Design of Experiment for Particle Thickness, Project Status Update

March 7, 2011

Dave Fisher, Tyco Electronics
Presentation Outline

- Introduction, project background
- Experiment plan
- Particle Measurement Equipment
- Equipment for IL/RL measurements
- Example Sample Measurement Trials
- Observation summaries
- Next Steps
• Previous research on mated connectors with contaminated end faces showed increases in IL and decreases in RL (increased reflectance).

• Information shared on the effects of end face gap and IL and RL performance showed wavelength dependence (M. Hodge, Molex Fiber Optics)

• We’d like to understand the contribution of contamination to end face separation and the resulting impact on optical performance—at 4 wavelengths.
• Design of Experiment (DOE) Block Diagram
Experiment Plan

• Clean and Record End-face Images
  – Clean DUT and reference fibers, and record the images prior to start of the IL/RL Repeatability Loop. This ensures that the mated connector pair is uncontaminated during the measurement to establish the baseline IL/RL data.

• Establish IL/RL Repeatability Loop
  – Obtain an estimate of the repeatability of the IL/RL measurement process, including mating and demating of the connectors. IL and RL are measured at four wavelengths; 1310, 1490, 1550 and 1625 nm.
• **Apply Contamination**
  – As in previous experiments, use Arizona road dust (ARD) as the contamination (1-5 μm grade). Contamination is applied to the DUT end only.
  – More recent studies have used silver particles and toner particles. These appear to be more easily applied and cause minimal end-face damage.

• **Measure Contaminated IL/RL**
  – After DUT end face is contaminated, record images. Connectors are mated, IL/RL measured, connectors are demated and images of DUT and reference are recorded. The data collected during these five matings are the principal data for the experiment.
Experiment Plan

• **Record Images**
  – In each block in the DoE Block Diagram labeled “Record Images”, complete the following steps:
    • Capture a 2D image using a traditional fiber microscope
    • Capture a 3D image using a confocal microscope
    • Capture a 3D image using a fiber white light interferometer*
  – Images for both the DUT and the reference fiber end faces are recorded.

• **Analyze the Data**
  – Images will be analyzed in accordance with an analysis plan that is currently being developed. Metrics from the images will be combined with the IL/RL data.

• **Report the Data**
  – A final report of the experiment will be generated.

*Note: To date, interferometer images have not been captured.*
NanoFocus µsurf Confocal Microscope
Equipment Setup for Measuring Insertion Loss and Return Loss (Reflectance), 4 wavelengths: 1310nm, 1490nm, 1550nm, 1625nm
Sample Measurements

2-D Full View - Leveled

μm

mm

nm

CONNECT WITH AND STRENGTHEN YOUR SUPPLY CHAIN
Sample Measurements

• Zoomed area encompassing the approximate OD of the fiber—initial contamination.
• Scale to the right shows heights.
Sample Measurements

- 3-D of the fiber area showing initial contamination
Sample Measurements

- End face image (Photo Simulation), initial contamination
Sample Measurements

- Step height of debris.
- Height is calculated as the difference between the heights of areas of 1 and 2, \( Z(\text{max})1 - Z(\text{mean})2 \).
- Process is repeated for each field of debris.
Sample Measurements, 1st Mating

- Zoomed area encompassing the approximate OD of the fiber—contamination after 1st mating.
Sample Measurements, 1st Mating

- 3-D of the fiber area showing contamination after 1st mating.
Sample Measurements, 1st Mating

- End face image (Photo Simulation), contamination after 1st mating.
Sample Measurements, 1st Mating

- Step height of debris after 1st mating.
- Height is calculated as the difference between areas 1 and 2.
Sample Measurements, 5th Mating

- Zoomed area encompassing the approximate OD of the fiber—contamination after 5th mating.
Sample Measurements, 5th Mating

- 3-D of the fiber area showing contamination after 5th mating.
Sample Measurements, 5th Mating

• End face image (Photo Simulation), contamination after 5th mating.
• Step height of debris after 5th mating.
• Height is calculated as the difference between the heights of areas of 1 and 2.
• This is the final mating.
Sample Measurements, 5th Mating

