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Understanding Coaxial Cable Testing

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1. Executive Summary

Coaxial cables are fundamental components in RF and microwave communication systems, providing the physical medium for transmitting high-frequency signals with minimal loss. Whether in wireless infrastructure, broadcast systems, satellite communications, or test environments, maintaining the integrity and performance of these cables is critical to system reliability. As frequency requirements extend into gigahertz ranges and systems demand more precise performance, testing coaxial cables over the desired band becomes not just advisable, but essential.

This article explores the four core tests used to evaluate the quality and reliability of coaxial cables within a specific frequency band: return loss, cable loss, distance-to-fault, and passive intermodulation (PIM). Each test provides unique insights into different performance aspects and potential failure points, enabling technicians and engineers to diagnose issues, optimize installations, and ensure the cable system meets the stringent requirements of modern RF systems.

1.1. Return Loss Test

Return loss is a key metric used to assess the impedance matching of a coaxial cable and its connectors. It measures how much of the signal is reflected back toward the source due to impedance discontinuities along the cable path. Expressed in decibels (dB), a higher return loss indicates better matching and less reflection, which translates into more efficient power transfer.

To perform this test, a vector network analyzer (VNA) or a cable and antenna analyzer is typically used. The instrument sends a signal through the cable and compares the input signal with the reflected signal. Poor return loss can be caused by damaged connectors, improper terminations, or manufacturing inconsistencies in the cable. Over the desired frequency band, the return loss should remain within acceptable limits, which are usually defined by system specifications or industry standards. Monitoring this parameter helps identify impedance mismatches before they evolve into more serious signal degradation.

1.2. Cable Loss Test

Cable loss, or insertion loss, quantifies the amount of signal power lost as it travels through the coaxial cable. Losses are due to the resistance of the conductors, dielectric losses, and leakage through the cable shield. Cable loss is frequency-dependent, increasing with frequency due to the skin effect and other high-frequency phenomena.

This test is usually conducted using a VNA or a scalar network analyzer by measuring the difference in signal strength between the cable's input and output across the operating frequency range. A known good reference cable is often used for calibration. Results are compared with manufacturer specifications to determine if the loss is within expected tolerances. Excessive cable loss can indicate physical damage, water ingress, or aging, and it directly impacts the efficiency and range of RF systems.

1.3. Distance to Fault (DTF) Test

The Distance to Fault test is a time-domain reflectometry (TDR) measurement that helps locate faults or discontinuities along the length of a coaxial cable. By sending a pulsed or swept RF signal into the cable and analyzing the reflected energy over time, the test determines the location and magnitude of reflections caused by impedance anomalies.

This method is extremely useful in identifying crushed, cut, or improperly terminated sections of cable, especially in longer runs where visual inspection is impractical. The DTF test plots return loss or VSWR versus distance, enabling technicians to pinpoint problem areas without disassembling the system. The test is typically performed using a cable and antenna analyzer with a DTF mode, and the accuracy depends on proper calibration and knowledge of the cable's velocity factor.

1.4. Passive Intermodulation (PIM) Test

Passive Intermodulation testing is critical in high-performance RF systems, particularly in cellular and broadcast applications where non-linear effects from passive components can cause interference. PIM arises when two or more high-power signals pass through a non-linear junction—such as corroded connectors or poor-quality materials—and generate unwanted intermodulation products at new frequencies.

To perform a PIM test, two high-power tones are injected into the cable, and the resulting intermodulation products are measured using a sensitive receiver. The test is typically conducted at or near the operating frequency band, and results are expressed in dBm or dBc (decibels relative to the carrier). Low PIM performance is essential in systems using frequency reuse or carrier aggregation, where even minor intermodulation can degrade receiver sensitivity and data throughput.

PIM testing requires specialized equipment and controlled conditions, as even minor contaminants or loose connections can introduce artifacts. A clean test setup and proper torque on connectors are essential to ensure accurate results. PIM measurements help verify the long-term RF cleanliness of the cable system and prevent performance degradation from unpredictable, passive sources.

2. Return Loss Test – Detailed Overview

Return loss is a critical parameter in evaluating the quality of signal transmission through a coaxial cable. It represents the ratio of reflected power to the incident power, caused by impedance mismatches or discontinuities along the cable. A well-matched cable system with minimal reflections will exhibit high return loss, typically measured in decibels (dB). This ensures efficient energy transfer and reduces signal degradation or standing wave formation, which can be especially detrimental in high-frequency systems.

2.1. Principle Behind the Test

The return loss RL is defined as:

$$RL(dB) = -10\log_{10}\left(\frac{P_{reflected}}{P_{incident}}\right)$$

Where:

- $P_{reflected}$ is the power reflected back toward the source.
- $P_{incident}$ is the original power transmitted into the cable.

Alternatively, return loss is closely related to Voltage Standing Wave Ratio (VSWR), but return loss is generally preferred for its directness and log-scale representation.

