2nd Space Passive Component Days (SPCD), International Symposium

12-14 October 2016
ESA/ESTEC, Noordwijk, The Netherlands

Improving Signal Integrity performance in high speed integrated circuit packages with application of coaxial wire-bonding technology

Rosenberger, Bernd
Rosenberger Hochfrequenztechnik
Hauptstrasse 1
83413 Fridolfing
Germany
bernd.rosenberger@rosenberger.de

I. Introduction

Interconnect technology does not keep up with Moore's Law. As on-chip speeds increase, connections become a bottleneck. Bandwidth is limited due to inductance of the bare bonding wire. Significant reflections due to large mismatches are reducing the possible bandwidth and performance of the integrated circuit. Since bonding wires are not shielded, radiation to neighbours and crosstalk degrade significant EMI and SSN. But wire bonding is the individual operation to connect the ports of a semiconductor with the pins of the final device. Wire bonding is part of the device packaging process. Metals used for bond-wires are: Aluminum, Copper and Gold. Most common technologies used are: ball bonding and wedge bonding. Wire Bonding is a cost effective and flexible technology widely used in the chip industry to do interconnections between the semiconductor die and the device package.

"Monolithic Microwave Integrated Circuit (MMIC) and Radio Frequency Integrated Circuit (RFIC) devices are operating at ever increasing speeds and over increasing frequency ranges. Plastic Quad-flat no-leads (QFN) packages reduce radio frequency parasitics by eliminating package leads and are known to be a low cost and common solution for frequencies below 10 GHz and in extreme cases, up to 28 GHz. Yet, the self and mutual inductance/capacitance of bond wires limit the use of these packages at higher mm-Wave (mmW) frequencies. Ceramic packages with shorter wire bonds are known to perform well up to 40-50 GHz but at much higher cost and may not be able to support higher frequencies. A simple wire bond inductance of 0.2 nH at 50 GHz, translates into an impedance of ~ j63 ohm in series with the common 50 ohm characteristic impedance of the die and printed circuit board (PCB), limiting the effective bandwidth of the packaged die. Bare die approaches compromise reliability of the devices because they are subjected to environmental stresses to a greater degree than packaged devices.

As a result, mmW designers of RFICs above 50 GHz have very limited choices if any, and many employ wafer level packaging (WLP) as the almost exclusive packaging alternative available. WLP's high non-recurring engineering (NRE) costs may not be justified for low to medium volume production quantities. Adding thermal dissipation considerations and further complications at the PCB, and many will steer away from the WLP approach. Moreover, WLP flipped die, because they are still unshielded interconnects, form a new unified 3D electro-magnetic (EM) challenge along with the PCB that may affect RFIC performance or circuit stability that cannot be overlooked during RFIC circuit and layout design, further imposing increased efforts and constraints. Unfortunately, while investing in tedious 3D EM simulations seems inevitable in such cases, WLP distribution layer, transitions and proximity parasitics may still yield high levels of cross-talk between package bumps, especially at high mm-Wave frequencies. Such parasitics may also limit BW and can be tuned out only over narrow frequency bands.

The Coax Wire Bond QFN (CWBQFN) package described in this paper solves most of the above mentioned issues. Based on standard a QFN package, it offers cost structures similar to QFN and requires little die specific NRE, while serving many different die and applications. MCQFN has good thermal dissipation through the package ground, with straight-forward PCB means for heat sinking and minimal tradeoff for signal cross-talk. Since all the die to package wire bonds are processed into controlled impedance coax lines, both package BW and isolation between the formed transmission-lines increases significantly. Finally, the MCQFN package integration with PCB is far simpler than WLP. Coax Wire Bond QFN allows for relatively simple 2D PCB design for fan out of different signals, bias lines and controls." [1]

II What is Coax Wire Bond?

Coax Wire Bond is a wire bond transformed into an impedance-matched coaxial cable with a typical outer diameter of 70 µm. It is compatible with common wire bonded SMT packaging. Modified QFN package allows for >90 Ghz bandwidth. It can be implemented in any packaging technology, i.e. BGA, Coreless, etc. It fits standard pick/place machines – automated assembly. Fig. 1.

