Instalaciones de fibra óptica en entornos de centros de datos y campus para suportar 40, 100g y más

Jim Davis
Regional Marketing Engineer
Fluke Networks
Agenda

• Where is the technology today
  • 10 G per Wavelength $\lambda$
  • SM vs MM (OM5)
• How to increase the Data Throughput of Fiber
  • More efficient encoding – PAM 4
  • More fiber – MPO
• What parameters do we measure
  • Tier I – Loss, Length, Polarity
  • Tier II – Tier I + OTDR (troubleshooting)
Where are we Today with Fiber

10 Gig Per Wavelength
2 fibers 10 Gig full Duplex
4 fibers (10 X 4) 40 Gig
10 fibers (10 X 10) 100 Gig
Single Mode vs Multimode

- Number of Wavelengths $\lambda$
- Cost of electronics
- Distance Requirements
- Ease of Use
  - UPC vs APC

[Diagram showing single mode and multimode fibers with cladding and core dimensions: 9 µm vs 50 µm]
Single Mode vs Multimode

- LC/UPC
- LC/APC
SC/UPC
SC/APC

APC

400 nm
Violet
Blue
Green
Yellow
Orange
Red
700 nm
New Capabilities for Multimode Fiber
Wideband Multimode Fiber OM5 (WBMMF)

• Optical characteristics other than bandwidth remain essentially the same.

• At 10 G per Wavelength, we can do 40 Gig (4 x 10 G) on a single fiber

• New Wavelengths Available – Short Wave Division Multiplexing
  – 850, 880, 910, and 953 nm
Wideband Multimode Fiber OM5 (WBMMF)

• Field Testing is the same as OM4
  – Tier I at 850 and 1300
  – Tier II at 850 and 1300
  – Loss at 850 = 3 dB/Km; 953 = 2.3 dB/Km; 1300 = 1.5 dB/Km

• Test with traditional duplex fiber OLTS
  – Encircled Flux compliant
  – Wavelengths at 850/1300nm
    • Bounds all wavelengths between
  • And the jacket will be green
Increased Throughput with the Same Fiber

- PAM4 – 4 symbols vs 2 – doubles throughput
- From 10 Gig per wavelength to 25 Gig per wavelength
- Where we were doing 4 x 10 for 40 Gig, now we can do 4 x 25 for 100 Gig
Serial LC/SC or Parallel MPO/MTP

- QSFP/CXP: MTP/MPO Connector
  - QSFP: 4Rx + 4 Tx
  - CXP: 12Rx + 12 Tx

- XFP/SFP+: LC Connector
  - One fiber transmit and one fiber to receive

- 1x12 Format for QSFP/4+4 applications
  (40G, proposed 100G @ 25G x 4)

- 2x12 Format for CXP/10+10 or 12+12 applications
  (100G @ 100G x 10)
From – Less Efficient Core/Aggregation/Access – More Latency
To More Efficient –
Spine and Leaf - Faster
For Port Density, put a 12 or 24 fiber QSFP in the spine and, potentially, 2 fiber LC in the Leafs (leaves?)
Fiber Testing and Certification

How can you determine if your premise fiber is good?
Fiber Cleaning
#1 Problem: Dirt!

- Contaminated connector end-faces: Leading cause of fiber link failures
- Particles of dust and debris trapped between fiber end faces cause signal loss, back reflection, and damaged equipment
- Many Sources of contamination:
  - Equipment rooms & Telecommunication rooms in filthy environments
  - Improper or insufficient cleaning tools, materials, procedures
  - Debris and corrosion from poor quality adapter sleeves
  - Hands of technicians
  - Airborne
Inspection images

Good Connector

Fingerprint on Connector

Dirty Connector

Real images
A Clean Connector
Connector with a Finger Print
This part of the presentation is only for those >17 years old
Notice the ring where the contact occurred in the center.
Fiber Inspection

• We all know how important it is
• It is rare that calls to our Technical Assistance Center from techs have ANY inspection equipment – but they tell us they have cleaned it
• Cleaning without inspection can result in this:

Solvent pens are better than IPA
Cleaning with a Solvent Pen

- **Start with a clean, lint-free wiping surface every time**
  - Material left exposed accumulates ambient dust
  - Material used once should not be used again

