2mm)	0.1dB		-0.95dBm
Bond wires connecting microstrip to Mixer	0.05dB		-1dBm
Mixer Conversion Loss	10dB		-11dBm
Loss from mixer wirebonds, stripline, package feedthrough, probe and cable connecting to PSA at IF frequency output	0.1dB		-11.1dBm
Conversion gain		6.9dB	

IV. LID CONSTRUCTION AND LAMINATION

We have investigated the multi-layer lid construction, the lid-to-substrate lamination method, and the cavity leak rates for the laminated cavity. We laminated a 2-mm-thick LCP sample and drilled a cavity. Ninety-five percent of the cavity depth was drilled mechanically for the purpose of saving cost and time, and the remaining five percent was drilled with a laser for precision. The thick lid cover provides rigidity to the package, and the cavity allows room for wire bonds. In laminating the lid to the package substrate we applied heat locally to avoid heating and damaging of the packaged components. Currently, our cavity achieves a $5x10^{-8}$ atm-cc/sec leak rate according to measurements taken at Sixsigma Services [10].

V. CONCLUSION

We have presented the development of a *Ka*-band receiver module in a thin-film LCP surface-mount package. We have described the LCP material and the design of the surface-mount package feed-through. We showed that our feed-through simulation indicates better than 20 dB return loss up to *Ka*-band. We showed the conversion gain measurement of the receiver and a gain/loss chart that lists sources of loss in the module. From the chart we showed that the package feed-through loss is approximately 0.4 dB at 38.4 GHz. We have also described the lamination of a multi-layer LCP lid onto the package substrate.

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