The benefits in regards to Signal Integrity are:

Exceptional bandwidth > 100 GHz
Bandwidth not limited by distance between the bonds
Superior Crosstalk & EMI performance
Tunable characteristic impedance from 5 Ohm to 75 Ohm allows crossed and nested wires

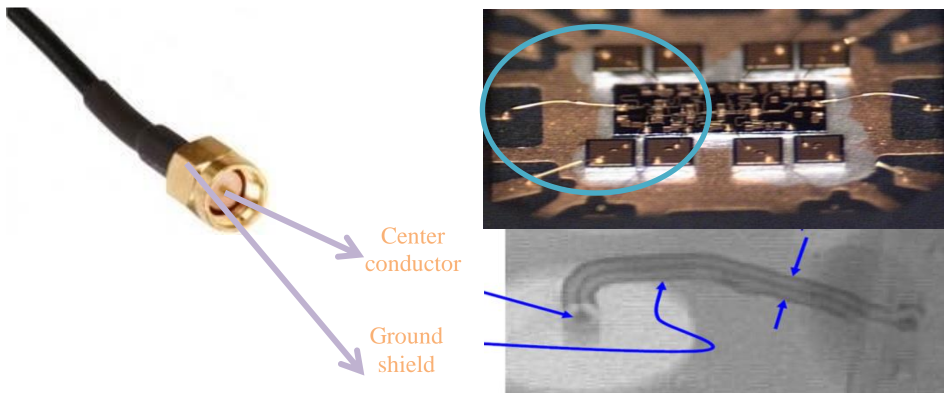


Fig. 1 Coaxial Cable vs. Coax Wire Bond CWB

III Semiconductor Packaging Process with Coaxial Wire Bond

The traditional semiconductor process is has as a first step the die attachment followed by wire bonding and finally leads to the IC encapsulation. Fig. 2
Coaxial Wire Bond is an additional process sequence. Fig. 3. Still, the process uses standard semiconductor equipment such as laser – vias, plasma cleaning and batch deposition.

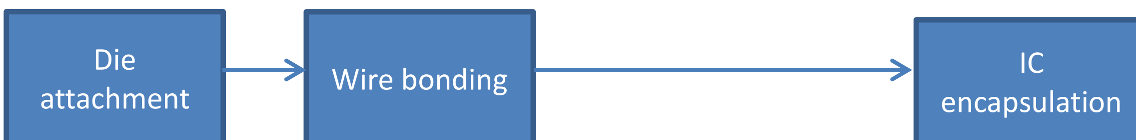


Fig. 2 Standard Packaging Process

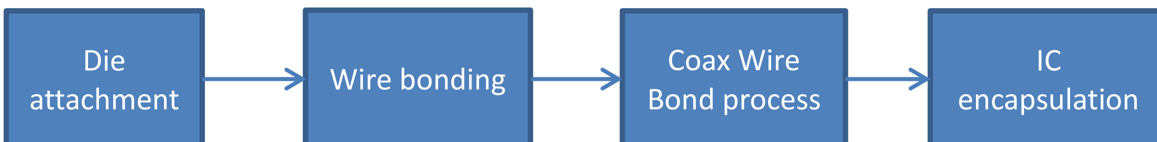


Fig. 3 Packaging Process including Coax Wire Bond

The basic principle for the implementation of Coax Wire Bond is explained from Fig. 4 to Fig. 8.

The first step is the attachment of the die and its wire bonded connections, followed by a conformal dielectric coating. After this first steps laser cut vias are applied to allow an electrical conducting metallic contact. The last step is the metallization of the ground shield.