- **Use a minimal amount of specialized solvent**
  - Important that solvent be removed after cleaning
  - Move the end-face from the wet spot into a dry zone
    - Cleaning with a saturated wipe will not fully remove solvent
    - Cleaning with a dry wipe will not dissolve contaminants and can generate static, attracting dust

- **Proper handling and motion**
  - Apply gentle pressure with soft backing behind cleaning surface
  - Hold end-face perpendicular to cleaning surface
  - No figure-8 motion as that’s for polishing only

- **Inspect both end-faces of any connection before insertion**
  - If the first cleaning was not sufficient, then clean again until all contamination is removed
Primero – Inspeccion! Video Microscope

• 2-second automated PASS/FAIL certification of fiber end-faces

• Graphical indication of problem areas due to contamination, pits, chips, and scratches

• Certify to industry standards
  – IEC 61300-3-35

• Eliminate human subjectivity from end-face measurements

• Save end-face views during certification process
On a not completely unrelated note...
How Automated Analysis Works

IEC 61300-3-35 UPC Multimode Specification

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Scratches</th>
<th>Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>No limit &lt;= 3 um</td>
<td>2 &lt;= 3 um</td>
</tr>
<tr>
<td></td>
<td>0 &gt; 3 um</td>
<td>None &gt; 3 um</td>
</tr>
<tr>
<td>Cladding</td>
<td>No limit &lt;= 5 um</td>
<td>No limit &lt; 2 um</td>
</tr>
<tr>
<td></td>
<td>0 &gt; 5 um</td>
<td>5 from 2 um to 5 um</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None &gt; 5 um</td>
</tr>
<tr>
<td>Adhesive</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td>Contact</td>
<td>No limit</td>
<td>No &gt;= 10 um</td>
</tr>
</tbody>
</table>

Next ID: 010

SCALE OFF
Cleaned *and* Inspected
Loss Limits for Multimode are getting tighter as speeds increase
Distances for MM are getting shorter
Limited by Modal Dispersion

Distance

Meters

Token Ring 4 Mb
Token Ring 16 Mb
FDDI
10 BASE-FL
100 BASE-FX
1000BASE-SX
10GBASE-SX
40GBASE-SR4
100GBASE-SR10

2000 Mtrs
500 M
300 M
150 M
100 M
Types of Standards and Specifications define the loss budget

• Application Standards
  – Fixed test limits are defined by ‘system’ specs
  – Examples: 100BASE-FX, 1000BASE-SX, 1000BASE-LX, 10GBASE-S, ATM, Fibre Channel

• Cable Installation Standards
  – Test limits for installed fiber link are independent of any network application
  – Limit is calculated, based on cable length, number of adapters, and number of splices
  – Examples: ANSI/TIA-568.D-3, ISO11801, EN50173
Which Limits to use?

• There is no “Cat 5e” for fiber
• There is conflict between what the standard will support and what the application requires

Cabling Standards:
- TIA 568
- ISO 11801

Application Standards:
- 10GBase-SR
- 40GBase-SR4
Using a TIA limit without understanding the application

- Customer wants to run 10GBASE-SR on this multimode link

\[
\text{TIA (tester) Limit} = 0.75 \text{ dB} + 0.75 \text{ dB} + 0.90 \text{ dB} + 0.75 \text{ dB} + 0.75 \text{ dB} \\
= 3.90 \text{ dB} @ 850 \text{ nm}
\]

\[
\text{10GBASE-SR Limit} = 2.55 \text{ dB} @ 850 \text{ nm}
\]

This design will not support 10GBASE-SR
Loss Budget 3.9 dB = Pass for TIA
• But not 10GBase-SR
Using a TIA limit without understanding the application

- Customer wants to run 10GBASE-SR on this multimode link

\[
\text{TIA (tester) Limit} = 0.75 \text{ dB} + 0.90 \text{ dB} + 0.75 \text{ dB} = 2.40 \text{ dB @ 850 nm}
\]

\[
10\text{GBASE-SR Limit} = 2.55 \text{ dB @ 850 nm}
\]

This design will support 10GBASE-SR
Loss Budget 2.4 dB = Pass for Both

Cabling Standards: TIA 568 ISO 11801

Application Standards: 10GBaseS 40GBase-SR4
What if your customer wants to do this?