- Step height of large debris field-- after 5th mating.
- Height is calculated as the difference between the heights of areas 1 and 2.
# Insertion Loss and Return Loss (Reflectance) data at 4 wavelengths: 1310nm, 1490nm, 1550nm, 1625nm

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<th>Insertion Loss (dB)</th>
<th>Return Loss (dB)</th>
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<tr>
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<td>ARD (1-5um)</td>
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<td>Cnt-2</td>
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<tr>
<td>Cnt-3</td>
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<td>Cnt-4</td>
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<td>Cnt-5</td>
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<tr>
<td>Cleaned</td>
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Observations

- IL/RL data don’t yet appear to correlate with gap—assuming there is any gap.
- With ARD, debris height seems to max out at under 4um.
- Contamination is difficult to control
  - Hard to apply and keep off the core and yet be large enough to contribute to gap
  - Difficult to distribute around the fiber area
  - Moves around, and can move over the core
- Contamination process is tedious
- ARD tends to leave permanent damage
Part II: Experiments with Tellabs samples

• Looking at new methods to apply contamination and introducing other, “friendlier” particles
  – ARD issues:
    • Difficult to apply consistently
    • Moves around
    • Damages fiber end face

• David Lach (Tellabs) developed 2 novel application methods and introduced 2 other particle types (silver, toner)
Selected one of the Tellabs samples, initially contaminated with silver particles, for a trial run
Part II: Experiments with Tellabs samples
Part II: Experiments with Tellabs samples
Part II: Experiments with Tellabs samples
Part II: Experiments with Tellabs samples

- Zmean(2) - Zmean(1): 0.177 μm
- Zmax(2) - Zmean(1): 4.42 μm
- Zmin(2) - Zmean(1): -4.9 μm
- Zmax(2) - Zmin(1): 4.43 μm
- Angle difference: 0.254°
After 5<sup>th</sup> mating. Now missing large particle formerly at 2 o’clock
Receive Lead: After 1\textsuperscript{st} mating, but similar after 5\textsuperscript{th} mating
Tellabs pigtail on left, mated to TE SC connector on right—through a ceramic sleeve.
### Part II: Experiments with Tellabs samples

- **Summary of particle height for all particles, after each mating**

<table>
<thead>
<tr>
<th></th>
<th>Particle &quot;A&quot;</th>
<th>Particle &quot;B&quot;</th>
<th>Particle &quot;C&quot;</th>
<th>Particle &quot;D&quot;</th>
<th>Particle &quot;E&quot;</th>
<th>Particle &quot;F&quot;</th>
<th>Particle &quot;G&quot;</th>
<th>Avg um</th>
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<td>3.340</td>
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<td>3.200</td>
<td>2.720</td>
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<td>2.360</td>
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<td>5.900</td>
<td>1.760</td>
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<td>2.860</td>
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<td>1.800</td>
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<td>1.890</td>
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<td>7.650</td>
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<td>1.980</td>
<td>1.690</td>
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Part II: Experiments with Tellabs samples

- Comparison of Theoretical Loss vs. Actual Loss

<table>
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<tr>
<th></th>
<th>IL 1310</th>
<th>IL 1490</th>
<th>IL 1550</th>
<th>IL 1625</th>
<th>RL 1310</th>
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<tr>
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<td>0.44</td>
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<td>0.92</td>
<td>0.74</td>
<td>0.76</td>
<td>0.76</td>
<td>11.70</td>
<td>10.50</td>
<td>10.30</td>
<td>12.50</td>
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<td>0.74</td>
<td>0.74</td>
<td>11.80</td>
<td>10.30</td>
<td>10.30</td>
<td>12.40</td>
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</tbody>
</table>
Part II: Experiments with Tellabs samples

Theoretical Performance

Insertion Loss vs. End Face Gap

![Graph showing Insertion Loss vs. End Face Gap for different wavelengths (IL_1310, IL_1490, IL_1550, IL_1625). The x-axis represents distance in micrometers (um) ranging from 0.00 to 3.50, and the y-axis represents Insertion Loss in decibels (dB) ranging from 0.00 to 0.70. The graph displays periodic patterns for each wavelength.](image-url)
Part II: Experiments with Tellabs samples