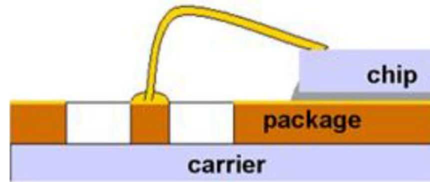


Fig. 4 Die attach and wire bond

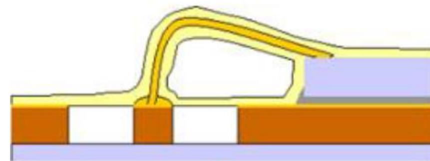


Fig. 5 Conformal dielectric coating

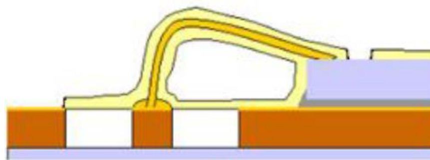


Fig. 6 Laser cutting of vias to allow metallic contact

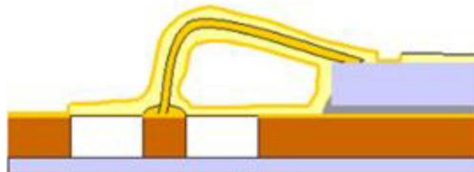
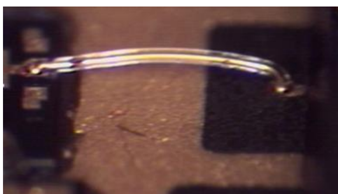


Fig. 7 Metallization of ground shields



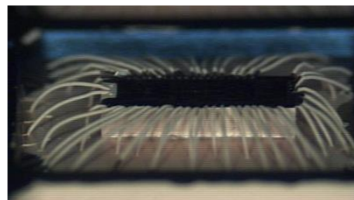


Fig. 8 Dielectric coated wire metalized bonding wires nested Coax Wire Bonds

Processed wire bond

IV. Open Cavity QFN including Coax Wire Bond

The package consists of a leadframe etched from Cu – alloy sheets. Fig. 9

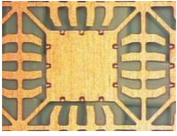


Fig. 9 Leadframe

Open cavity QFN packages are molded on a leadframe strip. Fig. 10

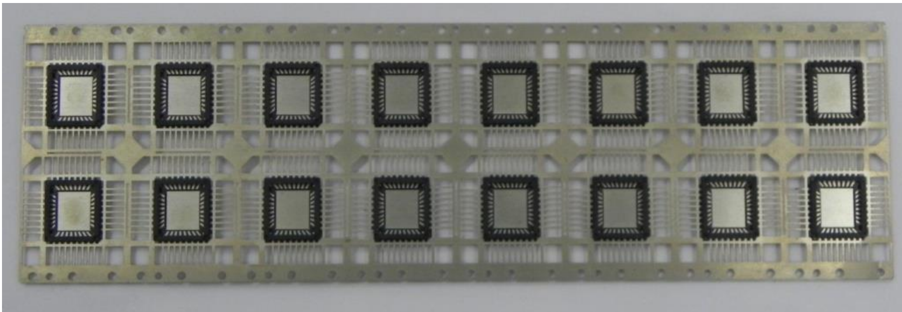
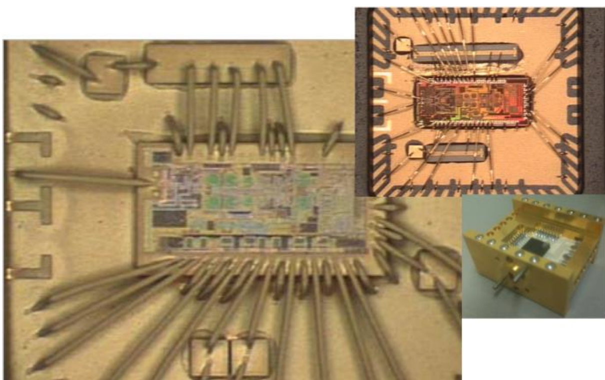


Fig. 10 Leadframe strip

Packages are singulated and ready for assembly and packaging process. Fig. 11

Fig. 11 Examples of open cavity QFN packages



80 GHz SiGe Transceiver in QFN package

V. Coaxial Wire Bond electrical performance

To verify the performance of a QFN package, a testbed was built. The testbed consisted of a PCB with matched traces and Rosenberger solderless 1.00 mm 100 GHz connectors. In the center of the board, a QFN package with a Coax Wire Bond thru – line was assembled. The results show a significant improvement of all relevant Signal Integrity parameters. The limiting factor was the precision of the PCB structures. Fig. 12

