Agenda

RF Connector Care

RF Cable Care
Agenda

RF Connector Care
RF Cable Care
Proper connector care is vital for reducing cost and errors

Bad Connectors

- Can damage other equipment and connectors
- Increase measurement errors
  - Can create false failures in good DUT’s
  - Can create false passes in faulty DUT’s
- Waste time
  - Unnecessary rerunning of tests
  - Unnecessary troubleshooting
  - Unnecessary diagnostics and repair

COMPOUNDING PROBLEM!
Connector Care: Why is this important?

These are compounding problems!

Example 1 – Equipment Damage

- Using a faulty connector with instrumentation
- Potential measurement errors
Connector Care: Why is this important?

These are compounding problems!

Example 1 – Equipment Damage

- Using a faulty connector with instrumentation
  - Potential measurement errors
  - Potential instrument connector damage
  - Wasted money and time on instrument repair
Connector Care: Why is this important?

These are compounding problems!

Example 1 – Equipment Damage

- Using a faulty connector with instrumentation
  - Potential measurement errors
  - Potential instrument connector damage
    - Wasted money and time on instrument repair
  - If damage not recognized immediately
    - Potential damage to other connectors
    - Potential errors in all measurements with instrument
    - Potential damage to items under test
Connector Care: Why is this important?

These are compounding problems!

Example 1 – Equipment Damage

- Repair Costs
  - Instrument Repair
  - Connectors
  - DUT Replacements

- Downtime Costs
  - Repair Times-15 days
  - Wasted Troubleshooting

<table>
<thead>
<tr>
<th>Item</th>
<th>Replacement Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 mm Sliding Load</td>
<td>2,000.00</td>
</tr>
<tr>
<td>2.4 mm Sliding Load</td>
<td>2,200.00</td>
</tr>
<tr>
<td>2.4 mm Flexible Cable</td>
<td>1,600.00</td>
</tr>
<tr>
<td>Instrument Test Port</td>
<td>3,000.00</td>
</tr>
<tr>
<td>2.4 mm PSC Short</td>
<td>550.00</td>
</tr>
<tr>
<td>3.5 mm PSC Short</td>
<td>340.00</td>
</tr>
</tbody>
</table>
Transmission Lines versus Hookups

- Transmission Line
  - Uniform
  - Wavelength (delay) comparable or < with Size (risetime)
  - Voltages and current are Local (components are distributed)

- Non TL
  - Probably not uniform
  - Wavelength >> Size
  - Voltage and current Global (components are lumped)
Transmission Line –
A Simple Electrical Circuit

What current will flow when the switch is closed?

GENERATOR 50 volts

50 Ω
Transmission Line
Distance & Propagation Time

What current will flow \textit{at the moment} the switch is closed?
Transmission Line

A Very-very Long Uniform Line

\[ \xrightarrow{\text{GENERATOR}} \]
50 volts

\[ \xrightarrow{v} \]

\[ \xrightarrow{t_0 \rightarrow t_1 \rightarrow t_2} \]

$\leftrightarrow$ Incident wave propagates forever

$\leftrightarrow$ Limited only by losses in the line

$\leftrightarrow$ etc.
Infinite Transmission Line

- Incident wave propagates forever
- Limited only by losses
The rest of the line being infinitely long, has a $Z_0$ characteristic impedance.
A Terminated Transmission Line

The transmission line, terminated with $Z_0$ behaves as if it were infinitely long, viewed from the generator.

- If the impedances do NOT match, reflected waves are created, which combine with the incident waves to generate standing waves in the cable.
Reflection Coefficient

Mismatched impedances create reflected waves

• Impedance mismatches create reflections, limiting power transfer
• Ratio of reflected waves to incident wave is reflection coefficient
  • Maximum reflection coefficient = 1.0 (Complete Z Mismatch)
  • Minimum reflection coefficient = 0 (Complete Z Match)

Reflection Coefficient, $\Gamma$

$$\Gamma = \frac{E_{\text{reflected}}}{E_{\text{incident}}} = \frac{Z_L - Z_S}{Z_L + Z_S}$$
Typical Connector Cross Section