2.2. Test Setup

To properly measure return loss, you need the following equipment:

- Vector Network Analyzer (VNA) or a **Cable & Antenna Analyzer**
- Precision RF test port adapters or connectorized cables
- Known good calibration kit (Figure 1)¹
- Matched load termination (typically 50 ohms, broadband)



Figure 1 – Calibration kits

¹ Calibration kit from Keysight: <https://www.keysight.com/br/pt/product/85054B/standard-mechanical-calibration-kit-dc-18-ghz-type-n-50-ohm.html>

2.2.1. Procedure:

- **Calibration:** Begin by calibrating the analyzer (usually with Open, Short, and Load standards) at the end of the test cable. Calibration eliminates the effect of test cables and adapters from the measurement.
- **Connection:** Connect one end of the cable under test (CUT) to the analyzer test port (Figure 1). The other end must be terminated with a matched load (usually 50 ohms) to absorb the signal rather than reflect it. This simulates an ideal matched system. It is possible to measure the Return loss of a entire passive rf system using the setup in Figure 2.
- **Measurement Sweep:** Configure the analyzer to sweep across the desired frequency band. The analyzer sends a signal into the cable and measures how much of it is reflected back, capturing the S11 parameter (reflection coefficient at port 1).
- **Data Output:** The analyzer displays return loss in dB vs. frequency. For example, a return loss of -30 dB at 2 GHz means that only 0.1% of the signal is reflected back, while the rest is successfully transmitted.

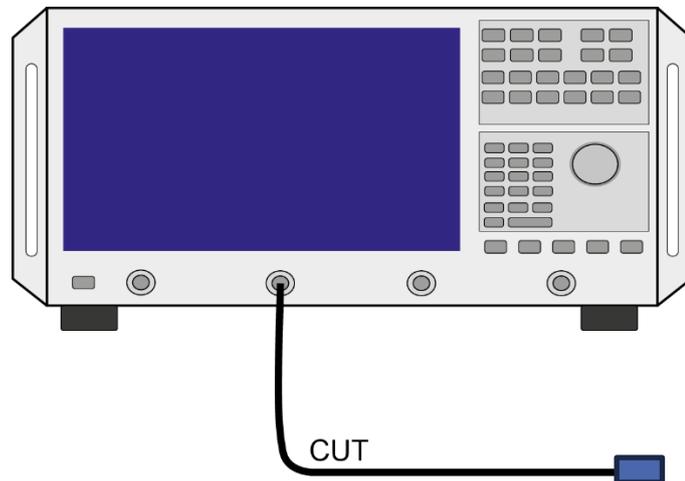


Figure 2 – Return loss – Cable under test

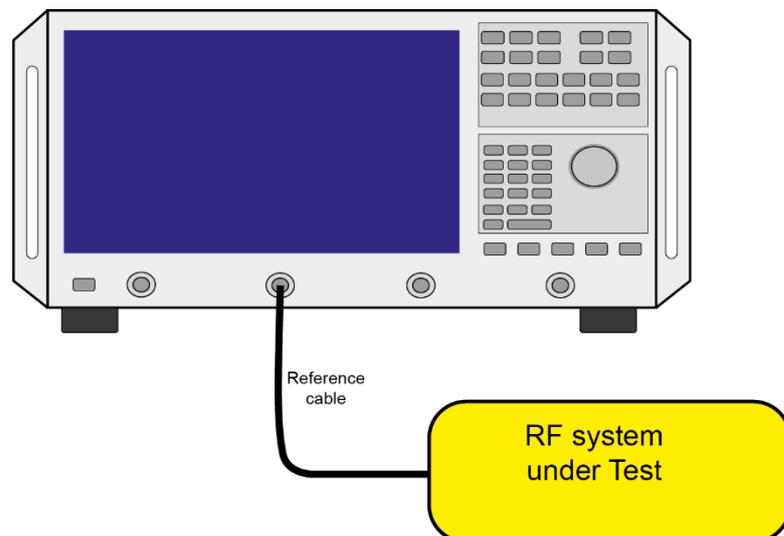


Figure 3 – Return loss – RF System under test

2.2.2. Understanding the Output

The output is typically a **frequency sweep graph** showing return loss (in dB) across the specified band. Key points include:

- High return loss values (e.g., -30 dB) are desirable, indicating minimal reflections.
- Low return loss values (e.g., -10 dB) signal mismatches or discontinuities.
- Sharp dips or irregularities suggest specific frequency points where reflections are more severe, possibly due to a connector, bend, or fault in the cable.

Return loss performance is typically considered acceptable if it exceeds 20 dB across the operational band, but the threshold may vary depending on the system specification.

3. Cable Loss Test – Detailed Overview

Cable loss, also known as **insertion loss**, quantifies how much signal power is attenuated as it travels through a coaxial cable. Loss occurs due to conductor resistance, dielectric losses, radiation, and imperfect shielding. Since these losses are frequency-dependent and often increase at higher frequencies, it is crucial to verify the actual loss over the operational band, especially for high-frequency RF systems.

This test is essential for validating whether a cable installation meets design expectations and whether degradation (due to age, moisture, damage, or poor connections) has occurred.