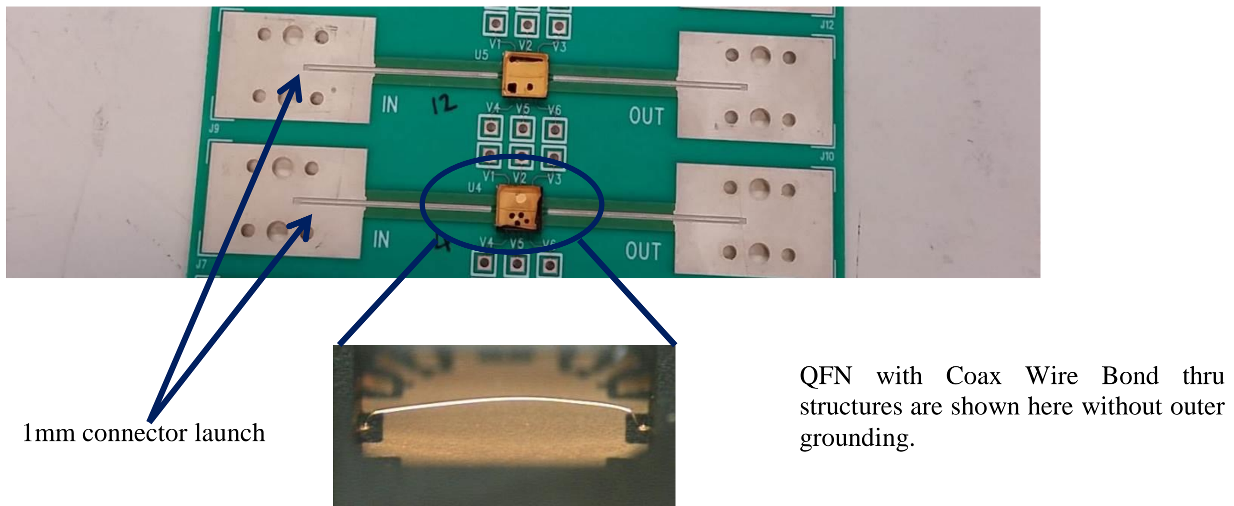


Fig. 12 Testbed

VI. Open cavity QFN with Coax Wire Bond testbed

First Testresults Fig. 13

Measurements include:

Approximately 500 um PCB trace
plus QFN launch x 2, plus QFN with 4.5mm Coax Wire Bond

