MoP guidelines for I&M of 4G and 5G cell sites

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VIAVI Solutions

Document objectives

VIAVI Solutions aims at sharing best practices and help improving the quality of cellular network installations.

In order to achieve optimum performance of 4G & 5G cell site transmission system, it is essential that all critical components of a network be installed and maintained to the highest standards, within practical means.

Antennas, coaxial and optical fiber cables, including connectors, diplexers and other elements are constantly exposed to the elements. Any degradation in the antenna system can directly impact the radio link, resulting in call setup failures, handover failures, degraded quality, or dropped calls.

The tests described in the following sections are suggested to ensure that antennas, cables and any additional tower mounted elements along with the fronthaul and backhaul connectivity perform to required specifications prior to the integration of a new cell site to the network.

For sites already on-air, the tests can also be used for troubleshooting problems.

This document comprises a choice of different method of procedures (MoP) and acceptance requirements to ensure the quality of 4G and 5G transmitted signals, antenna alignments, coax and optical fiber systems. The adoption of any of the suggested tests, should include on the use of standard setup and calibration techniques to establish the necessary criteria that determine the validity of the antenna systems being tested.

Document version

July 2020 v1.0	• **First released version**
Jan 2021 v2.0	• **Addition of PIM detection procedures**

Content index

Installation MOP guidelines

1. Antenna Alignment Procedures

1.1. Importance of antenna alignment


Small Cell


Panel


Microwave

During installation of a cell site, antenna alignment procedures are a critical requirement to ensure the radiating elements in the base-station (small cell, cellular tower and/or microwave links) will perform in terms of coverage and propagation as per the original plan and design of the network. Otherwise, it will result in coverage gaps, network performance degradation and loss of revenue.

Antenna alignment procedures must include a validation during installation of Azimuth, Tilt and Roll target values (typically in degrees) as specified during the RF design and planning stage.

GNSS-based antenna alignment tools remove any uncertainty errors and discrepancies produced by other methodologies like the ones based on magnetic compasses or smart-phone applications.

Antenna alignment is even more critical with the new generation of 5G massive MIMO antennas given these are now transmitting multiple reference signals in the form of reference beams and in very narrowband direction angles that define the actual coverage of the new 5G cell sites. This means for example a misaligned azimuth would negatively impact the distribution of the radiated beams and reduce the coverage and performance of the cell site. This is a fundamental difference compared to previous cellular generations that would be typically broadcasting one single reference signal per site antenna through its entire sector.

Regular monitoring of antennas misalignment is also strongly recommended in locations where cell sites are exposed to harsh climate conditions, including strong windstorms, heavy loads of rainfall or snow, seismic movements, etc. Continued monitoring of azimuth, tilt, or roll variations is made possible through use of available IoT devices attached to the back side of panel antennas that can provide around-the-clock remote monitoring and alarm reporting to any centralized assurance tool of choice through the use of an API function.

1.2. Attachment of the alignment tool to the antenna

1.2.1. Cellular panel antenna

Secure a correct attachment of the alignment tool to the antenna panel using the instrument vendor recommendations. The example in this picture shows the use of a universal strap mounting clamp that allows to wrap the webbing straps tight around the antenna and mount the tool onto the clamp.

Always try to place the alignment tool for this type of antennas on the top part of the panel antenna to have a clear view of the sky, and to avoid multipath issues or signal blockage.

1.2.2. Microwave dish antenna

Secure a correct attachment of the alignment tool to the antenna dish using the instrument vendor recommendations. The example in this picture, shows the use of a lip mounting clamp that allows to mount the tool onto the plate at the top of the dish.

Always try to place the alignment tool for this type of antennas on the top part of the dish to have a clear view of the sky, and to avoid multipath issues or signal blockage.

1.3. Antenna alignment procedures

The following steps are recommended for an effective antenna alignment operation:

- Always try to place the alignment tool at the top part of the antennas to have a clear view of the sky and to avoid multipath issues or signal blockage.
- Use the top antenna cover or antenna top mechanical bracket, as an alignment reference for the clamp installation.
- Confirm GNSS satellite coverage in the alignment tool and Azimuth acquisition.
- Set any designated antenna alignment thresholds which usually are carrier defined and represent the tolerance accepted for each of the alignment target measurements.
- If ground level height is required, as an option use a laser range finder for integrating an accurate ground level height measurement into the final antenna alignment report.
- Introduce into the alignment tool the related site information including the following references: Side ID, Sector, Antenna tag (e.g. serial number), designated target Azimuth value (per planning), designated target Tilt value (per planning) and designated Roll value (per planning).
- Manually move the panel antenna until the alignment tool confirms that the current azimuth, tilt and roll values match the designated target values. Firmly tight the antenna to its anchors at this point.
- Save the measurements and view the report on the alignment tool that confirms the antenna position is within targets in terms of location azimuth, tilt and roll like shown in the following example:

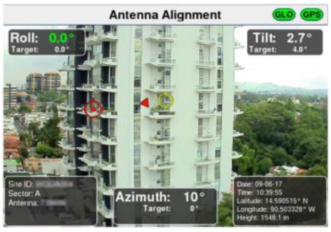
Antenna Alignment Report: DF6380

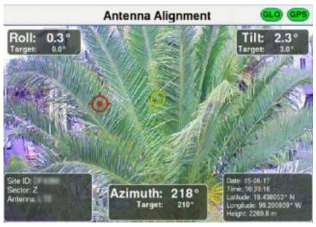
		Target			Measured									
Sector	Antenna	Azimuth	Tilt	Roll	Azimuth	Tilt	Roll	Height	Height Type	Latitude	Longitude	Date	Time	Image Name
X	LTE	80	3.0	0.0	79	1.8	0.2	2269.8 m	GPS AMSL	19.438133	-99.200394	Jun 15, 2017	10:23:50 AM	52RFA066
Z	LTE	210	3.0	0.0	218	2.4	0.2	2269.8 m	GPS AMSL	19.438053	-99.200806	Jun 15, 2017	10:30:16 AM	52RFA067
Z	LTE	210	3.0	0.0	218	2.9	0.2	2270.1 m	GPS AMSL	19.438049	-99.200813	Jun 15, 2017	10:50:33 AM	52RFA068
Z	UMTS	210	3.0	0.0	218	3.4	0.8	2270.2 m	GPS AMSL	19.438047	-99.200813	Jun 15, 2017	10:09:24 AM	52RFA069
X	UMTS	80	3.0	0.0	79	3.3	0.3	2268.4 m	GPS AMSL	19.438129	-99.200394	Jun 15, 2017	11:12:41 AM	52RFA070
Y	LTE	160	2.0	0.0	171	0.8	0.8	2268.6 m	GPS AMSL	19.437901	-99.200409	Jun 15, 2017	11:35:36 AM	52RFA071
Y	LTE	160	2.0	0.0	181	1.9	0.9	2268.9 m	GPS AMSL	19.437895	-99.200409	Jun 15, 2017	11:52:32 AM	52RFA072

Model#: 52RFV-2000 Firmware: 2.4.23 Units: Meters (m) Azimuth Threshold: 2 Roll Threshold: 0.0 Position: N-S decimal degrees
Serial#: 19480636 Calibration Exp: 01/01/2017 DATUM: WGS84 Time Zone: (GMT-06:00) Tilt Threshold: 0.0 * Azimuth Offset
Page 1 of 2

- Consider the need to export the antenna alignment report (PDF, CSV and JPG, or any similar file types) for file recording, offline processing and site or activity close out documentation.