Male

Mating Plane

Female

Center Conductor

Outer Conductor
Center Conductors

Male

Female

Slotless

Slotted
Slotted Female Center Conductor

Outer Conductor

Center Conductor

High Quality Male Pin

Damage by Oversize Male Pin
Slotless Female Center Conductor

Acceptable Male Pin

Certain Damage by Oversize Male Pin
Pin Depth

Pin Depth; Recession of Female Contact

Pin Depth; Recession of Male Pin Shoulder
Fundamentals of Connectors

- Test Port
- Pin Depth
- Mating Plane
- Cable
Definitions of Terms

Pin Depth
Distance that the female center conductor or the shoulder of the male pin differs from being flush with the outer conductor mating surface.

Mating Surface
Surface in the outer conductor where both connectors have physical contact. Also called Mating Plane or Reference Plane.

Connection Torque
A twisting force on a rigidly fixed object such as a shaft, about an axis of rotation. Typically torque is measured in Lb-in or N-cm.

Measurement Reference Plane
The plane of contact of the outer conductors.
Making A Connection

- Take electrostatic precautions
- Align connectors axially
- Make physical contact
- Engage connector nut applying even force, finger-tighten
- Use correct torque wrench

*Good connection techniques are *required* to produce Reliable Measurements.*
Using the Torque Wrench

Handle begins to break
(Correct point to stop)

Push here

Handle fully broken
(Not recommended)
Using a Second Wrench

- Hold
- Torque Direction
- Incorrect
  - Too much lift on connection
## Recommended Connector Torque Values

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Torque (lb-inch (N-cm))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision 7 mm</td>
<td>12 (136)</td>
</tr>
<tr>
<td>Precision 3.5 mm</td>
<td>8 (90)</td>
</tr>
<tr>
<td>SMA</td>
<td>5 (56)</td>
</tr>
<tr>
<td></td>
<td>Use the SMA torque value to connect male SMA connectors to female precision 3.5-mm connectors. Use the 3.5-mm torque value to connect male 3.5-mm connectors to the female SMA (8 lb-inch).</td>
</tr>
<tr>
<td>Precision 2.4 mm</td>
<td>8 (90)</td>
</tr>
<tr>
<td>Precision 1.85 mm</td>
<td>8 (90)</td>
</tr>
<tr>
<td>Type-N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type-N connectors may be connected finger tight. If a torque wrench is used, 12 lb-inch (136 N-cm) is recommended.</td>
</tr>
</tbody>
</table>
Why So Many Different Connector Types?

What connectors are available?

- 3.5 mm
- Type-N
- 2.4 mm
- Co-Planar
- 7 mm
- K-type
- Production Grade
- TNC
- Sexed vs Sexless
- BNC
- Slot Less Contacts
- Bulkhead
- 4-Slotted Collet
- Precision BNC
- 6-Slotted Collet
- Bulkhead
- V-type
- APC-7
- APC-3.5
- Cable
- Sexed vs Sexless
- 2.92 mm
- 1.0 mm
- 1.85 mm
- F-type
- Instrument Grade
- Metrology Grade
- Keysight Technologies
Three Types of Connector Specifications

- Characteristic Impedance
- Frequency Range
- Quality
Connector Characteristic Impedance

Model for Characteristic Impedance, $Z$ (Low-Loss Case)

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right)$$

$D$ = Inner diameter of outer conductor

$d$ = Outer diameter of inner conductor

$D = 7.0 \text{ mm}$

$d = 3.04 \text{ mm}$
Frequency Coverage

\[ f_{\text{max}}(\text{GHz}) = \text{approx. } \frac{120}{D} \text{ mm} \]

- 7 mm = approx. 18 GHz
- 3.5 mm = 32 GHz

- Ratio D/d constant
- Depends strongly on dielectric support and mating pin geometry
# Connector Frequencies ¹