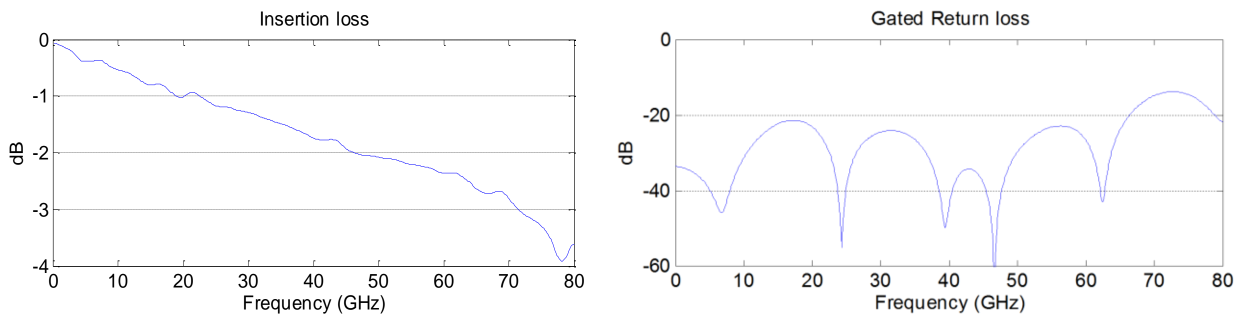


Fig. 13 Insertion Loss and Return Loss

VII. Coax Wire Bond Measurements up to 110 GHz. Fig. 14

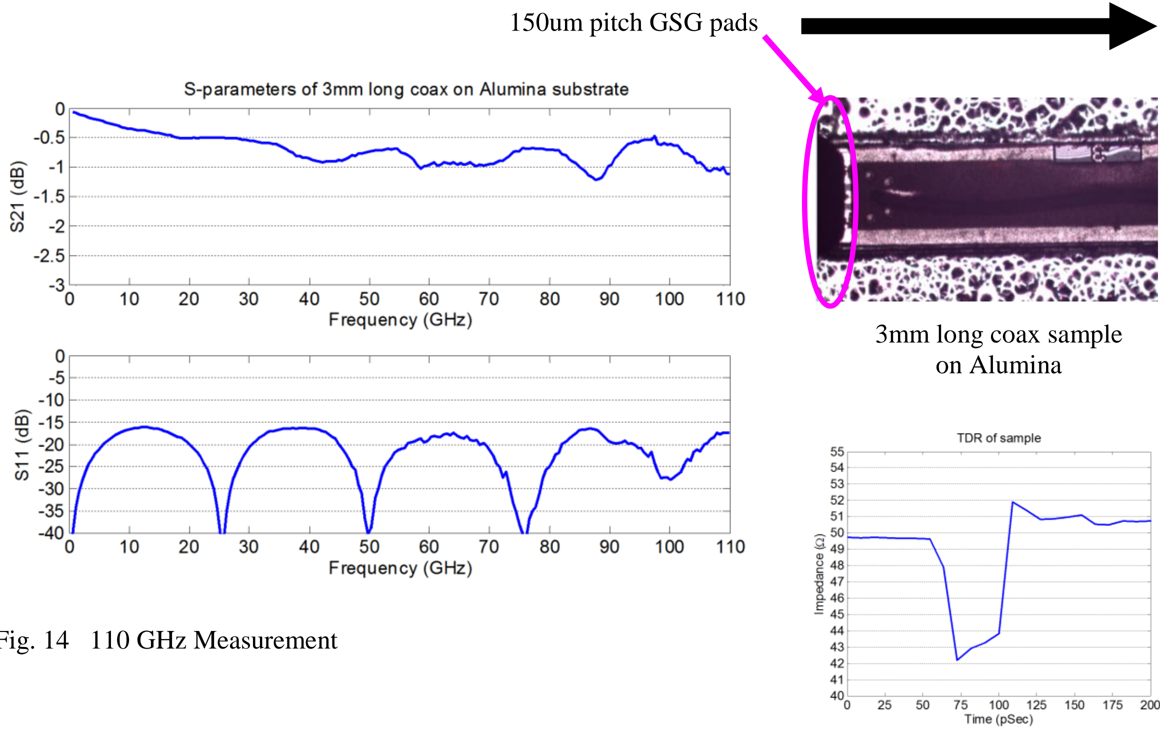


Fig. 14 110 GHz Measurement

VIII. Comparison of Coax Wire Bond with regular bonding wire up to 110 GHz. Fig. 15

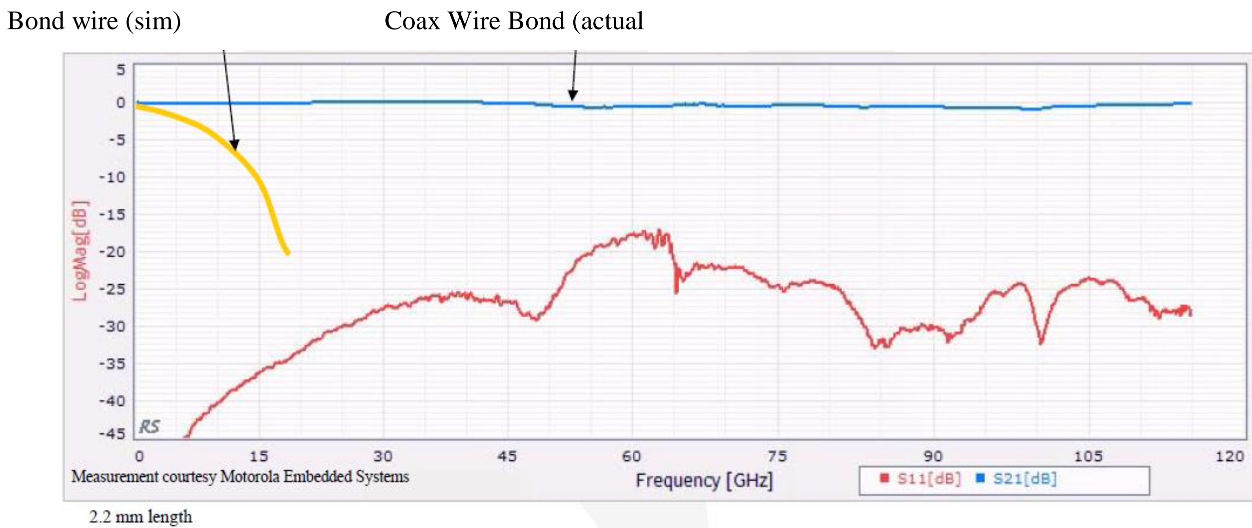
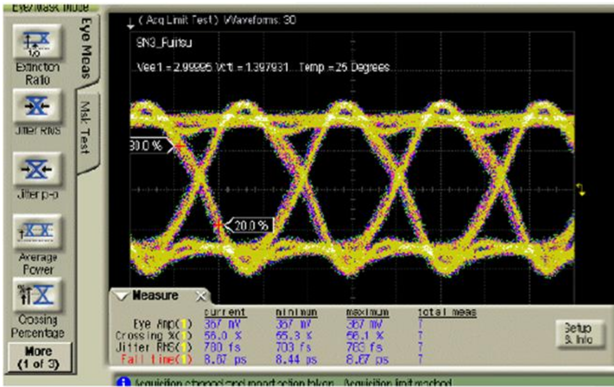


Fig. 15 Bond wire (sim) vs. Coax Wire Bond

IX. 40 Gbs data transfer test. Fig. 16

Eye is more open;
pulses more squared
Performance is *superior* to costly custom package



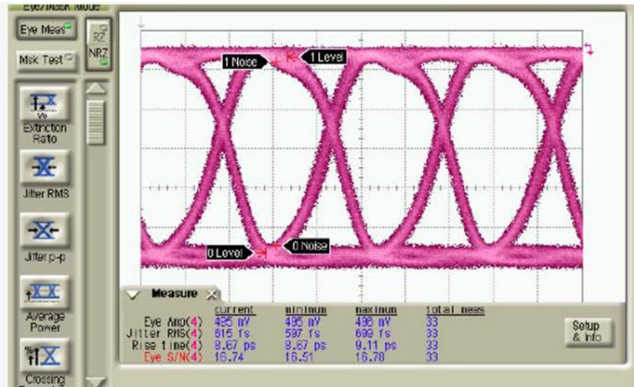


Fig. 16 Digital IC in custom LTCC package Digital IC in Coax Wire Bond QFN package

X. Simulation Results for Cross Talk and Simultaneous Switching Noise. Fig. 17a and Fig. 17b

Cross-talk improved by >25 dB
Shielding is more important than perfect match
50 Ω vs 30 Ω coaxes produce nearly identical results