3.1. Principle Behind the Test

Cable loss is defined as the ratio of input power to output power along the length of a cable. In decibels:

$$\text{Cable Loss}(dB) = 10\log_{10}\left(\frac{P_{input}}{P_{output}}\right)$$

Where:

- P_{input} is the power applied at the cable's input.
- P_{output} is the power measured at the cable's far end.

This loss includes both dielectric and conductor loss components. The exact loss per meter is typically provided by the manufacturer, but field measurements help verify real-world performance.

3.2. Test Setup

To perform a cable loss test, you will need:

- A Vector Network Analyzer (VNA) or spectrum analyzer with tracking generator, or a Cable & Antenna Analyzer

- A reference cable or through calibration
- An accurate RF load or termination (in some configurations)
- Access to both ends of the cable (ideal case)

3.2.1. Measurement Methods:

There are two main methods to measure cable loss, depending on whether you have access to both cable ends:

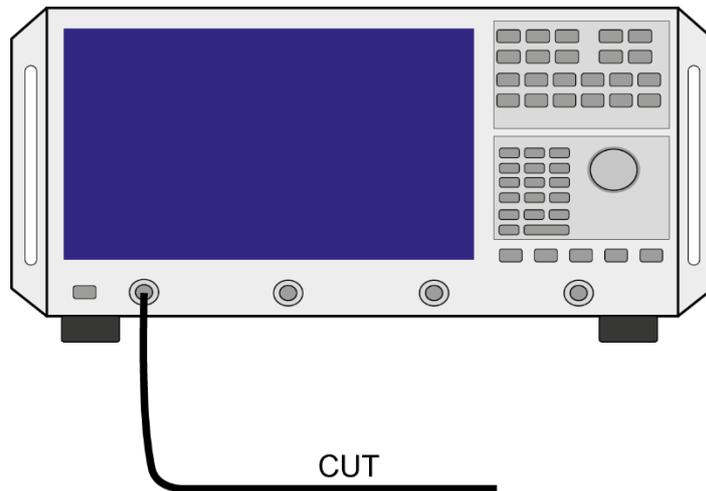


Figure 4 - One port measurement (S_{11} /reflection)

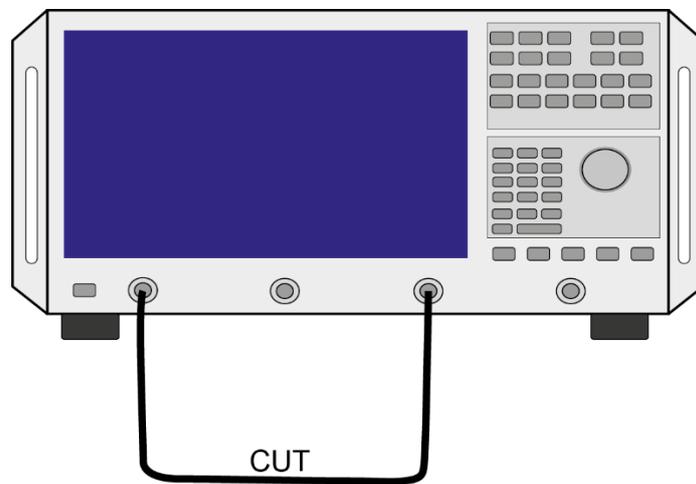


Figure 5 - Two port measurement (S_{21} /transmission)

1. One-Port Reflective Method (Single End Access – S_{11})

This is the most common method in the field, especially when one cable end is inaccessible (e.g., mounted antenna feedlines).

- Terminate the far end of the cable with a precision **short or open**.
- Perform a return loss sweep.
- The analyzer measures the reflected power and calculates the round-trip loss.
- Since the signal travels twice (forward and back), the result is divided by 2 to estimate one-way loss.

2. Two-Port Transmission Method (Both Ends Accessible – S21)

This method provides more accurate results.

- Connect port 1 of the analyzer to one end of the cable, and port 2 to the far end.
- Terminate both ports properly.
- Measure **S21** (insertion loss), which directly reflects the signal attenuation.
- The analyzer will display the insertion loss vs. frequency, usually in dB.

3.2.2. Data Output and Interpretation

The output from the analyzer is a frequency sweep graph showing insertion loss (in dB) across the desired frequency range.

A typical output might show:

- A **smooth, upward-sloping curve**, indicating that cable loss increases with frequency.
- For example, a 30-meter length of RG-213 may show a loss of about 1.5 dB at 100 MHz, rising to 5 dB at 1 GHz.
- Abrupt dips or spikes may indicate damage, moisture ingress, or kinks in the cable.

It's common to compare the measured results to the manufacturer's **datasheet specifications** for attenuation per unit length (e.g., dB/m). Significant deviation from expected values may signal cable aging or installation problems.

3.2.3. Do You Need Special Termination?

- **Yes**, the test requires matched terminations (usually 50 or 75 ohms) at both ends, depending on the system impedance and type test.
- In the **reflective method**, you intentionally use a short or open to reflect the signal.
- In the **transmission method**, both ends should be properly terminated with calibrated ports or loads.