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>d (in/mm)</th>
<th>D (in/mm)</th>
<th>Calculated $TE_{11}$ cutoff frequency (GHz)</th>
<th>Specified maximum frequency (GHz)</th>
<th>% cutoff frequency at max recommended frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNC/TNC</td>
<td>0.085/2.160</td>
<td>0.260/6.60</td>
<td>14.7</td>
<td>4.0/11.0</td>
<td></td>
</tr>
<tr>
<td>Precision-BNC</td>
<td>0.120/3.040</td>
<td>0.276/7.00</td>
<td>19.0</td>
<td>18</td>
<td>95%</td>
</tr>
<tr>
<td>Type-N</td>
<td>0.120/3.040</td>
<td>0.276/7.00</td>
<td>19.0</td>
<td>18</td>
<td>95%</td>
</tr>
<tr>
<td>APC-7</td>
<td>0.120/3.040</td>
<td>0.276/7.00</td>
<td>19.0</td>
<td>18</td>
<td>95%</td>
</tr>
<tr>
<td>SMA (2.2 $\varepsilon_r$)</td>
<td>0.050/1.265</td>
<td>0.138/3.50</td>
<td>27.0</td>
<td>18</td>
<td>87%</td>
</tr>
<tr>
<td>3.5 mm</td>
<td>0.060/1.520</td>
<td>0.138/3.50</td>
<td>38.0</td>
<td>26.5</td>
<td>70%</td>
</tr>
<tr>
<td>2.92 mm/K</td>
<td>0.050/1.270</td>
<td>0.115/2.92</td>
<td>45.5</td>
<td>40</td>
<td>88%</td>
</tr>
<tr>
<td>2.4 mm</td>
<td>0.041/1.042</td>
<td>0.094/2.40</td>
<td>55.4</td>
<td>50</td>
<td>90%</td>
</tr>
<tr>
<td>1.85 mm/V</td>
<td>0.032/0.803</td>
<td>0.073/1.85</td>
<td>71.9</td>
<td>60</td>
<td>83%</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>0.017/0.434</td>
<td>0.039/1.00</td>
<td>133</td>
<td>110</td>
<td>83%</td>
</tr>
</tbody>
</table>

¹50 Ω
Connector Frequencies

\[ f_{\text{cutoff}} = \frac{c}{\lambda_{\text{cutoff}}} = \frac{c}{\pi \left[ \frac{(d + D)}{2} \right] \sqrt{\mu_r \varepsilon_r}} \]

\[ f_{\text{cutoff}} \text{(inches)} = \frac{7.51393}{[d + D] \sqrt{\varepsilon_r}} \text{ GHz} \]

\[ f_{\text{cutoff}} \text{(meters)} = \frac{190.85}{[d + D] \sqrt{\varepsilon_r}} \text{ GHz} \]

\[ \lambda_{\text{cutoff}} = \frac{\pi \left[ \frac{(d + D)}{2} \right] \sqrt{\varepsilon_r}}{c} \]
WHY 50 Ω?

Lowest attenuation

\[
\frac{D}{d} = 3.6 \quad Z_0 = 77.6 \, \Omega
\]

Optimum power

\[
\frac{D}{d} = 1.65 \quad Z_0 = 30 \, \Omega
\]

\[Z_0 = 138 \log_{10} \left( \frac{D}{d} \right)\]
Typical Connector Power Capability
Passive Intermodulation (PIM)

Intermodulation Distortion created in passive components caused from multiple high power input signals.

3rd Order PIM’s from 2x43 dBm Test

3rd Order PIM of N Connector

Loose Connectors can significantly affect PIM!
Connector Quality and Grades

QUALITY
Definition = Degree of Excellence

GRADES
Metrology
Instrument
Production (Field)
## Connector Summary

<table>
<thead>
<tr>
<th>Connector</th>
<th>Metrology</th>
<th>Instrument</th>
<th>Production</th>
<th>Cutoff Freq (GHz)</th>
<th>Sexed</th>
<th>Precision Slotted Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type F(75)</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>1</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>BNC (50 &amp; 75)</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>2</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>SMC</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>7</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Type-N (50 &amp; 75)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>18</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>APC-7 or 7 mm</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>18</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>SMA (4.14mm)</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>22</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>3.55 mm</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>34</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>2.92 mm or &quot;K&quot;</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>44</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>2.4 mm(^2)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>52</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>1.85 mm(^2, 3)</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>70</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>110</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

