TOPIC: Reliability & Loss Properties of Copper Foil for 5G Applications

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Paper Code: S1-1

Date: Tue, Dec 21, 2021
## OUTLINE

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Project Participants

• iNEMI Staff
  – Steve Payne

• Project Co-Leaders
  – Ed Kelley, Isola
  – John Andresakis, Dupont
  – Steve Ethridge, Dell

• Participation representing:
  – Copper manufacturers
  – Laminate manufacturers
  – Process chemistry suppliers
  – OEMs
  – PCB fabricators
  – Others
Drivers – High Speed & High Frequency – 5G

- Growth in the volume & speed of data transmission enabled by 5G telecommunications, driven by applications including:
  - Internet video, IP VOD, Web based data & gaming
  - High-speed computing, including AI and blockchain
  - Automotive ADAS

- 5G frequencies
  - Low band: typically less than 1 GHz
  - Mid-band: typically between 1 and 6 GHz
  - High-band: 24 to 40 GHz and above

- Drives need for low Dk/low Df base materials
  - Dielectric losses – historical focus
  - Conductor losses – become critical at high frequencies

![40G - 100G - 400G Switch Port Transition](image-url)
Conductor Loss Drives Need for Ultra Low-Profile Copper

As frequency increases, skin depth decreases, and a significant amount of the current is carried in the bond treatment portion of the copper – including on the oxide alternative side.
Copper Surface Topography & Treatments

Copper foil manufacturers apply surface treatments to copper foil and PCB fabricators treat copper surfaces to improve adhesion to dielectric resin systems. This treatment is essential for PCBs to survive thermal shock of the soldering operations and for in-service durability. However, this treatment which provides a roughening of the copper surface, can have a detrimental effect on electrical performance by increasing signal loss.

Baseline 0% is VLP1

Similar measured roughness on clad laminate side

Illustration courtesy of Isola

Illustrations courtesy of MacDermid Alpha
The requirements of 5G products require low-profile copper foil with low loss dielectrics to reduce signal losses; this combination can reduce adhesion between copper and dielectric, reducing reliability. Traditional metrology for copper adhesion such as peel strength are not always indicative of the durability and reliability of printed circuits.

Illustrations from IPC TM-650 2.2.22

Illustration courtesy of IBM
Reliability Issues With Ultra-Low Profile Copper Foils

• Methods to enhance copper bond strength in clad laminates & multilayer PCBs can lead to reliability problems:
  – Delamination: copper-to-dielectric (clad laminate side OR oxide alternative side) or dielectric-to-dielectric (prepreg to etched laminate surface)
  – Bond line CAF growth at dielectric-to-dielectric interface (prepreg to etched laminate surface)
Project Benefits & Value To Industry

The choice of copper foil material and chemical pre-bond treatments requires consideration of electrical performance and PCB durability, in addition to cost penalties for over specifying.

By formulating a compendium of material performance criteria and cross referencing to a suite of existing standards, a user will be able to specify a category of materials that will meet electrical performance and reliability requirements while minimizing excessive costs through over specification.

Additional cost and time savings may be realized by reducing the need for design reiteration and requalification to meet OEM specifications.

Completion of the project will:

- Enable commonality in specifying topology of copper foil and bonding treatments.
- Provide better assurance for meeting PCB electrical performance characteristics.
- Provide predictability of durability and reliability of copper foil adhesion with respect to signal loss for various copper surface finishes. Potentially suggesting process controls.
- Reduce product qualification costs and associated timescales.
<table>
<thead>
<tr>
<th>This Project IS:</th>
<th>This Project IS NOT:</th>
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<tbody>
<tr>
<td>To align terminology for copper surface topology and recommend quantitative</td>
<td>To develop new Standards</td>
</tr>
<tr>
<td>descriptions for bonding treatment of copper surfaces</td>
<td></td>
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<tr>
<td>To review existing methods (IPC 2.2.22) and measurement parameters to</td>
<td>Not to define Pass and Fail parameter values</td>
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<td>characterize the copper foil surface properties</td>
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<tr>
<td>To determine which characteristics correlate best to adhesion and conductor</td>
<td>Not to develop a new methodology nor new device</td>
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<td>loss (e.g., Sa, Sz, Sq, etc.)</td>
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<tr>
<td>To characterize copper foils with various levels of roughness on the laminate</td>
<td>Not to develop new types of surface measurement.</td>
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<td>bonding side, as measured by non-contact methods, and correlate to high</td>
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<td>frequency signal integrity performance (including 5G) using low loss resin</td>
<td></td>
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<tr>
<td>systems – use both simulation and experimental methods</td>
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<tr>
<td>To characterize copper foil surfaces on the external bonding side, before and</td>
<td>Not to rank or bias among metrology system suppliers</td>
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<tr>
<td>after different bonding processes, and correlate to high frequency signal</td>
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<td>integrity performance using low loss laminates</td>
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<tr>
<td>To determine if traditional measures of copper adhesion are adequate to assess</td>
<td>Not to highlight or promote specific suppliers of copper, copper surface preparation chemistries, or laminate types.</td>
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<td>reliability in multilayer PCBs for 5G applications, and if not, evaluate and</td>
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<td>assess new possible test methods</td>
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Project Plan

• **Task 1: DoE (Design of Experiment)**
  - Metrology assessments – foil and oxide alternative treated surfaces; non-contact measurement systems
  - Define frequency range of interest, followed by design of signal integrity test vehicle
  - Define methodology for modelling I/L (insertion loss), signal trace resistance and other parameters.
  - Agree on foil types, thicknesses, oxide alternative processes and dielectric base materials
  - Agree test equipment & methodology to be used for measuring signal loss.
  - Include copper adhesion test vehicle, (e.g., IPC TM 650 5.8.3)
  - Identify additional test methods for bond strength & reliability testing

• **Task 2: Study correlation between copper topology and signal loss**
  - Undertake modelling of I/L (insertion loss), signal trace conductivity and other parameters.
  - Fabricate test vehicles, including bonding treatments of samples.
  - Measure and analyze signal integrity data vs. copper & surface treatment variables

• **Task 3: Characterize metrology for copper to resin adhesion in terms of PCB reliability & signal loss**
  - Investigate expected failure mechanisms due to poor adhesion between copper and dielectric.
  - Determine test structure to provide meaningful prediction of durability and reliability of copper adhesion.
  - Undertake comparative testing to determine best approach for predicting reliability of multilayer PCB with different copper surface roughness.
Current Status - Metrology Assessment

There is a need to take accurate and repeatable measurements of the copper surface to characterize surface finish and correlate to signal integrity properties and copper-resin adhesion/reliability. The objective is to use more than one measurement system from project members and investigate correlation between systems, while measuring various copper types and oxide alternative treatments.

Metrology assessment samples have been prepared and sent to companies performing measurements. Measurement data is being collected and should be complete in early January. Multiple types of roughness measurement are being collected.

Next steps: analyse data across measurement systems for correlation & begin designing SI and reliability test methods.

### 2.1 Measurement of Copper Foil - Treatment Side

<table>
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<tr>
<th>Variables</th>
<th>Levels</th>
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<tr>
<td>A</td>
<td>Copper Type</td>
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<tr>
<td>B</td>
<td>Roughness</td>
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### 2.2 Measurement of Copper Foil - Surface Treatment/Oxide Alternative

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- Measurement to be taken before and after surface treatment
- Treatment A: Ra=0.209, Rz=3.123, RSAR=0.245
- Treatment B: Ra=0.256, Rz=5.691, RSAR=0.634
- Treatment “Nano”
The End
Thank you!

IMPACT 2021
Dec 21 (Tue) – 23 (Thur)
Taipei Nangang Exhibition Hall