If terminations are mismatched or connectors are poorly installed, it can skew results by introducing reflections or extra loss.

3.2.4. Calibration and Best Practices

- **Calibrate** the analyzer using a standard calibration kit before testing.
- For two-port testing, perform **through calibration** using a known-good cable.
- Ensure cables and connectors are clean, dry, and properly torqued.
- Avoid sharp bends and stress on the cable during the test.

If you're testing over longer cables or at higher frequencies (e.g., above 2 GHz), even small issues like slight impedance mismatches or oxidation on connectors can significantly affect accuracy.

3.2.5. Typical Coaxial Cable Loss Values

Table 1 - Typical Coaxial Cable loss values

Cable Type	Loss @ [dB/100m]					Impedance
	100 MHz	500 MHz	1 GHz	2 GHz	3 GHz	
RG-58 (50Ω)	~10.8	~25.0	~36.0	~53.0	~65.0	50 Ω
RG-213 (50Ω)	~4.2	~9.6	~14.4	~22.5	~28.5	50 Ω
LMR-240	~6.6	~14.5	~21.7	~32.5	~40.9	50 Ω
LMR-400	~2.7	~6.3	~9.2	~13.6	~17.0	50 Ω
Heliac 1/2"	~1.5	~3.7	~5.3	~7.8	~10.0	50 Ω
RG-6 (75Ω)	~5.3	~12.1	~18.0	~27.0	~34.0	75 Ω
RG-11 (75Ω)	~3.1	~7.2	~10.8	~16.8	~21.5	75 Ω

Note: These are approximate manufacturer-provided values at room temperature and may vary slightly by vendor, environmental conditions, and cable aging. Loss values increase with frequency and are **not linear**.

How to Use This Table in the Field

- **Compare against measured results:** If you're testing a 50-meter run of LMR-400 at 2 GHz, you'd expect around 6.8–7 dB of loss. A reading of 10 dB might indicate damage, kinks, water ingress, or poor connector installation.
- **Check manufacturer datasheets:** Always refer to the specific cable manufacturer's datasheet when high accuracy is needed, especially for installations exceeding 10 meters at GHz-range frequencies.
- **Adjust for length:** Since the loss is often specified per 100 meters, scale accordingly for the cable under test. For example, 20 meters of RG-213 at 1 GHz would have ~2.9 dB of loss (14.4 dB/100m × 0.2).

4. Distance to Fault (DTF) Test – Detailed Overview

The Distance to Fault (DTF) test is a diagnostic tool used to identify and locate impedance discontinuities or physical faults along a coaxial cable. It works by analyzing the reflections of a signal that travels through the cable and bounces back from any mismatches, opens, shorts, or damage points.

DTF testing is especially valuable in systems where cables are concealed within towers, walls, conduits, or underground — areas that cannot be visually inspected. By detecting and locating issues without disconnecting the cable from both ends, DTF significantly speeds up troubleshooting and reduces maintenance time.

4.1. Principle Behind the Test

DTF is based on **Time Domain Reflectometry (TDR)**, adapted for RF/microwave systems by transforming frequency-domain reflection data (like return loss or VSWR) into the time or distance domain using an inverse Fourier transform.

The test sends a swept RF signal into the cable and measures the reflected signals that return from any discontinuities. The time delay of these reflections is converted into a physical distance using the cable's **velocity factor** — a constant that represents the speed of the signal through the cable as a percentage of the speed of light.

The core equation is:

$$Distance (m) = \frac{v_f \times c \times t}{2}$$

Where:

- v_f is the velocity factor (e.g., 0.66 to 0.88 depending on the cable),
- c is the speed of light ($\approx 3 \times 10^8$ m/s),
- t is the round-trip time,
- Division by 2 accounts for the round trip.

4.2. Test Setup

Required Equipment:

- Cable and Antenna Analyzer with DTF mode
- Precision RF connectors or adapters
- **Shorted or open termination** at the far end (for full reflection)
- Cable datasheet to get the exact velocity factor (v_f)