1. Compatible with SMA and 3.5 mm connectors.
2. Not compatible with SMA, 3.5 or 2.92 mm connectors
3. Compatible with 2.4 mm connector

The SMA Connector

DC to 18 GHz (specified)

Usually Teflon: this expands with temperature

This pin is often the center wire of the semi-rigid cable
The Precision 3.5 mm Connector

DC to 26.5 GHz
(specified)

Air dielectric:
is stable
with temperature
MATING SMA WITH APC-3.5 mm (TYPICAL)

FREQUENCY in GHz

SWR

SMA/SMA Conventional Mated Pair
APC-3,5/SMA Conventional Junction
APC-3.5 Mated Pair

KEYSIGHT TECHNOLOGIES
Precision 3.5 mm Interface

3.5mm - 3.5mm

3.5mm - SMA
The SMA Connector

SMA Connector Mating Planes – Connector Mismatch

- Pin Depth
- Center Pin Plane
- Cable
- Teflon
- Air Gap
- Mating Planes
- Multiple internal reflections in Air Gap

The SMA Connector
The Type-N Connector

DC to 18 GHz

RECESSION OF
MALE CONTACT
PIN SHOULDER

OUTER
CONDUCTOR
MATING
PLANE

RECESSION
OF FEMALE
CONTACT
FINGERS

OUTER
CONDUCTOR
MATING
PLANE
## Connector Examples

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type F</td>
<td></td>
<td>APC 7</td>
<td></td>
</tr>
<tr>
<td>BNC</td>
<td></td>
<td>SMA</td>
<td></td>
</tr>
<tr>
<td>SMC</td>
<td></td>
<td>3.5 mm</td>
<td></td>
</tr>
<tr>
<td>Type N</td>
<td></td>
<td>2.92 mm or K</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.4 mm</td>
<td></td>
</tr>
</tbody>
</table>
Some Precision Adapters

- N(f)-BNC(m)
- N(m)-BNC(m)
- Triaxial(m)- BNC(f)
- Triaxial(f)- BNC(m)
- Triaxial(f)- BNC(f)
Some Precision Adapters

N(m)-3.5(f)  N(m)-3.5(m)  N(f)-3.5(m)  N(f)-3.5(f)

Matched phase adapters
1.0 mm Coaxial Adapters
75 Ω Connectors

Note: 75 Ω center conductor is smaller
4-slot vs 6-slot Collets on 7mm Connectors

4-slot collet resonance somewhere between 14-16 GHz

APC-7 as well as Type-N (f) center conductor
Connector Limitations

Frequency and power performance of a series of connections is dependent upon worst performing connector

http://www.keysight.com/upload/cmc_upload/All/EPSG085963.html?&cc=US&lc=eng
Cascaded Adapter Limitations-Frequency

Example: 3.5mm to Precision N to N to BNC to SMA
Cascaded Adapter Limitations - Frequency

Example: 3.5mm to Precision N to N to BNC to SMA

Usable frequency range now limited to BNC’s 4 GHz
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Connectors not perfectly matched, leading to uncertainties

- Following the amplitude and phase uncertainty equations:

\[
\text{Amplitude Mismatch Uncertainty} = \pm 2 \times |\Gamma_A| \times |\Gamma_B| \times 100\%
\]

\[
\text{Amplitude Mismatch Uncertainty} = 20 \times \log (1 \pm |\Gamma_A| \times |\Gamma_B|) \text{ dB}
\]
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Connectors not perfectly matched, leading to uncertainties

- Following the amplitude and phase uncertainty equations:

\[
\text{Phase Mismatch Uncertainty} = \frac{180}{\pi} \times |\Gamma_A| \times |\Gamma_B|
\]

A

B
Cascaded Adapter Limitations-Uncertainty

Cascading adapters increases measurement uncertainty

Example: Device Under Test connected to Test Cable

- **Device Under Test:** Return Loss = -9.5 dB → $|\Gamma|_A = 0.33 → VSWR = 2.00$
- **Test Cable:** Return Loss = -20.0 dB → $|\Gamma|_B = 0.1 → VSWR = 1.22$

\[
RL = -20\log(|\Gamma|) \quad |\Gamma| = 10^{\frac{-RL}{20}} \quad VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}
\]
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Example: Device Under Test connected to Test Cable