- It is recommended the use of antenna alignment tools with integrated cameras that can include a picture of the final alignment results into the report. This provides a visual confirmation of any possible line-of-sight (LOS) obstructions in front of the antenna, that might have not been taken into consideration during design and planning stages, like new building constructions, growing trees, etc.:





1.4. Antenna alignment test flow process

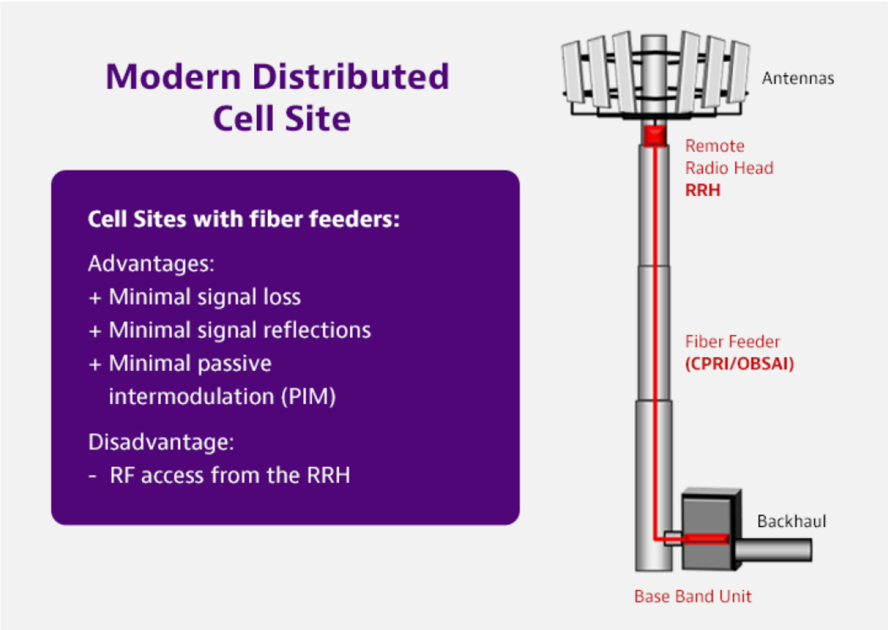
The following flow chart summarize the recommendations for an effective antenna alignment operation:

2. Optical Fiber Verification

2.1. Fiber-to-the-antenna installations

Modern cell sites have evolved from coax-based infrastructure, where generally radio units are installed close to digital equipment at the base of the tower, to fiber-to-the-antenna (FTTA) cell sites, in which radio equipment (remote radio head or RRH, also referred as remote radio unit or RRU) is installed at the top of the tower.

The RRH is connected to the digital equipment (base band unit or BBU) at the base of the tower, through a fiber cable using either CPRI or OBSAI protocol.



Regardless the type of cell-site (macro towers, roof top mounts, small cells or DAS systems) the performance of the optical cabling and components between the RRU (Radio remote Unit) and BBU (Base Band Unit) is key to delivering optimized system performance between the backhaul network and end users.

Fiber micro-bends, macro-bends and dirty connectors are all common problems when installing fiber cable systems in modern cell sites because they induce signal and power loss, permanent damage to cables and components, creating signal transmission errors. Troubleshooting statistics show connector contamination as the number one cause of poor network performance, and mating contaminated fibers is the primary cause of permanent optical component damage.

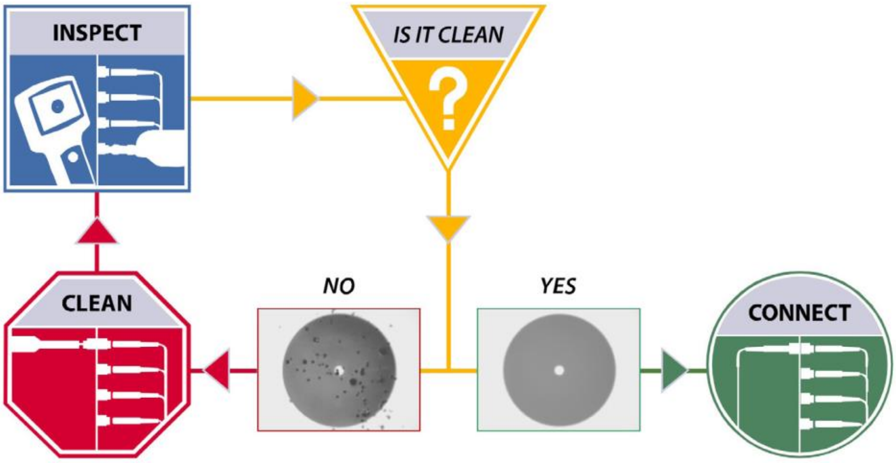
With the current deployment of next generation 5G active antennas the importance of fiber verification is increasing due to the fact these new massive MIMO antennas have the radio and antenna elements tightly integrated in the same system and any coaxial jumpers have been fully replaced with optical fiber links.

Optical Fiber verifications tests may include:

- Optical connector face inspection
- Circuit path verification using visual fault locator (VFL)
- Insertion loss measurements (IL)
- Optical return loss measurements (ORL)
- OTDR testing (bidirectional)

2.1.1. Fiber inspection

Before connecting any fibers together, it is recommended for technicians to inspect and (if necessary) clean all connectors. Failure to inspect and clean prior to mating can cause permanent damage to connectors and may even damage the radio equipment.



To guarantee a common connector performance level, the International Electrotechnical Committee (IEC) created standard IEC-61300-3-35, specifying pass/fail requirements for end face quality inspection before they are connected.

Effective fiber connector inspection can be achieved with portable fiber scopes and a variety of probes in fiber bulkheads and patch cords as shown here, including the most recent MPO connector-types:

The tables below list the acceptance criteria standardized by the International Electrotechnical Commission (IEC) for single-mode and multimode connectors as documented in IEC 61300-3-35 Ed. 1.0.

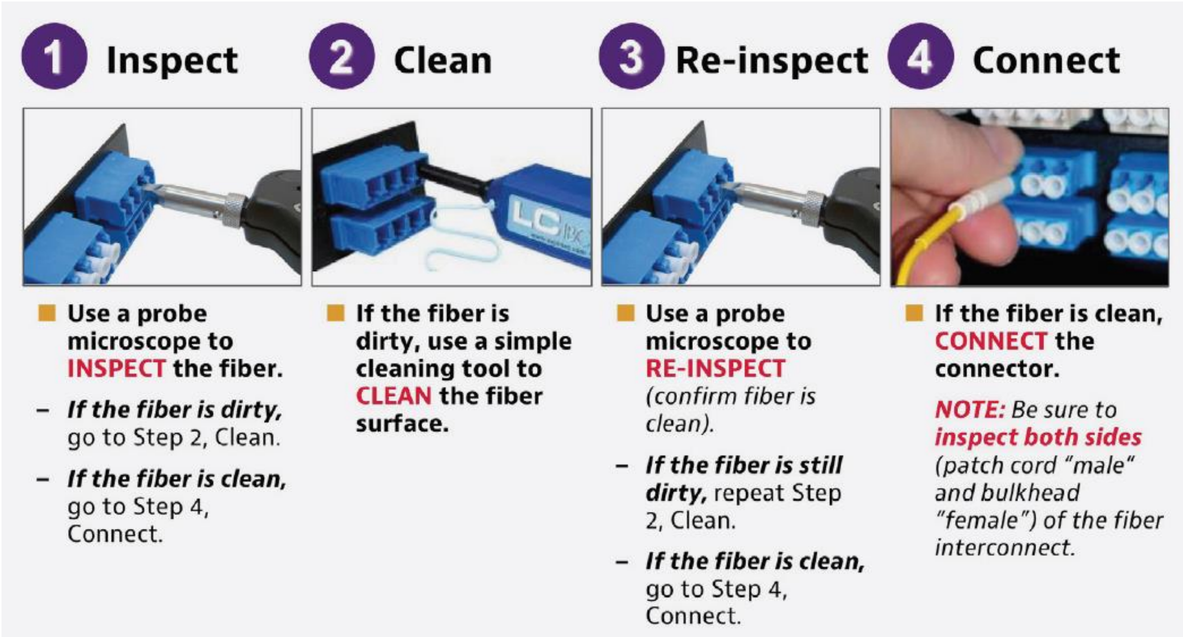
Recommended Acceptance Criteria for SM-UPC Connectors (IEC 61300-3-35 Ed. 2.0)