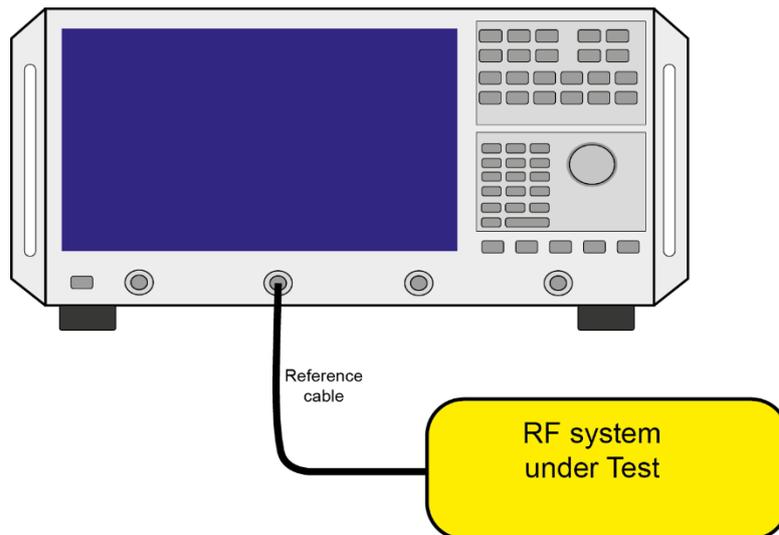


Figure 6 – DFT – RF System under test

4.2.1. Procedure:

1. **Calibrate** the analyzer at the end of the test cable (with Open, Short, Load standards).
2. Set the **frequency range** wide enough to provide sufficient resolution and distance range (the higher the frequency range, the better the distance resolution).
3. Enter the correct **velocity factor** for the cable under test (from manufacturer specs).
4. **Connect the cable** to the analyzer and leave the far end open or shorted — this ensures strong reflection from the end.
5. Run the **DTF sweep** — the analyzer sends multiple frequencies, measures reflections, and converts them to a plot of reflection vs. distance.

4.2.2. Understanding the Output

The analyzer will display a **DTF trace**, which looks like a one-dimensional map of the cable with peaks showing reflection intensity at different distances.

Key elements of the output:

- **X-axis:** Distance from the analyzer (in meters or feet)
- **Y-axis:** Reflection magnitude, usually shown in return loss (dB) or VSWR
- A **flat, low-level trace** indicates no significant reflections (a healthy cable)
- **Peaks on the trace** indicate impedance discontinuities, such as:
 - Connector faults
 - Bends or crush points
 - Moisture ingress
 - Partial shorts or opens
 - The cable's physical end (highest peak if terminated with open/short)

For example, if you see a large reflection at 12 meters, this could correspond to a damaged connector, or a poorly seated jumper, especially if the cable length is longer.

4.2.3. Do You Need Special Termination?

- **Yes** — for accurate DTF, you must **leave the far end open or shorted** intentionally. This provides a clear, strong reflection from the end of the cable.
- Avoid using a matched load, as it absorbs the signal and prevents a measurable reflection from the end.

Note: The open or short condition is intentional here, unlike in return loss or insertion loss tests where matched termination is essential.

4.2.4. Best Practices and Considerations

- **Use the correct velocity factor (VF)** from the manufacturer — even small inaccuracies can significantly affect distance calculations.
- Use **appropriate distance range settings** to cover the full length of the cable without sacrificing resolution.
- **Resolution bandwidth** is tied to the frequency span — a wider span improves resolution (e.g., identifying faults 0.5–1 meter apart).
- Ensure **connectors are tight and clean**, and don't move the cable during testing.
- Take multiple sweeps for repeatability and compare to baseline installation data, if available.

Example Interpretation

Let's say you're testing a 30-meter LMR-400 cable with a velocity factor of 0.85. The DTF plot shows a reflection spike at approximately 14.5 meters. You suspect a connector issue midway. Physically inspecting the cable at that point reveals a partially seated connector — confirming the fault indicated in the test.

5. Passive Intermodulation (PIM) Test – Detailed Overview

Passive Intermodulation (PIM) is a critical concern in high-frequency communication systems, particularly in cellular networks, DAS (Distributed Antenna Systems), and broadcast infrastructure. Unlike active intermodulation (which originates from nonlinear active devices), **PIM is generated by passive components** — cables, connectors, antennas, and mounts — due to slight imperfections, corrosion, poor materials, or improper assembly.

These nonlinearities cause two or more high-power tones to mix and generate **undesirable spurious signals** at predictable frequencies. These intermodulation products can **fall within receive bands**, causing self-interference and degrading signal quality, coverage, and throughput.

5.1. Principle Behind the Test

The basic concept is to inject **two high-power test tones (f_1 and f_2)** into the cable system and monitor for **intermodulation products**, especially the **3rd-order PIM** ($2f_1 - f_2$ and $2f_2 - f_1$), which are the most harmful.

For example, if:

- $f_1 = 900$ MHz
 - $f_2 = 901$ MHz
- Then:
- 3rd-order PIM = 899 MHz and 902 MHz

These fall very close to the transmit or receive band and can interfere directly with RF performance.

PIM is typically expressed in:

- **dBm** (absolute value of the spurious signal)
- **dBc** (relative to the carrier tones)

Lower PIM values (e.g., -110 dBm or -120 dBc) are better.

5.2. Test Setup

Required Equipment:

- PIM analyzer or portable PIM tester
- **Two-tone RF source** (typically 20W or higher per tone)
- **Precision loads and filters** to isolate and suppress harmonics
- **RF-safe test environment** (to avoid radiated PIM)
- High-quality, torque-verified test cables and adapters

5.2.1. Procedure:

1. **Connect the PIM test equipment** to the coaxial cable under test, ensuring all test ports are clean and connectors are torqued to spec.
2. Select the **appropriate test frequency band** matching the system (e.g., 900 MHz for GSM, 1800 MHz for LTE).
3. Inject **two high-power test tones** into the cable (usually between 2×20 W and 2×40 W).
4. Use a highly sensitive receiver to scan for **intermodulation products**, especially the 3rd-order signals.
5. Monitor the result live or record for analysis.