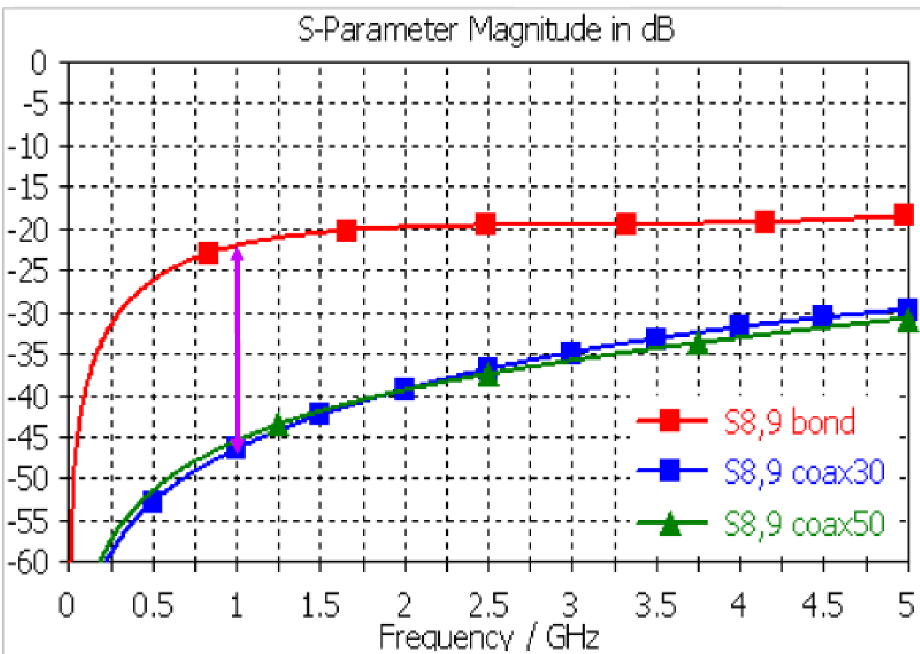


Fig. 17 a

Reduced Simultaneous Switching Noise
1 V input on Aggressors induces spike on Victim
Significant reduction of induced voltage with Coax Wire Bond
12 x improvement at chip pad and 4 x better at ball!
7 x improvement of settling time

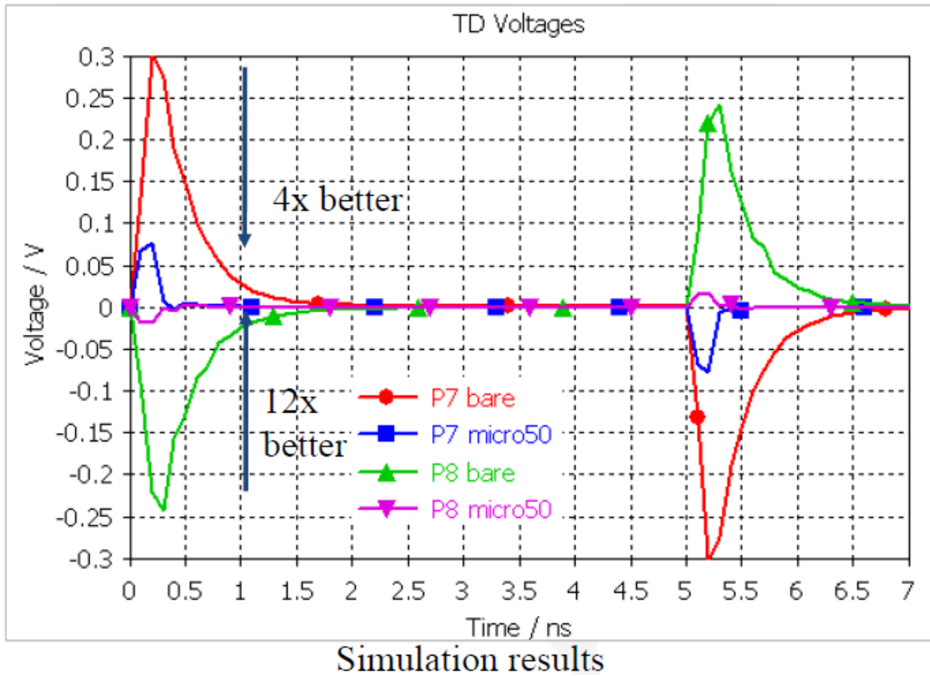


Fig. 17 b

XI. Bridge/ lateral inter PCB connection with MCI and Coax Wire Bond. Fig. 18

MCI (=Monolithic Compliant Interconnect) pins are soldered on carrier PCB and provide short signal path (~0,5mm) for good Signal Integrity.

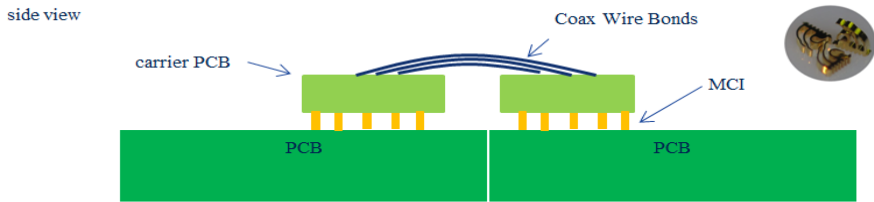
A carrier PCB with via-structures is used to transfer signals from the impedance controlled pin pattern to coaxial structures.