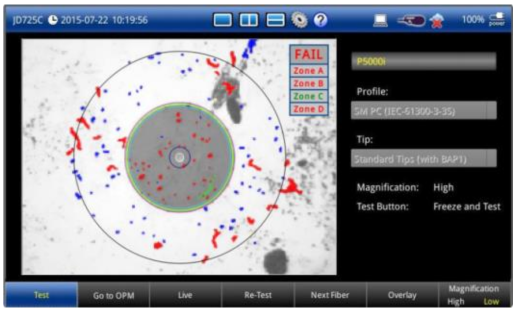
Zone Name (diameter)	Scratches	Defects
A, Core Zone (0-25µm)	none	none
B, Cladding Zone (25-115µm)	No limit ≤ 3µm None > 3µm	no limit < 2µm 5 from 2 - 5µm none > 5µm
C, Adhesive Zone (115-135µm)	no limit	no limit
D, Contact Zone (135-250µm)	no limit	none > 10µm

Recommended Acceptance Criteria for MM-PC Connectors (IEC 61300-3-35 Ed. 2.0)

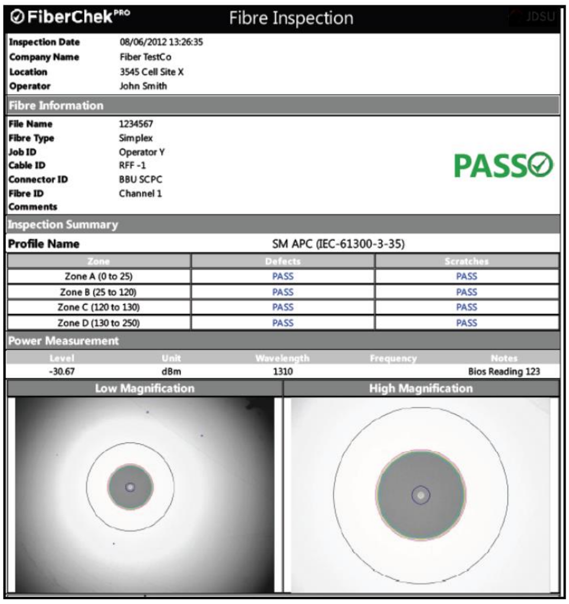
Zone Name (diameter)	Scratches	Defects
A, Core Zone (0-65µm)	No limit ≤ 3µm None > 3µm	4 ≤ 5µm none > 5µm
B, Cladding Zone (65-115µm)	No limit ≤ 5µm None > 5µm	no limit < 5µm 5 from 5 - 10µm none > 10µm
C, Adhesive Zone (115-135µm)	no limit	no limit
D, Contact Zone (135-250µm)	no limit	No limit < 20µm 5 from 20µm to 30µm None > 30µm

When the inspection procedure indicates fiber is dirty above the given acceptance criteria, it must be cleaned using an approved fiber cleaning kit and further inspected until showing within acceptable clean criteria ranges.





A certification report after the fiber inspection procedure is complete it is recommended to be added to the records of the cell site for comissionign:



FiberChek PRO — Fibre Inspection

Inspection Date	08/06/2012 13:26:35
Company Name	Fiber TestCo
Location	3545 Cell Site X
Operator	John Smith

Fibre Information

File Name	1234567
Fibre Type	Simplex
Job ID	Operator Y
Cable ID	RFF -1
Connector ID	BBU SCPC
Fibre ID	Channel 1
Comments	

PASS

Inspection Summary

Profile Name: SM APC (IEC-61300-3-35)

Zone	Defects	Scratches
Zone A (0 to 25)	PASS	PASS
Zone B (25 to 120)	PASS	PASS
Zone C (120 to 130)	PASS	PASS
Zone D (130 to 250)	PASS	PASS

Power Measurement

Level	Unit	Wavelength	Frequency	Notes
-30.67	dBm	1310		Bios Reading 123

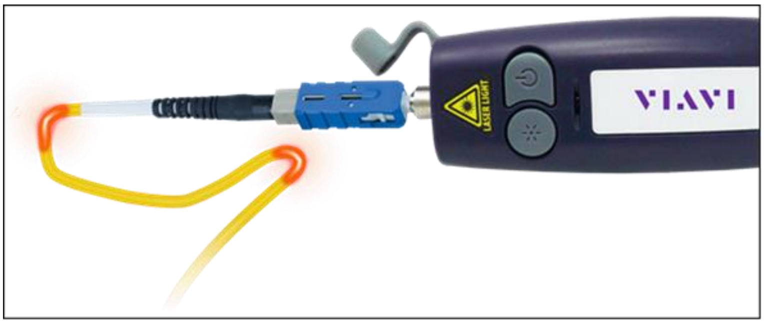
Low Magnification | High Magnification

A typical connector endface certification should include details related to the PASS/FAIL condition in accordance with IEC standards and details related to link and power loss.

2.1.2. Circuit path verification

Testing fiber continuity is recommended for circuit path verification using a visual fault locator (VFL) device.

A visual fault locator (VFL) emits visible light to let the technician easily see light escaping from bends or breaks in the fiber. This simple test is recommended for continuity checking and also to provide a means to identify the correct remote fiber feeder (RFF) cable is routed to the correct RRH port.



2.1.3. Optical power level measurement

The absolute power level (the system power measurement) is the amount of optical power present in the system, measured in dBm. The source of this power is the transmitter or transceiver sending information through the system. This test determines whether the output power of the transceiver is at the correct level or (when tested at the end of the link) to determine if the signal level is within the receiver's sensitivity range.

2.1.4. Optical insertion and return loss measurement

An insertion loss measurement for fiber acceptance test during onsite build is a non-destructive method and is used to measure the attenuation across a fiber, a passive element, or the entire optical link.

This is often required where during the installation phase there is not active equipment provisioning onsite or where cable infrastructure and equipment installs are performed by separate teams.

It is recommended to measure the output from the source fiber and a reference fiber directly. Then, a measurement should be made with the fiber under test added to the system. The difference between the two results provides the attenuation of the fiber.

Attenuation Measurement (optical link loss) on optical components or fiber optic links (for example, fiber connectors, cable assemblies, and installed fiber optic links) are acquired by measuring the relative power level (dB) at the far end of the link or device under test.

Relative Power Level (attenuation measurement) is the amount of power lost (attenuated) by the optical link being tested, measured in dB. The source of this power is typically a handheld optical light source. This test determines whether the optical link is constructed properly, either as a qualification test or when troubleshooting the fiber cabling.