This test is often conducted with the far end of the cable terminated in a **low-PIM load**, although **open-end PIM testing** may be used to localize faults via reflection (less common).

NOTE: please follows the instructions in the PIM test equipment manual, specially regards the maximum input signal in the equipment.

5.2.2. Understanding the Output

A typical PIM analyzer displays:

- PIM level (dBm or dBc) versus time
- **Pass/fail status** based on threshold criteria (e.g., < -107 dBm = Pass)
- Optional **distance-to-PIM** localization (in advanced equipment)

Example Output:

- 3rd-order PIM: -120 dBm (excellent)
- PIM: -98 dBm (fail for most LTE networks)
- Distance-to-PIM: 4.8 meters (localized reflection due to damaged connector)

If PIM is detected above threshold, it usually suggests:

- Loose or poorly torqued connectors
- Dirty or oxidized contact surfaces
- Poor-quality materials (brass, dissimilar metals)
- Mechanical stress (bent cable, overtightened clamps)

Special Considerations and Best Practices

- **Always clean and inspect** connectors using proper tools before testing.
- **Use torque wrenches** to meet manufacturer specifications (e.g., 8–12 in-lbs for 7/16 DIN connectors).
- **Avoid unnecessary adapters**, which are frequent PIM sources.
- **Use certified low-PIM components** — including test cables, loads, and antennas — rated below -155 dBc or better.
- **Minimize movement and vibration** during testing, as PIM can be dynamic (a phenomenon called “dynamic PIM” or “walking PIM”).

Also, keep in mind that **PIM is cumulative**: if multiple minor issues exist, they can combine to push PIM levels over the failure threshold.

5.2.3. When and Why to Use the Test

PIM testing is often required:

- During new installations (e.g., carrier networks or public safety systems)
 - During troubleshooting of uplink noise issues
 - In maintenance of systems where receiver sensitivity is mission-critical (e.g., airports, base stations, emergency services)
-

5.2.4. PIM Performance Reference Table

Table 2 - PIM Performance Reference Table

PIM Level (dBm)	PIM Level (dBc)	Interpretation
-120 dBm	-140 dBc	Excellent (typical spec limit)
-110 dBm	-130 dBc	Acceptable in many cases
-100 dBm	-120 dBc	Borderline
-90 dBm	-110 dBc	Failing – investigate source
> -85 dBm	> -105 dBc	Serious issue – retest needed

Cellular operators often specify minimum PIM thresholds of -107 dBm (-127 dBc) or lower for passive infrastructure.

5.3. Structural and Grounding-Induced PIM: The Hidden Interference Sources

While coaxial cables, connectors, and antennas are the most obvious suspects in Passive Intermodulation (PIM) issues, **non-RF structural elements** such as tower hardware, mounting brackets, grounding straps, and even rusted bolts can also become significant PIM sources. This form of **external or radiated PIM** is particularly challenging because it originates outside the direct signal path — yet still produces harmful intermodulation products that can fall into the receive band and degrade system performance.

PIM arises when **RF energy couples into non-linear junctions**, which can exist anywhere there is:

- Contact between dissimilar metals
- Loose mechanical connections
- Corroded or oxidized surfaces
- Poorly bonded or improperly installed **grounding hardware**

For example:

- A galvanized steel bracket supporting an antenna, if poorly torqued, can generate strong PIM.
- A grounding lug or braid with loose contact may introduce non-linear effects, especially when subjected to RF leakage or near-field exposure.
- A bolt connecting a rusted antenna frame to the tower may act as a passive diode — creating a mixing point for high-power signals.

These non-linear junctions **do not need to be in the direct RF path**. If they are **within the radiating near-field** of high-power signals (often within 1–2 meters of antennas or feeder cables), they can reflect and re-radiate intermodulation products back into the system — especially in base station sites with high transmit power.

5.3.1. Symptoms and Troubleshooting

PIM from metallic structures often manifests as:

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- High and **intermittent PIM levels** (e.g., weather-dependent or vibration-induced)
- Uplink noise that increases when the wind blows or when the site is under mechanical stress
- Consistent failure of PIM tests even after replacing cables, connectors, or antennas

To troubleshoot structural PIM:

- Temporarily **remove or isolate** grounding braids, brackets, or bolts near antennas and repeat the test.
- Use **distance-to-PIM** analysis (if your test set supports it) to localize the source of intermodulation.
- Apply **non-PIM grease** or corrosion inhibitors to suspect metal junctions.
- Ensure all metallic interfaces are **tightened to spec** and well bonded.

