Additive manufacturing solutions to mm-wave heterogenous circuits

Jean-Marc Rollin, Jennifer Arroyo, Kuan Zhang, Akash Anand
Nuvotronics Inc.

Nuvotronics Inc., 2305 Presidential Drive Durham, NC 27703
jmrollin@nuvotronics.com, (800) 341-2333

Keywords: Additive process, phased array, 5G, heterogenous integration, PolyStrata®, mm-wave, filter

Abstract

An overview of mm-wave PolyStrata® components and their packaging implementations are presented. A Ka-Band bandpass filter and an E-band filter bank highlight the miniaturization, performance and monolithic integration capabilities that PolyStrata technology offers. An overview of different mm-wave transitions from air-coax lines to MMICs or circuit boards are reviewed up to 250 GHz.

INTRODUCTION

Next generation 5G wireless networks are aimed at faster, lower latency access for better connections in both urban and remote locations. To achieve this, industry is pushing radios to operate at mm-wave frequencies where larger bandwidths are available. However, at mm-wave frequencies, RF circuits have lower output power, and RF circuit boards have higher resistive, dielectric, and radiation losses. One solution is to use mm-wave heterogenous circuits to integrate different components with a variety of technology to improve performance and reduce cost. Heterogenous integration at mm-wave frequencies can also reduce MMIC interface loss, lower routing loss, achieve more repeatable performance, and lower assembly and test cost.

ADDITIVE PROCESS FOR MM-WAVE HARDWARE

The PolyStrata® process is an additive process were mm-wave structures are fabricated by depositing layers (strata) of copper [1] on to a substrate. Any type of substrate can be used. Once the structures are fabricated, the resist is dissolved to deliver air-copper structures. For the air-coax cross-section depicted in Fig. 1, dielectric polymers supporting the center conductor are a part of the 3rd and 5th layer, respectively, and multiple dielectric supports may also be used. The heights of the 5-layer and 11-layer lines are approximately 450 µm and 900 µm respectively. The PolyStrata® process offers micron tolerance in X/Y/Z directions enabling tuning free design of mm-wave circuits up to 300 GHz. A variety of micro-coaxial millimeter-wave components have been demonstrated and published, including directional couplers [2], resonators [3], antennas [4] and 90-degree hybrids [5].

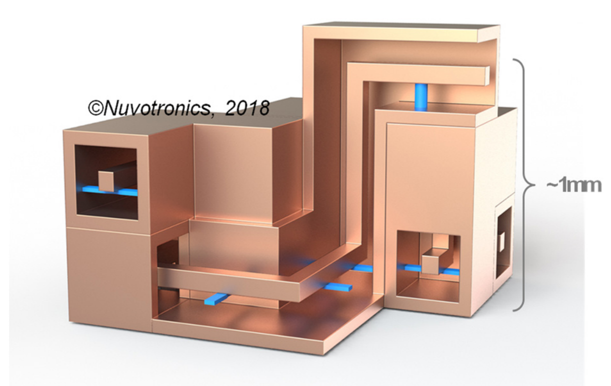

Fig. 1 Rendering of a PolyStrata® multi-layer air-coax routing structure.

MM-WAVE PACKAGING USING ADDITIVE PROCESS

As frequencies increase into mm-wave region, higher assembly and part tolerances are needed to insure low return loss and insertion loss at the transition points. PolyStrata components can be integrated on standard circuit board using Surface Mount Technology (SMT) and be delivered in tape and reel. The transition return loss from PolyStrata components to RF circuit board are typically better than 15dB up to 110 GHz. Above 60 GHz, part placement accuracy is