- **Device Under Test**: Return Loss = -9.5 dB → $|\Gamma_A| = 0.33$ → VSWR = 2.00
- **Test Cable**: Return Loss = -20.0 dB → $|\Gamma_B| = 0.1$ → VSWR = 1.22

Amplitude Mismatch Uncertainty = $\pm 2 \times 0.33 \times 0.1 \times 100\%$

**Amplitude Mismatch Uncertainty** = $\pm 6.9\%$

Amplitude Mismatch Uncertainty = $20 \times \log(1 \pm 0.33 \times 0.1)$ dB

**Amplitude Mismatch Uncertainty** = +0.30 dB, -0.29 dB

Phase Mismatch Uncertainty = $\frac{180}{\pi} \times 0.33 \times 0.1$

**Phase Mismatch Uncertainty** = 1.92°
Cascaded Adapter Limitations-Uncertainty

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

• Assume for all: Return Loss = -10.0 dB → \(|\Gamma| = 0.32\) → VSWR = 1.92
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- **Assume for all:** Return Loss = -10.0 dB → |Γ| = 0.32 → VSWR = 1.92

- Four Internal Connections
- For each:
  - |Γ|_A = |Γ|_B = 0.32
- Other Uncertainties
  - Outer Connectors
  - Cable Loss
  - Instrumentation
  - Reflections
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- **Assume for all:** Return Loss = -10.0 dB → |\(\Gamma\)| = 0.32 → VSWR = 1.92

- **Four Connections**
- **For each:**
  - Amp. Mismatch Uncertainty = ± 20.0%
  - Amp. Mismatch Uncertainty = -0.83 dB to +0.92 dB
  - Phase Mismatch Uncertainty = 5.73°
Cascaded Adapter Limitations - Uncertainty

Cascading adapters increases measurement uncertainty

Example: Multiple Connectors Cascaded

- Total Cascaded Worst Case Uncertainties:

Cascaded Amplitude Mismatch Uncertainty:
\[ 4 \times \pm 20.0\% = \pm 80.0\% \]

Cascaded Amplitude Mismatch Uncertainty:
\[ 4 \times -0.83\, \text{dB} \text{ to } +0.92\, \text{dB} = -3.31\, \text{dB} \text{ to } +3.66\, \text{dB} \]

Cascaded Phase Mismatch Uncertainty:
\[ 4 \times 5.73^\circ = 22.92^\circ \]
Cascaded Adapter Limitations - Uncertainty

Rule of Thumb: Minimize connections to reduce uncertainties
Principles of Connector Maintenance

✓ Protect during storage
✓ Inspect visually for damage
✓ Clean to remove metal flakes, oil and dust
✓ Gage pin depth and male pin size
Handling and Storage

• Keep connectors clean.
• Do not touch the mating surfaces.
• Protect the mating surface using plastic end caps.
  • Caps also provide ESD protection.
Visual Inspection

Look for damage and debris

- Minor defects
- Damage
- Dirt

Clean with compressed air and alcohol
Example: Connector Problems
Damage From Protrusion

(1) Correct Pin Depth

(2) Protruding Male Pin

(3) Test Port Impedance Changed
Replace Damaged Connectors

- Scratched
- Bent, Deformed
- Broken
Damaged Precision Female Connector

Damaged Finger Contact

scratches
Damaged Connectors

- Bent/Deformed
- Missing Finger Contacts
- Scratched Conductor
Connector Inspection Flowchart

✓ Visually inspect the connector…. (LOOK inside the connector)
  • Look for metal particles, scratches and dents.
✓ Clean the connector if it is dirty.
✓ If damaged or cannot be cleaned, discard the connector.
✓ Get a new or undamaged connector.
✓ Inspect all connectors carefully BEFORE making a connection.