NOTE: It is common practice to make a simple insertion loss measurement using an optical light source (OLS) at the BBU and an optical power meter (OPM) at the RRH/RRU to check the link loss. However, in order to minimize the operations and tools required at the remote end, a loopback device is often used to enable measuring the loss of the entire channel. Both methods are described below:

Optical Budget for SM and MM fibers:

Fiber network element	**Maximum loss (dB)**
Fiber attenuation	0.4 dB/km at 1310nm (SM) 0.3 dB/km at 1550nm (SM) 3,5 dB/km at 850nm (MM) 1,5 dB/km at 1300nm (MM)
Splice Loss SM Fiber MM Fiber	 0.2 dB 0.2 dB
Connector Loss SM Fiber MM Fiber	 0.75 dB 0.75 dB

Optical Budget Calculation

Calculating the optical budget allows the measured insertion to be compared to the expected (calculated) optical insertion loss to determine any anomalies with the link installation.

Add values when qualifying the complete network according to the various elements and wavelengths.

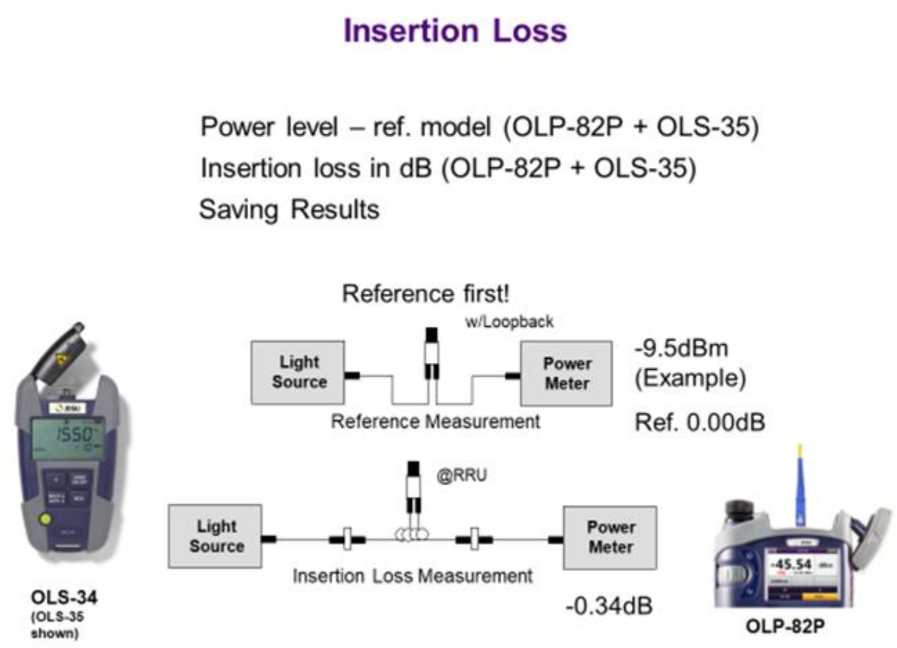
Typical Formula used is: **IL = (LxF)+ (#xS) + (#xC)**

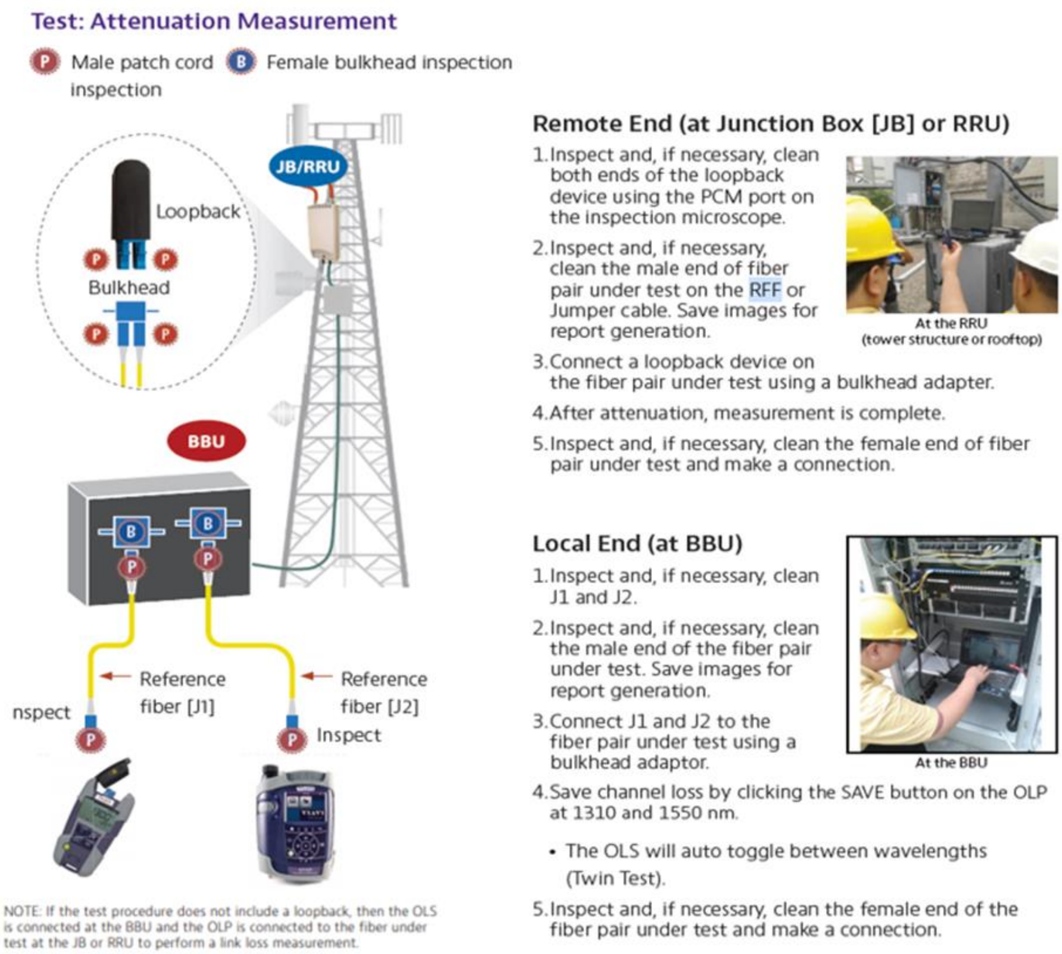
where *L= Length*
F = Fiber Attenuation
 # = Number of elements
S = Splice Loss
C = Connector Loss

<u>Example Link</u>: 200m of fiber (loopback), and 4 connectors at 850nm: <u>IL = 0,2x3,5 + 4x0,75 = 3,7dB</u>

To measure attenuation, you must:

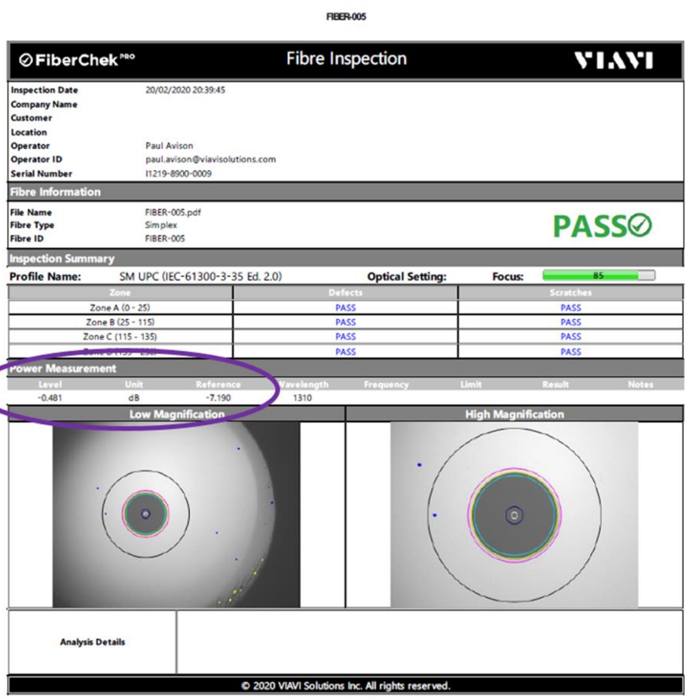
1. Reference the power meter/light source.
2. Insert the device or system under test
3. Measure relative loss compared to the Reference





NOTE: Loss testing of single-mode fiber links is specified in ANSI/TIA/EIA-526-7 and ISO/IEC-TR-14763-3. Loss testing of multimode fiber links is specified in ANSI/TIA/EIA-526-14A and ISO/IEC-TR-14763-3.

Example of a combined report with Power Measurement and Fibre Inspection:



FIBER-005

FiberChek PRO — Fibre Inspection — VIAVI

Inspection Date	20/02/2020 20:39:45
Company Name	
Customer	
Location	
Operator	Paul Avison
Operator ID	paul.avison@viavisolutions.com
Serial Number	I1219-8900-0009

Fibre Information

File Name	FIBER-005.pdf
Fibre Type	Simplex
Fibre ID	FIBER-005

PASS

Inspection Summary

Profile Name: SM UPC (IEC-61300-3-35 Ed. 2.0) Optical Setting: Focus: 85

Zone	Defects	Scratches
Zone A (0 - 25)	PASS	PASS
Zone B (25 - 115)	PASS	PASS
Zone C (115 - 135)	PASS	PASS
[illegible]	PASS	PASS

Power Measurement

Level	Unit	Reference	Wavelength	Frequency	Limit	Result	Notes
-0.481	dB	-7.190	1310				

Low Magnification	High Magnification

Analysis Details

2.2. OTDR testing during cell site construction phase

An **OTDR** (Optical Time-Domain Reflectometer) measures the end-to end optical link loss and provides the optical loss and distance for all other impairments (events) along the fiber.

An OTDR is the only single-ended tool able to measure loss from all of the components along the fiber link such as connectors, splices, micro-bends, and macro-bends; these measurements are critical for correctly characterizing the quality of installation or when fault finding.

The ability to do single-ended measurements can dramatically impact operational costs when constructing or troubleshooting a Fiber-to-the-Antenna (FTTA) network and, in some cases, can prevent unnecessary tower climbs.

2.2.1. Validating Tx and Rx Fibers using a Loopback

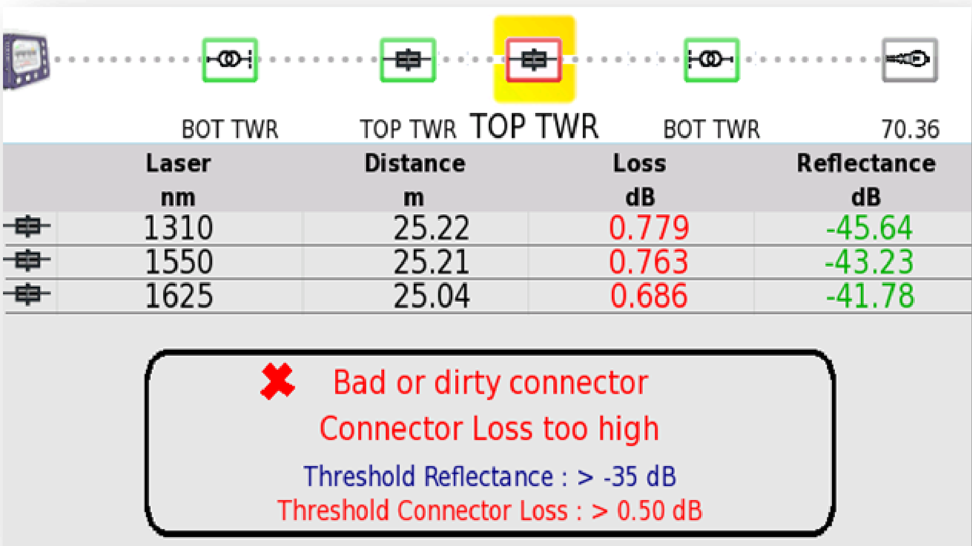
This validation test procedure is recommended during construction stage as part of a commissioning report.

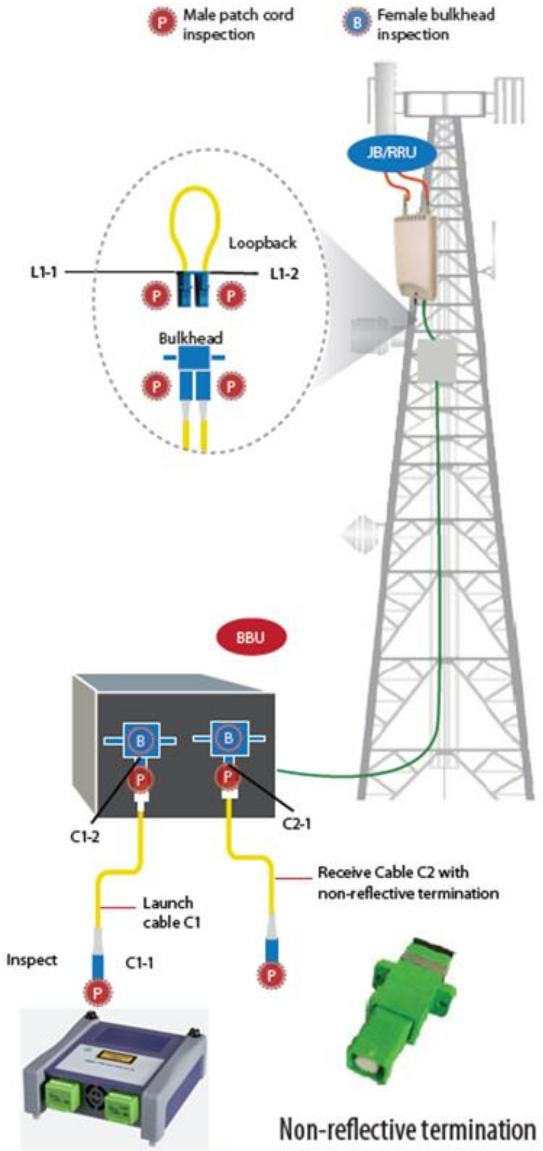
An insertion loss measurement for fiber acceptance test during onsite build is a non-destructive method and is used to measure the attenuation across a fiber, a passive element, or the entire optical link.

During construction, a patch cord loop (e.g. ~20m) is placed on each duplex pair after tower/rooftop installation: a patch cord is looped at the top for a test of the duplex pair. A patch cord allows the two duplex pairs to be measured for loss and reflectance. A launch cable placed between the OTDR testing instrument and the base station connector and a receive cable placed on the far side of the down-loop base station connector (~10m-20m length recommended for each) allows the loss of each of the base station connectors to be measured.