- Concatenate two MPO jumpers/trunks
What if your customer wants to do this?

- Concatenate two MPO jumpers/trunks
- And run 10Gig

4 X 0.75 + 62 m * 3 dB/Km > 2.6 dB
Welcome to Low Loss Cassettes

- Manufacturers offer cassettes with > 0.5 dB of loss

4 X 0.50 + 62 * 3 dB/Km < 2.6 dB
Tier I Testing – How much Light is Coming Out of the Fiber

How to measure reliably and repeat-ably
Keys to Running an Accurate Test
Reducing Uncertainty

• One Jumper Reference
  – Better if you can verify the ‘known good’ leg
    • < 0.15 dB of loss in Multimode
    • < 0.25 dB of loss in Single-mode
    • May not be possible with pinned plugs
  – EF with Multimode
  – LED Source with Multimode
  – Reference Grade Connectors
Keys to Running an Accurate Test
Reducing Uncertainty

• One Jumper Reference
  – Better if you can verify the ‘known good’ leg
    • < 0.15 dB of loss in Multimode
    • < 0.25 dB of loss in Single-mode
    • Save Results!!
    • May not be possible with pinned plugs
  – EF with Multimode
  – LED Source with Multimode
  – Reference Grade Connectors
Loss Budgets must be more accurate to support these new links

- In ISO/IEC 14763-3 (2006), cords were recognized as a source of great uncertainty
- This standard reduced uncertainty by defining the performance of the test cord connector
- Reference grade connectors were required
  - Multimode ≤ 0.10 dB
  - Singlemode ≤ 0.20 dB

0.10 dB 0.75 dB
≤ 0.30 dB

0.20 dB 0.75 dB
≤ 0.50 dB
Multimode Old Values with Reference Grade TRCs

Loss Budget = 0.75 + 0.75 + X Mtrs * 3.5
Multimode New Values with Reference Grade TRCs

Loss Budget = 0.3 + 0.3 + X Mtrs * 3.0
Multimode New Values with Reference Grade TRCs

Loss Budget = 0.3 + 0.3 + 0.75 + 0.75 + X Mtrs * 3.0
Vamos Ver si esta bien!

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2426</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>850 nm</td>
</tr>
<tr>
<td>Result</td>
<td>PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.08</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>0.20</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
</tr>
</tbody>
</table>

Number of Adapters: 2
Number of Splices: 0
Connector Type: LC
Patch Length1 (m): 2.0
Reference Date: 05/31/1
1 Jumper
Valor de Referencia esta bien +/- -22 dB

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2426</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2 PASS</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
<tr>
<td>850 nm</td>
<td>1300 nm</td>
</tr>
<tr>
<td>Result</td>
<td>PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.08</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>0.20</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
</tr>
</tbody>
</table>

Number of Adapters: 2
Number of Splices: 0
Connector Type: LC
Patch Length1 (m): 2.0
Reference Date: 05/31/1 Jumper
Limit de perdida esta Bien Para TIA y tambien para 10GBASE-SR

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2426</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss (dB)</td>
</tr>
<tr>
<td>Limit (dB)</td>
</tr>
<tr>
<td>Margin (dB)</td>
</tr>
<tr>
<td>Reference (dBm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>850 nm</th>
<th>1300 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>1.88</td>
<td>1.02</td>
</tr>
<tr>
<td>2.08</td>
<td>1.34</td>
</tr>
<tr>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>-23.26</td>
<td>-23.76</td>
</tr>
</tbody>
</table>

Number of Adapters: 2
Number of Splices: 0
Connector Type: LC
Patch Length1 (m): 2.0
Reference Date: 05/31/1 Jumper
2.08 dB = Solo Pasa TIA
Limit de IEEE 10GBASE-SR= 2.55
Como llegamos al límite?

#Km * 3dB/Km

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2420</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>850 nm</td>
</tr>
<tr>
<td>Result</td>
<td>PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.08</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>0.20</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
</tr>
</tbody>
</table>

492 * 3 dB/Km = 1.47 dB
Como llegamos al límite?