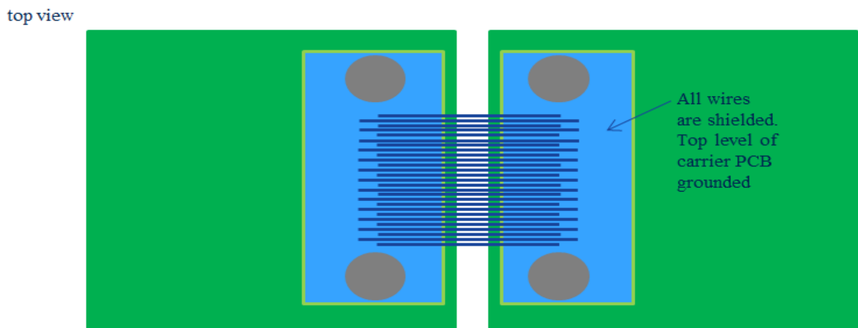
The board is made of multilayer low loss material to minimize loss and crosstalk.

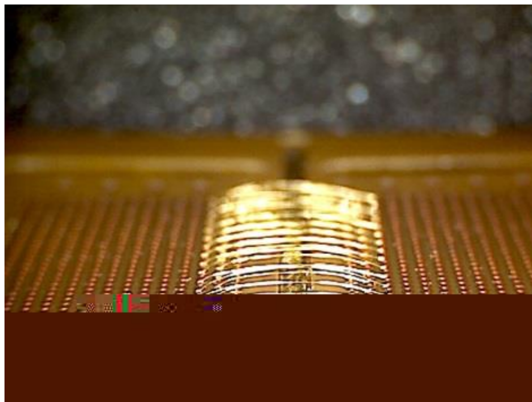
The carrier PCBs are assembled onto PCB boards.
Alternatively it could be snapped into the PCBs with an U-shaped stiffener element.

Coax Wire Bond connections are coated and metallized standard bond wires.

Coax Wire Bond offers the possibility to re-route signal lines if required (crossing of wires is possible).







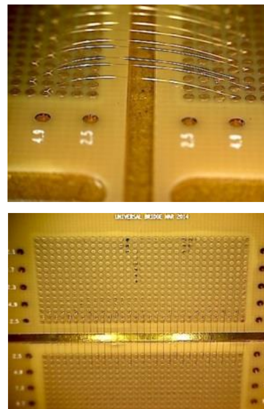


Fig. 18

XII. Conclusions and applications

The Coax Wire Bond packaging technology is a viable tool to address the discrepancies between the increasing data and / or signal speed in todays IC 's according to Moore's law. This law implies, the number of transistors on a die doubles every two years at the same area available. Today these figures are not valid anymore. There is a general observation, that these figures double within 16 month, while the surrounding infrastructures can double the capacities required by these figures within 24 month only.
At signal speeds of 30 + GHz, controlled impedance in every segment of the transmission path is necessary, to guarantee high level of signal Integrity for the whole system. A package is not a mechanical enclosure with some wires connecting to the surrounding environment anymore. The package has turned into one of the most important passive components to maintain signal speed and other characteristics such as signal loss, reflection coefficient, crosstalk, EMI performance a. o.
Finally, the implementation of Coaxial Wire Bond opens up a new perspective in every area where the improvement of distance to noise figures is essential for integration and miniaturization in high speed signal processing and high speed signal transmission devices and passive components.

While the semiconductor industry is preparing for MtM, "-More than Moore's law-", Coaxial Wire Bond has the potential to support these trends with high level Signal Integrity interconnections at PCB and IC packaging level.

Applications:

Monolithic Microwave Integrated Circuits
Multi-Chip Modules
High speed communications
Military/Defense RF
Test & measurement devices
New connectivity solutions for micro structures with RF requirements

References:

[1] Cahill, Sean S.; Sanjuan, Eric A.; Regev, Dror "Scaling Quad-Flat No-Leads Package Performance to E-band Frequencies". IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems (COMCAS). Tel Aviv, 2013.