On the far end of the receive cable, a non-reflective terminator or an APC connector is recommended to minimize the reflectance on the far connector.

Recommendations:
- Overall loss should be calculated using the provided formula
- Reflectance per connector should be >-35dB as shown for the following example:





Test the remote end (at junction box JB/RRU at the top of a tower):

1. Inspect and, if necessary, clean connectors L1-1 and L1-2 of the loopback device.
2. Connect the loopback device on the fiber pair under test using a bulkhead adapter.
3. Wait for the end of OTDR acquisition from the BBU.
4. After the OTDR test is complete, disconnect loopback, inspect, and, if necessary, clean the RRU port.
5. Make the connection.

Test the local end (at the BBU at the bottom of a tower):

1. Inspect and, if necessary, clean connectors C1-1 and C1-2.
2. Inspect and, if necessary, clean the first BBU jumper connector.
3. Connect C1-2 to the first BBU jumper using a bulkhead adapter.
4. Inspect and, if necessary, clean the OTDR port.
5. Connect C1-1 to the OTDR port.
6. Inspect and, if necessary, clean connectors C2-1 and C2-2.
7. Inspect and, if necessary, clean the second BBU jumper connector.
8. Connect C2-1 to the second BBU jumper using a bulkhead adapter.
9. Launch OTDR acquisition.
10. Check if results pass or fail (use schematic view).
11. Save results and generate a certification report.
12. Inspect and, if necessary, clean BBU ports.
13. Make the connection.

OTDR modular field test set

2.2.2. Testing Tx or Rx Fibers (No Loopback)

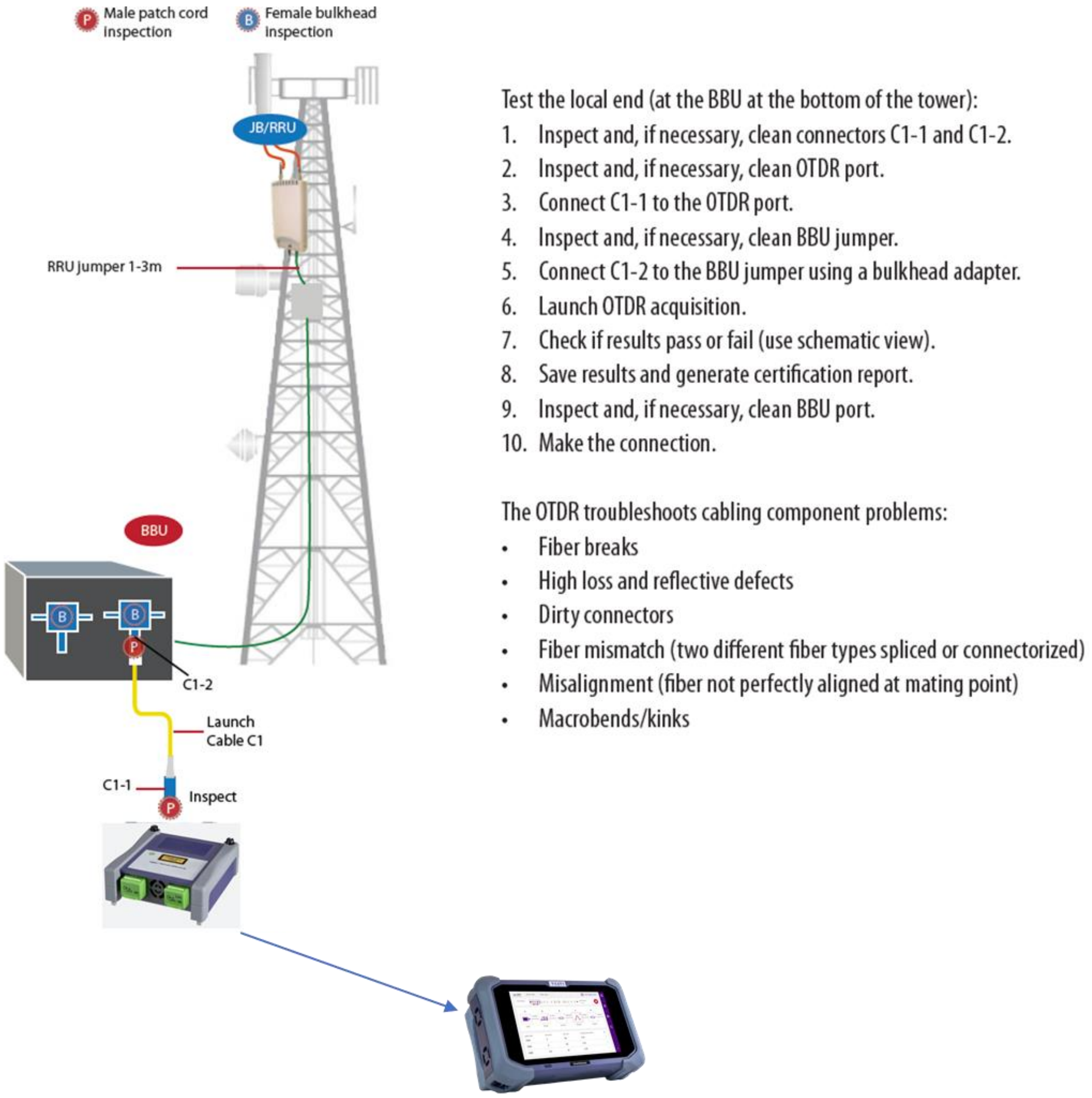
This validation test procedure is recommended during regular maintenance and for troubleshooting purposes.

During the maintenance phase, a launch cable can be placed between the OTDR testing instrument and the base station connector (~10m-20m length recommended for each) allowing the loss and reflectance of the base station connector to be measured. Because of typical limitations for access to the top of a tower/rooftop at the other the far-end, the fiber is usually plugged into the RRU equipment.

This is not a live network testing procedure, meaning before performing the OTDR measurement, the technician needs to make sure that the fiber being tested has no signal and that the equipment is shut down.

Recommendations:

- Overall loss should be calculated using the provided formula
- Reflectance per connector should be >-35dB.



OTDR modular field test set

3. Site synchronization and CPRI Validation

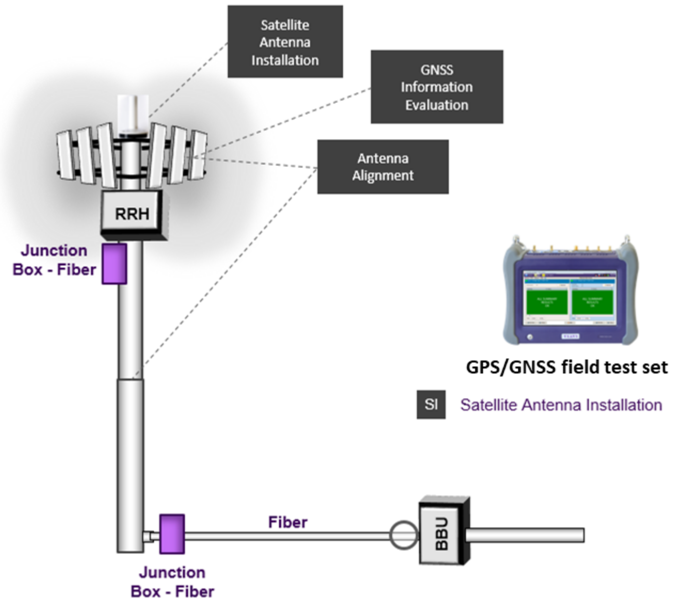
3.1. GNSS / GPS antenna installation validation