Best Practices to Minimize Structural PIM

- Use **PIM-rated grounding kits** and mounting hardware.
- Avoid using dissimilar metals unless properly bonded.
- Inspect all mechanical junctions for **corrosion, oxidation, and wear**.
- Keep the **area around antennas clean** — even small metal debris (e.g., a forgotten wrench or wire tie) can become a PIM source.
- Use **star washers or bonding straps** to maintain pressure and conductivity in bolted joints.

5.3.2. Conclusion: PIM Is a System-Level Problem

PIM is not just a cable or connector issue — it is a **system-level problem**. Even the best coaxial components cannot compensate for poor installation practices, corroded hardware, or improperly grounded towers. Recognizing the role of structural elements in generating PIM is vital for maintaining high-performance wireless systems, particularly in densely packed sites where carriers use wide bandwidths, carrier aggregation, and advanced MIMO techniques.

Proactive site design, rigorous installation standards, and regular PIM testing — including checks of non-RF structures — are essential for minimizing interference and ensuring long-term signal integrity.

6. Final Conclusion: Precision Testing as the Backbone of Coaxial Cable Reliability

In modern RF, broadcast, and wireless communication systems, the performance of coaxial cables is far more than a passive detail — it is a critical pillar that supports the entire signal chain. Reliable signal transmission, minimal reflection, and clean spectral environments all depend on the quality and integrity of the physical transmission medium.

A comprehensive testing strategy that includes **Return Loss, Cable Loss, Distance to Fault (DTF)**, and **Passive Intermodulation (PIM)** provides a holistic view of cable health — from

electrical performance to mechanical integrity and nonlinear interference risks. Each test offers a unique diagnostic perspective:

- **Return loss** reveals impedance mismatches and reflective discontinuities.
- **Cable loss** confirms whether attenuation remains within expected parameters for a given frequency and length.
- **DTF** allows precise localization of faults such as pinched cables, water ingress, or connector issues.
- **PIM testing** detects the often-hidden but highly disruptive nonlinearities introduced by poor materials, loose contacts, or even tower hardware.

Importantly, effective testing is not only about instruments — it is about **procedure, discipline, and system awareness**. The best tools in the world cannot compensate for an uncalibrated setup, poor grounding practices, or uninspected corrosion in mounting brackets. As discussed, **structural PIM** caused by oxidized bolts, grounding straps, and dissimilar metals near RF elements is a serious and frequently overlooked source of performance degradation.

With the right test equipment, training, and standards of care, technicians and engineers can identify and resolve problems before they impact service quality — ensuring that coaxial cable infrastructure operates efficiently and meets the increasingly demanding specifications of today's RF systems.

Ultimately, **precision in coaxial cable testing translates into reliability, performance, and long-term system value**. Whether installing new systems, performing maintenance, or troubleshooting unexpected interference, these test methodologies provide the foundation for confident, high-performance RF deployment.

Paulo Sigrist is a senior management professional with over 30 years of experience in telecommunications and urban infrastructure, specializing in smart city technologies and complex urban system integration.

7. Appendix A: Modern Test Equipment for Coaxial Cable Testing

7.1. Return Loss & Cable Loss Test

These tests are typically performed using **Vector Network Analyzers (VNAs)** or **Cable & Antenna Analyzers**.

Common Equipment:

- **Anritsu Site Master Series** (e.g., *S331P*, *S332E*)
Compact, field-ready cable and antenna analyzers with return loss, VSWR, and DTF capabilities.
- **Keysight FieldFox RF Analyzer** (e.g., *N9912A*, *N9914A*)
Rugged portable analyzers offering full 2-port VNA capabilities for insertion loss and return loss.
- **Rohde & Schwarz ZPH Cable Rider**
Lightweight, field-optimized analyzer with excellent RF performance and intuitive interface.
- **VIAVI CellAdvisor** (e.g., *JD720C*)
Field analyzer that includes cable loss, return loss, and sweep tests, often used in cellular site maintenance.

7.2. Distance to Fault (DTF) Test

DTF is typically integrated into the same instruments used for return loss and cable loss but utilizes the **TDR function in frequency domain**.

Same Equipment as Above, but explicitly supporting DTF:

- **Anritsu S332E / S362E**
- **Keysight FieldFox N9913A (with DTF option)**
- **VIAVI JD720B/C**
- **R&S Cable Rider ZPH**

These tools allow the user to input **velocity factor**, perform **frequency sweeps**, and convert reflections into distance-domain plots.

7.3. Passive Intermodulation (PIM) Testing

PIM requires dedicated high-power, two-tone analyzers with ultra-sensitive receivers.

Common Equipment:

- **Anritsu PIM Master Series** (e.g., *MW82119B*)
Highly portable, battery-powered PIM analyzers for 700 MHz to 2600 MHz, with **Distance-to-PIM (DTP)** capabilities.
- **Kaelus IQA / iXA Series**
Bench and field PIM analyzers supporting multiple frequency bands, often used in telecom carrier acceptance testing.
- **Rosenberger PIM Analyzer**
High-performance test benches used for lab-grade and field-level PIM testing (including modular systems).
- **CommScope PIM Testing Kits**
Commonly used for base station and DAS certification with carrier-specific configurations.