NEVER use a damaged connector!
Three Cleaning Methods

*Don’t Make a Mess Cleaning Up!*

- Compressed Air

- Foam swab moistened with isopropyl alcohol for exterior surfaces

- Lint free cloth wrapped around a toothpick moistened with isopropyl alcohol for interior surfaces
Cleaning

*To clean a connector, follow these guidelines:*

- Apply a mild blast of dry compressed air or Nitrogen to loosen any contaminants.
- Use the minimum amount of pure alcohol to clean the mating plane surface.
- Cut the round tip off of a wooden toothpick and wrap the end with a lint-free cloth.
- Moisten the cloth with a small amount of isopropyl alcohol.
- Insert the toothpick with cloth into the connector.
- Dry the connector with compressed air.
Cleaning

WRONG

• Circular strokes leave torn fibers snagged on edges of center collet

CORRECT

• Radial strokes do not leave fibers

• Use circular strokes for outer conductor face only
Don’ts of Connector Cleaning

DO NOT
Ø Use acetone, methanol or CFCs (freon)
Ø Overuse the isopropyl alcohol
Ø Wet any plastic or dielectric parts in the connectors
Ø Break or bend the center conductor while cleaning
Ø Use a toothpick with a diameter >1.7 mm on a 3.5mm connector or one with a diameter >1.2mm on a 2.4mm connector
Ø Blow on the connector
Ø Clean with cotton swabs
Ø Use circular strokes when cleaning the interior of the connector
Gage Test Ports
Gage All Devices Under Test
Use connector Gages
- Before connecting any device for the first time on test ports every 100 connections
- To verify visual inspection at any time
Connector Gages only provide coarse measurements
- They do not prove pin size
Mechanical Inspection

- Outer conductor mating plane

![Diagram of mechanical inspection with labels A, D, d, dm, MP, and FP.]
Using Connector Gauges

Inspect and clean before each use
Use multiple measurements
Zero the gauge
Connecting the Gauge Master

Screw on the gauge master and hand-tighten
Use correct torque wrench

- Settle the gauge
- Adjust the zero knob to zero the gauge
Measure the Connector

Zero the Gage
Connect the device
Settle the Gage
Read recession or protrusion
Connection Techniques

Good connection techniques are **required** to produce Reliable Measurements.

Before each connection:

- LOOK
- Clean
- Inspect
- Gage

**PRACTICE MAKES PERFECT!**
Connector Considerations

Repeatability
• Allows us to connect/disconnect instrumentation repeatedly to devices or systems under test

Measurement Accuracy
• Connecting and disconnecting connectors greatly affects measurement accuracy.
• Connector misalignment, over-tightening, mechanical tolerance or dirt also affects measurement accuracy.

Types
• It is important to select the best of several types for your specific application.

Wear
• With frequent use, connectors wear out and must be replaced.
• Connectors are consumables and, therefore, have a limited lifetime.
• Damaged connectors mean increased cost.
Using Adapters as Connector Savers

Protect Connectors on test set or cable

Example: Becomes Port 1 and Port 2 of your VNA

Link for determining connectors for your instrumentation:

http://na.support.keysight.com/pna/connectorcare/What_mates_with_what.htm#NMD
Using Adapters as Connector Savers

Protect Connectors on test set or cable

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Make sure:

• Connector grades adequate
• Connector savers calibrated out in tests
• Uncertainties from connector savers adequate
• To still check connector savers for damage!
Connector Care Summary

✓ **LOOK** at connector before attaching – make it a habit
✓ Choose appropriate connector style
✓ Frequency range
✓ Application environment
✓ Use minimal adapters to decrease uncertainties
✓ Use clean connectors
✓ Do not use damaged connectors
✓ Use connector savers
Agenda

RF Connector Care

RF Cable Care
Cable Care: Why is this important?

Proper connector care is vital for reducing cost and errors

Bad Cables (just as bad connectors)

• Can damage other equipment and connectors
• Increase measurement errors
  • Can create false failures in good DUT’s
  • *Can create false passes in faulty DUT’s*
• Waste time
  • Unnecessary rerunning of tests
  • Unnecessary troubleshooting
  • Unnecessary diagnostics and repair

COMPOUNDING PROBLEM!
Cable Characteristic Impedance

Model for Characteristic Impedance, $Z$ (Low-Loss Case)

$$Z_0 = \frac{138}{\sqrt{\varepsilon_r}} \ln \left( \frac{D}{d} \right)$$

- $D =$ Inner diameter of outer conductor
- $d =$ Outer diameter of inner conductor

Dependent Upon:
- Cable Geometry
- Cable Dielectric
Cable Loss

Return Loss due to Impedance Mismatches

Cable Impedance

\[ Z_0 = \frac{138}{\sqrt{\varepsilon_r}} \ln \left( \frac{D}{d} \right) \]

Reflection Coefficient

\[ \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \]

Return Loss

\[ RL = -20 \log(\|\Gamma\|) \]
Cable Loss

Cables losses also have geometric dependencies!