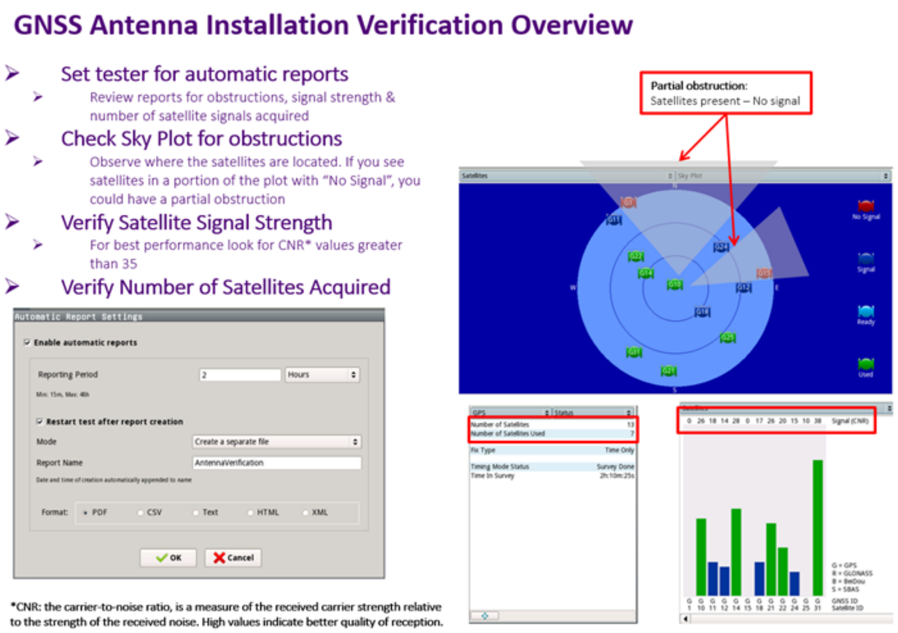
When timing in a cell site is provided via satellite signal, it is critical to verify GNSS/GPS antenna is positioned properly, the antenna cable installation is optimal, and GNSS information is received properly (e.g. error free extraction of UTC, ToD, 1PPS, UTC, location data, etc.)

Note this validation requires a field test set that can check satellite antenna installations including positioning, signal quality and evaluation.

Recommended test procedures:

- Connect GNSS antenna to field test set & start monitoring test procedures
- Monitor signal strength over time (Sky Plot, 24h)
- Record and verify extracted information (Location coordinates, UTC, ToD, 1PPS)





3.2. RRH – BBU connectivity verification and CPRI validation

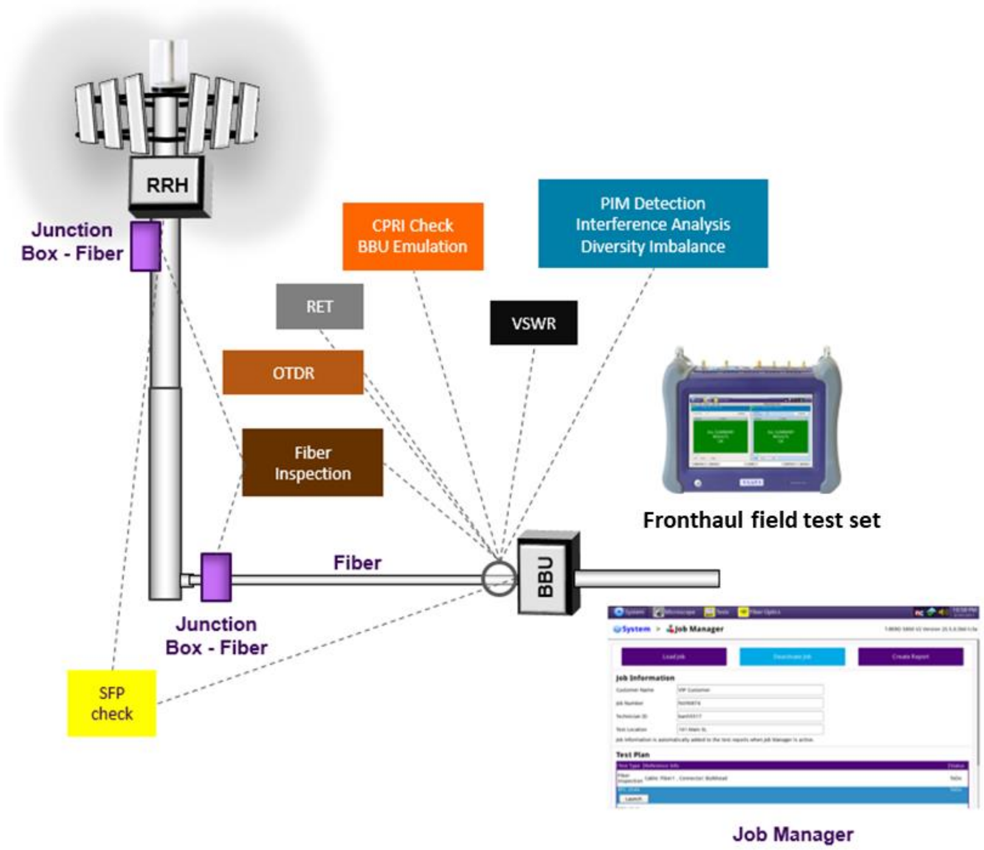
Troubleshooting of FTTA (fiber-to-the-antenna) cell sites often requires verifying BBU - RRH connectivity and evaluate basic system KPIs on fronthaul protocol layers, including active elements like SFP modules in use.

Note this validation requires a field test set that can support a number of the following testing functionalities:

- Read out from SFP vendor type and specific data (e.g. power level, bitrate etc.)
- Perform optics self-test to check SFPs being used in BBU and RRH/RRU for error free checks
    - source CPRI/eCPRI with BERT payload to verify BER
    - emulate BBU-RRH user plane communication to check more details (e.g. RTD, spectrum)
    - run monitor mode and capture CPRI protocol for offline decode

Recommended test procedures:

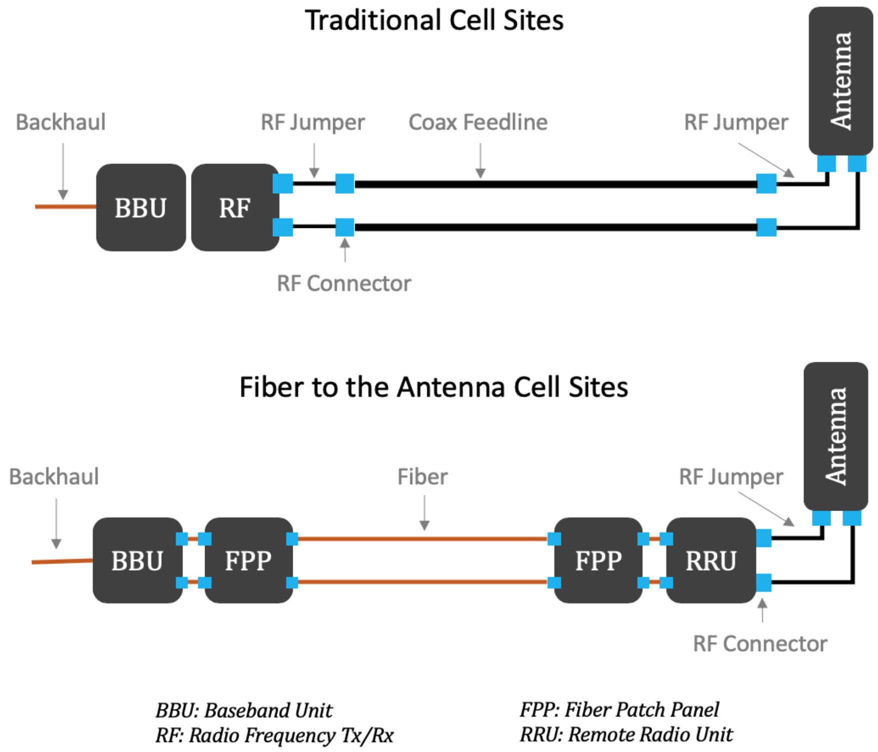
- **BBU / RRU SFP in test set and perform optics self-test**
- BBU SFP in test set, connect fiber perform CPRI/eCPRI BERT (loop testing) & verify BER
- CPRI check & BBU Emulation (ALU only, RRH FW, SFP type & SN)
- RFoCPRI for PIM detection, check VSWR, RET
- Use Monitor Mode to capture CPRI / eCPRI protocol for offline decode & analysis