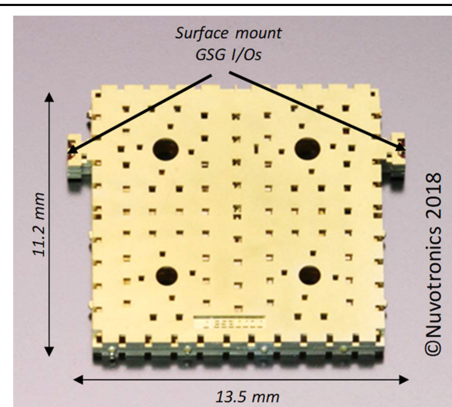

Fig. 2 Batch manufacturing SMT Band Pass Filter

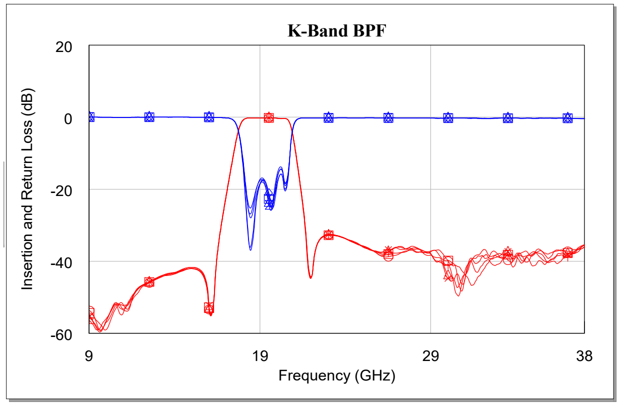

Fig. 3 Return and insertion loss for Ka-band band pass filter.

critical and is required to be better than +/15 µm to insure good return loss. Figure 2 shows an example of a surface mount technology (SMT) Ka-Band bandpass filter utilizing ground-signal-ground (GSG) transitions. The resonators in the 4-pole loaded cavity filter have unloaded quality factors of Q_u = 1150 at 20 GHz. The filter has a bandwidth of 1.9 GHz with an insertion loss of 0.3dB and return loss better than 15dB, Figure 3. The PolyStrata® parts are compatible with standard pick and place technology using either solder or conductive epoxy attachment.

For more complex multi-chip modules, the PolyStrata technology serves as the integration platform for both RF active and passive components. Figure 4 shows an example of a 71-86 GHz filter bank. This module integrates 6 different bandpass filters covering the following bands: 71-81 GHz, 77-79 GHz, 79-81 GHz, 71-76 GHz, 81-86 GHz and 76-78 GHz. Each filter can be selected using a cascade of single pole triple throw (SP3T) switches.

The PolyStrata circuits offer lower routing loss, higher isolation, operating frequencies from DC to 300 GHz, and monolithically integrated high Q filters. Beyond providing high performance mm-wave circuits, PolyStrata also enables lower loss transition to MMICs, circuit board and connectors. These transitions have demonstrated low loss, wideband operation from DC to 250 GHz. Table 1 summarizes the different transitions to MMICs and circuit board with their associated insertion loss, return loss and frequency of

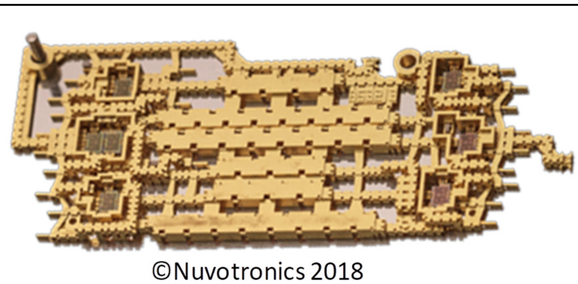

Fig. 4 Monolithic 71-86 GHz filter banks with integrated switch MMICs.