#Km * 3dB/Km
+ # adaptadores * 0.75 dB

492 * 3 dB/Km = 1.47 dB
2 * 0.3 dB = 0.6.
Como llegamos al límite?

$1.47 + 0.60 = 2.08 \text{ dB}$

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2426</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2 PASS</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>850 nm PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.08</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>0.20</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
</tr>
</tbody>
</table>

$492 \times 3 \text{ dB/Km} = 1.47 \text{ dB}$

$2 \times 0.3 \text{ dB} = 0.6$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>850 nm</th>
<th>1300 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propagation Delay (ns)</td>
<td>2426</td>
<td></td>
</tr>
<tr>
<td>Length m</td>
<td>492.2</td>
<td>PASS</td>
</tr>
<tr>
<td>Limit 2000</td>
<td>492.2</td>
<td>PASS</td>
</tr>
<tr>
<td>Result</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
<td>1.02</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.08</td>
<td>1.34</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>0.20</td>
<td>0.32</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
<td>-23.76</td>
</tr>
</tbody>
</table>

Number of Adapters: 2
Number of Splices: 0
Connector Type: LC
Patch Length1 (m): 2.0
Reference Date: 05/31/1
1 Jumper

Valor Medido < Limit
1.88 vs 2.08
1.88 dB = Pasa TIA y Limit de IEEE 10GBASE-SR= 2.55

Cabling Standards:
- TIA 568
- ISO 11801

Custom Limits

Application Standards:
- 10GBaseS
- 40GBase-SR4
Este Link Supporta 10GBASE-SR??

<table>
<thead>
<tr>
<th>Propagation Delay (ns)</th>
<th>2426</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length m</td>
<td>492.2</td>
</tr>
<tr>
<td>Limit 2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>850 nm</td>
</tr>
<tr>
<td>Result</td>
<td>PASS</td>
</tr>
<tr>
<td>Loss (dB)</td>
<td>1.88</td>
</tr>
<tr>
<td>Limit (dB)</td>
<td>2.98</td>
</tr>
<tr>
<td>Margin (dB)</td>
<td>1.10</td>
</tr>
<tr>
<td>Reference (dBm)</td>
<td>-23.26</td>
</tr>
</tbody>
</table>

Number of Adapters: 2
Number of Splices: 0
Connector Type: LC
Patch Length1 (m): 2.0
Reference Date: 05/31/2
1 Jumper
Como?!?
2Km = Pasa TIA y
Limit de IEEE 10GBASE-SR= 400

Cabling Standards:
TIA 568
ISO 11801

Application Standards:
10GBaseS
40GBase-SR4

Custom Limits
TIER 2 TESTING

Tier II testing is Tier I *plus* the use of an OTDR
Ideal for Troubleshooting
Accurate OTDR Testing for HighSpeed Links

Launch Fiber

Tail Fiber

Will give loss of the first connector

Will give loss of the last connector
OTDR testing for High Speed Links

- Must use launch and receive fibers
- Need to run the test Bi-Directionally
- Need to measure reflectance
Bad – No Tail/Receive fiber – what is loss at far connector?
Bad – No Tail/Receive fiber – what is loss at far connector?
Good Measurement – Launch and Tail/Receive Fiber used
so both connectors can be measured
Good Measurement – Launch and Tail/Receive Fiber used so both connectors can be measured

Fiber Length: 51.63 m
Overall Loss: 0.82 dB

Tail Event
at 51.63 m
- Loss: 0.17 dB
- Reflectance: -24.29 dB

Launch Event
at 0.00 m

OTDR Port
at -107.51 m

End1

End at 158.73 m

End2

107.10 m

51.63 m

107.51 m
By the Way, the 2nd Connector is Bad
Notice the Poor Reflectance Value
What is reflectance?