Cable Impedance

\[ Z_0 = \frac{138}{\sqrt{\varepsilon_r}} \ln \left( \frac{D}{d} \right) \]

Reflection Coefficient

\[ \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \]

Return Loss

\[ RL = -20 \log(|\Gamma|) \]
Additional Cable Loss Factors

Insertion loss per unit length (dB)

Skin Effect Losses - function of frequency

\[ r = \sqrt{\frac{\omega \mu}{2\sigma}} \quad \omega = 2\pi f \]

\[ Loss(f) = 8.68 \frac{r}{4\pi Z_0} \left( \frac{1}{D} + \frac{1}{d} \right) \]

\[ = A \cdot f^{1/2} \]

Dielectric Losses – dielectric dependent

\[ Loss(f) = A \cdot f^b \]

\( b \) is a dielectric specific factor
Example Coaxial Cable Loss Curves
Insertion Loss and Cable Flexure

Minimally Flexed Cable

Test Cable Return Loss
• Cable is minimally flexed
Insertion Loss and Cable Flexure

Flexed Cable

Test Cable Return Loss

- Cable is flexed within extents
Insertion Loss and Cable Flexure

Flexing a cable will alter its characteristics

- Modifies internal geometries
- Changes Impedance, VSWR, Loss, etc.
Insertion Loss and Cable Flexure

Flexing a cable will alter its characteristics

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- Changes Impedance, VSWR, Loss, etc.

Scenario:

- Un-flexed cable with poor flexure stability calibrated before test
- Cable flexed to connect to device under test
Insertion Loss and Cable Flexure

Flexing a cable will alter its characteristics

- Modifies internal geometries
- Changes Impedance, VSWR, Loss, etc.

Scenario:

- Un-flexed cable with poor flexure stability calibrated before test
- Cable flexed to connect to device under test
  - Measurement uncertainty increased due to changes in cable
  - Calibration factors invalid (cal done on unflexed cable)
  - Potential false passes or fails

Flexing Cable increases Measurement Uncertainty!
Insertion Loss and Cable Flexure

Flexing a cable will alter its characteristics

• Modifies internal geometries
• Changes Impedance, VSWR, Loss, etc.

Additional Scenario:

• Overtightening cables with cable or “zip” ties in systems
  • Overtightening cables can affect cable geometries
  • Slight reflections can occur due to discontinuities
Insertion Loss and Cable Flexure

Cable flexure error reduction solutions

• Use cables with high flexure stability specifications
  • Phase stability upon flexure
  • Amplitude stability upon flexure
Insertion Loss and Cable Flexure

Cable flexure error reduction solutions

- Use cables with high flexure stability specifications
  - Phase stability upon flexure
  - Amplitude stability upon flexure

- Limit cable flexure after calibrations
  - Try to flex cables similar to future connection during calibration
  - Limits change in flexure and therefore cal factor deviations
Cascaded Cable Limitations-Performance

Just as with Adapters

Frequency and power performance of a series of cables is dependent upon worst performing cable.
Cascaded Cable Limitations - Uncertainty

Just as with Adapters

Cascading cables increases measurement uncertainty

And Multiple Flexure Deviations!
Cascaded Cable Limitations-Uncertainty

Rule of Thumb: Minimize cables to reduce uncertainties
Other Sources of Cable Errors

Temperature

• Modifies dielectric properties of cable:
  • Affects phase

\[
\phi = \frac{360 \cdot f \cdot \text{length} \cdot \sqrt{\varepsilon_r}}{c}
\]

Scenario:

• Cable calibrated in temperature chamber once
• Temperature change causes phase errors
Other Sources of Cable Errors

Temperature

- Modifies dielectric properties of cable:
  - Affects phase

\[ \phi = \frac{360 \cdot f \cdot \text{length} \cdot \sqrt{\varepsilon_r}}{c} \]

Scenario:

- Cable calibrated in temperature chamber once
- Temperature change causes phase errors

Solutions:

- Calibrate test setup again after large temperature shifts
- Use cables with high temperature stability specifications
Damaged Cables

Damaged cables create

• Deviations from original performance specifications
• Impedance mismatches
• Unwanted reflections
  • Calibration doesn’t prevent reflections
• Potential damage to other devices

Throw away damaged cables!
Damaged Cables

Causes of cable damage

- Exposure to temperatures below or above specifications
- Excessive power transmission
- Flexing beyond extents
- High usage
  - Twisting and stretching
  - Connecting/Disconnecting

Cables and connectors have life cycle specifications
Visual Inspection

Look for discontinuities in the cable

✓ “Kink” in cable as shown in figure
  • Excessive flexure or other physical damage

✓ Warping in cable jacket
  • Temperature induced damage

✓ Burn marks or jacket discoloration
  • Excessive power transmitted
  • Environmental damage

✓ Check connectors for damage
  • Follow connector care guidelines
Further Inspection

Cable damage is not always physically noticeable!

Damage may not be visible

• Internal conductor and dielectric damage hidden by jacket

Many application specific cable test procedures

• Power Handling, Velocity of Propagation, Impedance, Insertion Loss
• Performing all would be time consuming
Further Inspection

“Quick and Easy” functional cable tests

Check S-Parameters along frequency range with a Network Analyzer

- Reflection Coefficient
- Insertion Loss
Further Inspection

“Quick and Easy” functional cable tests

Check S-Parameters along frequency range with a Network Analyzer

- Reflection Coefficient
- Insertion Loss
- Flex cable along extents during measurements
  - Look for changes in performance beyond cable’s specifications
  - Aids in spotting less noticeable cable damage
Further Inspection

“Quick and Easy” functional cable tests

Check S-Parameters along frequency range with a Network Analyzer
  ✓ Reflection Coefficient
  ✓ Insertion Loss
  ✓ Flex cable along extents during measurements
    • Look for changes in performance beyond cable’s specifications
    • Aids in spotting less noticeable cable damage

• Recommended before lengthy tests

• Takes a few minutes per cable
  • A few minutes to test each cable << Time wasted in faulty test
Connector and Cable Care Summary

Rules of Thumb

- Use appropriate grade connectors
- Use cables with specifications fit for the application and environment
- Routinely check connectors and cables for damage
- Replace damaged cables and connectors immediately
- Properly care for cables and connectors
  - Routinely clean connectors
  - Use torque wrenches when making connections
  - Don’t bend cables beyond extents or expose to damaging temperatures
- Minimize cascaded adapters and cables to reduce uncertainties

Routinely refresh cable and connector inventories!
Resources

Handbook of Microwave Component Measurements

Joel P. Dunsmore
Resources

Literature


Application Notes
• Application Note AN 1449-1, 2, 3 and 4, Fundamentals of RF and Microwave Power Measurements (Parts 1, 2, 3 and 4).

• Application Note AN 1287-3, Applying Error Correction to Network Analyzer Measurements

• Application Note AN 1287-9, Understanding the Fundamental Principles of Vector Network Analysis
Connector Compatibilities
(What else can mate with what?)

<table>
<thead>
<tr>
<th>Connector</th>
<th>Mates With</th>
</tr>
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<tbody>
<tr>
<td>3.5 mm</td>
<td>SMA, 2.92 mm</td>
</tr>
<tr>
<td>2.92 mm</td>
<td>SMA, 3.5 mm</td>
</tr>
<tr>
<td>SMA</td>
<td>3.5 mm, 2.92 mm</td>
</tr>
<tr>
<td>2.4 mm</td>
<td>1.85 mm</td>
</tr>
<tr>
<td>1.85 mm</td>
<td>2.4 mm</td>
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</tbody>
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