operation. Wire bond transitions up to 50 GHz can be done using standard processes. Above 50 GHz, higher tolerance, smaller loop height, and shorter length wire bonds (<100 µm) are required to minimize the parasitic inductance. Similarly, PolyStrata parts can be assembled to RF circuit boards using standard epoxy or solder SMT. As frequency moves to mm-wave, smaller size pads are required to minimize parasitics due to parallel plate capacitance between the pads and the backside metallization. Above 70 GHz, the pad size can become as low as 60 µm, increasing the placement tolerance requirements to below +/-10 µm. Table 1 shows an example of a PolyStrata GSG transition to circuit board which is tuned to operate from DC-110 GHz on a Megtron 6 high frequency circuit board. Above 110 GHz, transition to MMICs become extremely challenging due to reduce signal pad size (<60 µm) and sensitivity to parasitics. Nuvotronics has demonstrated micro-fabricated transitions capable of operating up to 250 GHz. A near zero length wire bond transition was reported in 2015 [6]. By reducing the length of the wire bonding to almost zero and by optimizing the signal launch pad, it was possible to use wire bonds up to 250 GHz. Direct connection to MMICs or circuit board could improve the loss and increase operating frequency while reducing significantly the packaging cost. Over the course of the DARPA DAHI program, Nuvotronics demonstrated direct transition to CMOS, GaAs and InP. An example of direct transition to CMOS is shown in Table 1.

TABLE 1
SUMMARY OF MM-WAVE TRANSITIONS

Wirebond	Surface Mount	Diving Board
		
- Insertion Loss: <0.2 dB - Return Loss: <-15dB	- Insertion Loss: <0.2 dB - Return Loss: <-15dB	- Insertion Loss: <0.4 dB - Return Loss: <-10dB
DC-110 GHz Standard Wirebond, ribbon, ball bond	DC-110 GHz Surface Mount, Tape and Reel	DC-220 GHz Near zero length wirebond

CONCLUSIONS

An overview of different PolyStrata mm-wave packaging technology was presented showing different paths for increased miniaturization, higher operating frequency and lower cost packages. The viability of higher data rate networks operating up to D-band will require novel and cost-effective packaging techniques. Wafer level packaging where MMICs are integrated monolithically into RF circuits could be a solution to even cheaper packaging by removing the need for wire bonds and high mm-wave assembly cost.

ACKNOWLEDGEMENTS

The authors thank DARPA Program Manager Daniel Green and Space System Loral for their support of this work.

References

[1] D. Filipovic, Z. Popovic, K. Vanhille, M. Lukic, S. Rondineau, M. Buck, G. Potvin, D. Fontain, C. Nichols, D. Sherrer, S. Zhou, W. Houck, D. Fleming, E. Daniel, D. Wilkins, V. Sokolov, 1. Evans, "Modeling, Design, Fabrication and Performance of Rectangular micro-Coaxial Lines and Components," IEEE 2006 IMS Digest, San Francisco, June ‘06

[2] K. Vanhille, Rollin, S. Rondineau, O'Brien, Wood, S. Raman, Z. Popovic, "Ka-Band Surface-Mount Directional Coupler Fabricated using Micro-Rectangular Coaxial Transmission Lines," to be presented at the 2008 IEEE IMS Symposium, Atlanta, June 2008.

[3] K. Vanhille, D. Fontaine, C. Nichols, D. Filipovic, and Z. Popovic,”Quasi-planar high-Q millimeter wave resonators," IEEE Trans. Microw. Theory Techn., vol. 54, no. 6, pp. 2439-2446, June 2006.

[4] K.Vanhille, D. Fontaine, C. Nichols, Z. Popovic, D. Filipovic, "Ka-band Miniaturized Quasi-Planar High-Q Resonators," IEEE Trans. Microw. Theory Techn., vol. 55, no. 6, pp. 1272-1279, June 2007.

[5] M. Lukic, D. S. Filipovic, “Surface Micromachined, Dual Ka-band Cavity Backed Patch Antenna”, IEEE Transaction on Antennas and Propagation, pp.2107-2109, July 2007.

[6] David Miller, Hooman Kazemi, Miguel Urteaga, Zachary M. Griffith, Jean-Marc Rollin, “A PolyStrata® 820 mW G-band Solid State Power Amplifier”, Compound Semiconductor Integrated Circuit Symposium (CSICS), 2015 IEEE

Acronyms

HBT: Heterojunction Bipolar Transistor
TDMA: Time Division Multiple Access
SMT: Surface Mount Technology
GSG: Ground Signal Ground
DAHI: Diverse Accessible Heterogenous Integration