7.4. Optional Accessories and Supporting Tools

- **Torque wrenches** (e.g., Times Microwave, Amphenol) – Essential for proper connector installation.
- **Calibration kits** – Open/Short/Load (OSL) kits matched to connector type (e.g., N, 7/16 DIN, SMA).
- **Low-PIM test cables and loads** – Rated to at least -155 dBc for accurate PIM testing.
- **Connector inspection microscopes and cleaning tools** – From companies like *VIAVI, AFL, and Fluke*.

7.5. Note for Selection

- **For field work**, rugged analyzers like the Anritsu Site Master or Keysight FieldFox are ideal.
- **For lab testing or detailed diagnostics**, full VNAs (e.g., Keysight E5071C or R&S ZNB) offer greater precision.
- **For PIM**, ensure the system supports the required **band and power level**, and always use **certified low-PIM accessories**.

8. Appendix B: Comparison: Coaxial vs. Twisted Pair Cables in Testing and RF Performance

In terms of frequency handling and signal type, coaxial cables are engineered specifically for the transmission of high-frequency RF signals, often extending into several gigahertz. Their unique concentric construction — with a central conductor surrounded by a dielectric insulator, shielding, and an outer jacket — provides excellent electromagnetic isolation. This results in low-loss signal transmission, high bandwidth capability, and strong resistance to external interference, making coaxial the preferred choice in RF, broadcast, and analog communication systems.

Twisted pair cables, including standards like Cat5e, Cat6, and Cat8, are primarily designed for baseband digital applications such as Ethernet, DSL, and telephony. These cables function effectively in the megahertz range, with Cat8 supporting up to around 2 GHz under controlled conditions. Rather than relying on shielding, twisted pair cables use differential signaling and the twisting of conductor pairs to counteract crosstalk and external EMI. While effective for digital signals over short to medium distances, this design is not suitable for analog or continuous-wave RF signals.

One critical distinction is the potential for wiring errors. Twisted pair systems are more prone to pin assignment issues and pair swapping — a common fault during field installation or manual termination. Because signal integrity depends on precise matching of transmit and receive pairs, any misalignment can severely impact performance or prevent operation entirely. Coaxial cables, with their single-conductor structure, are immune to this type of wiring fault.

Overall, coaxial cables offer superior performance in high-frequency, analog, and RF environments, while twisted pair cables remain a practical and efficient solution for digital data transmission within defined limits.

8.1. Return Loss and Impedance Matching

- **Coaxial Cables** are sensitive to impedance mismatches. Return loss testing is crucial to identify reflection points, especially in RF systems, where mismatches degrade signal quality and can cause standing waves.
- **Twisted Pair Cables** also require impedance matching (typically 100 ohms), but the effect of minor mismatches is less severe due to the digital nature of most signals. Return loss is tested as part of **cable certification** using time-domain reflectometry (TDR) or network analyzers.

8.2. Cable Loss and Attenuation

- **Coaxial Cable Loss** increases with frequency and length, and varies by cable type (e.g., RG-6 vs. LMR-400). Loss testing is typically done using a **swept frequency test** and requires precise calibration.

- **Twisted Pair Loss** (insertion loss) is tested during cable certification (e.g., with Fluke testers). Since most applications are digital, the concern is maintaining signal integrity above the noise margin, not absolute linearity.

8.3. Fault Localization (Distance to Fault)

- **Coaxial Cables** use **frequency-domain reflectometry (FDR)** for distance-to-fault (DTF) measurements, often integrated into RF analyzers.
- **Twisted Pairs** use **time-domain reflectometry (TDR)** to locate opens, shorts, and split pairs.

8.4. Passive Intermodulation (PIM)

- **Coaxial Systems** are vulnerable to **PIM**, especially in high-power RF environments (e.g., cellular base stations). PIM testing is critical to ensure nonlinearities from connectors, cables, or tower elements don't cause signal distortion.
- **Twisted Pair Systems** do **not experience PIM**, as they operate in digital mode and at lower frequencies and powers. The concern is typically EMI or crosstalk, not nonlinear mixing products.

8.5. Shielding and Susceptibility

- **Coaxial** has a grounded shield around the center conductor, offering excellent protection from external EMI and enabling use in noisy RF environments.
- **Twisted Pair** relies on differential signaling and twisting geometry to cancel out noise. Shielded versions (STP, FTP) add extra EMI protection but still don't match coaxial shielding effectiveness.

8.6. Summary Table

Table 3 – Summary table

Aspect	Coaxial Cable	Twisted Pair Cable
Frequency Range	Up to GHz (RF, analog/digital)	Up to 2 GHz (digital)
Return Loss Sensitivity	High	Moderate
Cable Loss Testing	Frequency-dependent, complex	Standardized, easier
Fault Location Method	Frequency-domain reflectometry	TDR-based (time domain)
PIM Susceptibility	Yes (critical)	No
Shielding Effectiveness	Very High	Moderate to High (with STP)
Typical Applications	RF, broadcast, cellular	Ethernet, DSL, VoIP