Theoretical Performance

Reflectance vs. End Face Gap

Reflectance (dB)

Distance (um)

RL_1310
RL_1490
RL_1550
RL_1625
Part II: Experiments with Tellabs samples

• Still no apparent correlation between physical height measurements and IL/RL performance
• Too many particles / too much height?
• Are particles lifting when DUT is uncoupled, resulting in artificially high particle height values?
Part III: Experiments with Tellabs samples

- Two new samples were supplied, 3e and 7e:

  Silver Particles (3e)  
  Toner Particles (7e)
Part III: Experiments with Tellabs samples

- Initial contamination, Sample #3e.
- Zoomed area encompassing approximately 250µm centered over the fiber.
- Scale to the right is height reference.
Part III: Experiments with Tellabs samples

- 3-D of the fiber/ferrule area showing initial contamination.
Part III: Experiments with Tellabs samples

- End face image (Photo Simulation), initial contamination
• Microscope view of end face contamination
Part III: Experiments with Tellabs samples

- Step height of debris (the highest of the group, ~11um).
- Height is calculated as the difference between the heights of areas of 1 and 2.
- Process is repeated for each field of debris.
Part III: Experiments with Tellabs samples

- Final mating
- Zoomed area encompassing approximately 250um centered over the fiber.
- Scale to the right shows heights.
Part III: Experiments with Tellabs samples

3-D of the fiber area after final mating
Part III: Experiments with Tellabs samples

- End face image (Photo Simulation), after final mating.
Part III: Experiments with Tellabs samples

- Microscope view of DUT end face contamination after final mating.
Part III: Experiments with Tellabs samples

- After final mating
- Step height of debris (the highest of the group.
- Height is calculated as the difference between the heights of areas of 1 and 2.
- Process is repeated for each field of debris.
Part III: Experiments with Tellabs samples

- Image of the reference connector end face after the 5th mating.
Part III: Experiments with Tellabs samples

- Photo Simulation view—after 5th mating.
- Transfer occurred after the first mating and now appears to cover the fiber core.
Part III: Experiments with Tellabs samples

- Microscope image of the reference connector end face after the 5th mating. Fiber core is obscured.
### Part III: Experiments with Tellabs samples

**Particle Heights on Contaminated End Face (Receive Lead)**

<table>
<thead>
<tr>
<th></th>
<th>Particle “A”</th>
<th>Particle “B”</th>
<th>Particle “C”</th>
<th>Particle “D”</th>
<th>Particle “E”</th>
<th>Particle “F”</th>
<th>Particle “G”</th>
<th>Particle “H”</th>
<th>Particle “I”</th>
<th>Particle “J”</th>
<th>Particle “K”</th>
<th>Particle “L”</th>
<th>Particle “M”</th>
<th>Particle “N”</th>
<th>Particle “O”</th>
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<tbody>
<tr>
<td>Initial</td>
<td>5.580</td>
<td>3.840</td>
<td>3.220</td>
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<td>NP</td>
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<td>1st</td>
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<td>0.499</td>
<td>1.670</td>
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**Particle Heights on Reference Connector End Face (Launch Lead)**

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<th>Particle “E”</th>
<th>Particle “F”</th>
<th>Particle “G”</th>
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<th>Particle “L”</th>
<th>Particle “M”</th>
<th>Particle “N”</th>
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*Initial (Prior to any matings) Application*
Part III: Experiments with Tellabs samples

• Comparison of Theoretical Loss vs. Actual Loss

<table>
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<tr>
<th></th>
<th>IL 1310</th>
<th>IL 1490</th>
<th>IL 1550</th>
<th>IL 1625</th>
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<th>RL 1490</th>
<th>RL 1550</th>
<th>RL 1625</th>
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<tbody>
<tr>
<td>1st</td>
<td>0.51</td>
<td>0.15</td>
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<td>17.91</td>
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• It’s clear after the 1st mating that high IL is due to debris over the core. The maximum theoretical loss due to air gap is approximately 0.63dB
• Sample #7 (toner particles) was intended to be evaluated, but was stubbed on the way into the holding fixture. Could not be used.
• Suggest that we focus on the practical experiment to see how IL and RL behave with induced air gap.
• Other recommendations….?