An air gap between the end faces of a fiber also cause Fresnel reflections to occur.
Reflectance is Caused by Poor Termination and Dirty Connectors
Reflected Signal Arriving Outside of Bit Period

Fiber with poor reflectance

10 Gb/s
Bit Period

FCS/CRC Error

Fiber with Good Reflectance

10 Gb/s
Bit Period

Slide courtesy of OFS
Reflected Signal Arriving Outside of Bit Period

Fiber with poor reflectance

Fiber with Good Reflectance

10 Gb/s Bit Period
Reflected Signal Arriving Outside of Bit Period

Fiber with poor reflectance

Fiber with Good Reflectance

10 Gb/s Bit Period

51.69 m
Exemplo de una Fantasma

![Graph showing dB vs Meters (m)](image-url)
Specify a Reflectance Limit for OTDR testing

- OTDR loss event measurements heavily rely on good reflectance
- Poor reflectance can result in
  - Optimistic / negative loss readings
  - Errors when the application runs
- Agree on a reflectance limit
- As a guide (talk to your vendor)
  - -35 dB for multimode
  - -40 dB for singlemode
  - -55 dB for APC singlemode
Vamos ver otro ejemplo?
Tenemos Resultados Bi-Direcionales

Esto está bien!
Pocos eventos, nada inesperado

<table>
<thead>
<tr>
<th>Events</th>
<th>850 nm</th>
<th>1300 nm</th>
<th>Limit</th>
<th>850 nm</th>
<th>1300 nm</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>156.48 m End</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td>-54.31</td>
<td>-55.15</td>
<td></td>
</tr>
<tr>
<td>51.66 m Tail Event</td>
<td>0.15</td>
<td>0.10</td>
<td>0.75</td>
<td>-55.85</td>
<td>-56.42</td>
<td>-35.00</td>
</tr>
<tr>
<td>0.00 m Launch Event</td>
<td>0.08</td>
<td>0.05</td>
<td>0.75</td>
<td>-47.96</td>
<td>-52.10</td>
<td>-35.00</td>
</tr>
<tr>
<td>-107.32 m OTDR Port</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td>-48.89</td>
<td>-48.65</td>
<td></td>
</tr>
</tbody>
</table>
### Perdidas Menores a 0.75 dB

<table>
<thead>
<tr>
<th>Events</th>
<th>Loss (dB)</th>
<th>Reflectance (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>850 nm</td>
<td>1300 nm</td>
</tr>
<tr>
<td>156.48 m End</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>51.66 m Tail Event</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>0.00 m Launch Event</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>-107.32 m OTDR Port</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Y la Reflectancia? Esta Bien 😊

<table>
<thead>
<tr>
<th>Events</th>
<th>850 nm</th>
<th>1300 nm</th>
<th>Limit</th>
<th>850 nm</th>
<th>1300 nm</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>156.48 m End</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td>-54.31</td>
<td>-55.15</td>
<td></td>
</tr>
<tr>
<td>51.66 m Tail Event</td>
<td>0.15</td>
<td>0.10</td>
<td>0.75</td>
<td>-55.85</td>
<td>-56.42</td>
<td>-35.00</td>
</tr>
<tr>
<td>0.00 m Launch Event</td>
<td>0.08</td>
<td>0.05</td>
<td>0.75</td>
<td>-47.96</td>
<td>-52.10</td>
<td>-35.00</td>
</tr>
<tr>
<td>-107.32 m OTDR Port</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td>-48.89</td>
<td>-48.65</td>
<td></td>
</tr>
</tbody>
</table>

Cable ID: 007B6
Date / Time: 02/09/2017 07:29:37 AM
Cable Type: OM3 Multimode 50
Backscatter Coefficient: -68.0dB (850 nm) Backscatter Coefficient: -75.8dB (1300 nm)

Test Summary: PASS
Modal Bandwidth: 2000MHz-km (850 nm)
Modal Bandwidth: 500MHz-km (1300 nm)
In Conclusion

• Looking forward to 25G per $\lambda$
• Know your current requirements
  – At least 10G?
• Future applications will have tighter loss and length budgets
• Measure accurately
  – Tier I – use correct budget values REF vs STD
  – Tier 2 – Measure reflectance in addition to loss
Thank you, Gracias, Obrigado

Jim Davis
Fluke Networks

Jim.Davis2@flukenetworks.com
6920 Seaway Blvd
Everett, WA 98271