RF RFoFiber Analysis – PIM Detection, Diversity Imbalance
C CPRI Check & BBU Emulation – RRH firmware, SFP type, Serial #
CB CPRI BERT
R RET Test – read and adjust angles
V VSWR Test

4. Cable and Antenna System Verification

4.1. Coaxial Cable & RF Jumpers



Coaxial cables and RF jumpers are used as a transmission line for radio frequency signals.

These coax-based systems are still common in legacy base-stations, passive/analog DAS and in modern cell sites for connecting RRU units to the antenna elements at the top of the macro towers.

This category will include other RF elements in the feeder line with different transmission roles, for example:

- Amplifiers, including tower-mounted amplifiers (TMA)
- Splitters, Couplers and Duplexers
- Connectors and adapters
- Attenuators
- Filters

Line sweeping measures signal attenuation or insertion loss and return loss as a function of frequency. Once the measurements indicate an issue with the line, then sweeping is also used to estimate the physical location of a fault or damage along the transmission line using the distance-to-fault (DTF) measurement available on many RF and microwave signal analyzers.

A complete system sweep testing consists of several tests such as Return Loss and Distance to Fault (DTF).

Return loss is a frequency domain sweep and is a measurement of the match between RF components. DTF is a time domain sweep (vs. distance) and is a measurement for pinpointing the location and reflection amplitude of a transmission line and associated component and connection. It is primarily used for troubleshooting after return loss sweep fails.

4.2. Coax Sweep Test Scenarios

The functionality of an antenna system, i.e. antenna, feeder & jumper cables, and TMA (tower mounted amplifier), is determined by these basic tests, which are based primarily on the impedance of the system:

- VSWR/Return Loss
- DTF (Distance-To-Fault)
- Insertion Loss

Note: all screenshots and sweep log files should be stamped with measurement date and time.

Test equipment shall be allowed to stabilize in the test environment prior to calibration for an specified period of time, and shall be recalibrated every given time and after any change in environment, to ensure accuracy.

Sweep test must be performed for each line. The sector being tested should be shut off, to prevent spurious transmissions from polluting the test results. No sweeps will be passed that show interference from nearby antennas. All tests for a given line must be from the same date.

4.2.1. Reflection verification of Antenna (verify antenna quality)

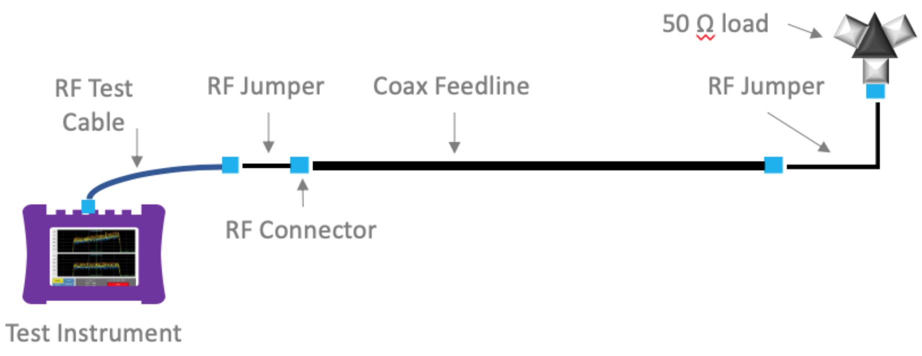
This procedure is recommended for all antennas including new and reused ones. Testing all antennas before mounting onto the antenna support structure eliminates any possibility of rework and cost that may occur due to a faulty antenna. Testing should include all the antenna ports and cover for all operating frequency bands.

Configure the sweep test instrument for **RETURN LOSS or VSWR** by either recalling the saved reflection test setup for a frequency band of interest or start a new measurement procedure according to your instrument.

Note: it is recommended conducting a fresh calibration at the end of the test port cable before proceeding.

4.2.2. Reflection verification of Feedlines (verify cable system quality)

This procedure is recommneded for all feedlines (coaxial cable using 50-ohm) by connecting a 50-ohm LOAD standard at one end of the coaxial cable, like shown here:



Any feedline impedance impairment will reflect signal back to the test instrument and will be represented as a high return loss or VSWR when conducting sweep test.

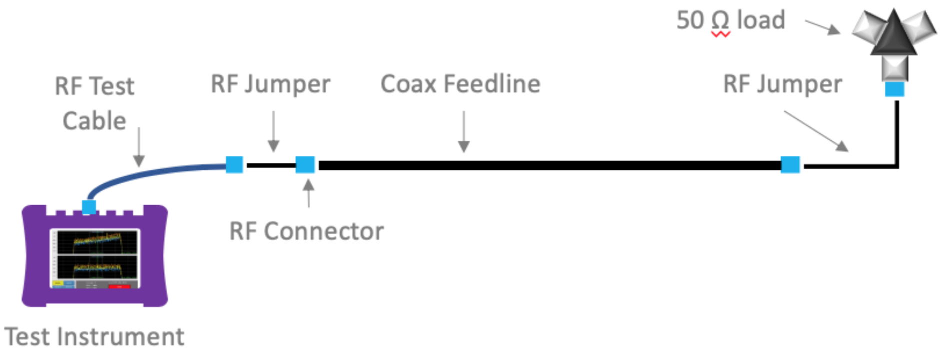
Configure the sweep test instrument for **RETURN LOSS or VSWR** by either recalling the saved reflection test setup for a frequency band of interest or start a new measurement procedure. It is recommended to conduct RETURN LOSS or VSWR with a 50-ohm LOAD.

Place instrument display markers on peak and save a screen capture to memory and record PEAK values.

Note: always verify user calibration is valid and is displayed on the top of the display.

4.2.3. Distance-to-Fault (DTF) of Feedlines (check cable system continuity)

This procedure is recommneded for all feedlines (coaxial cable using 50-ohm) by connecting a 50-ohm LOAD standard at one end of the coaxial cable, like shown here:



Distance to fault test results are used to determine the component within the system where the fault exists.

Configure the sweep test instrument for **DTF – RETURN LOSS or DTF – VSWR** by either recalling the saved DTF setup for a frequency band of interest or start a new measurement procedure according to your testing instrument. On the instrument in the main DTF screen, verify the following:

a. Cable type is correct (predominant cable type installed).

b. End Distance is at least 20% longer than the maximum line length to test.

c. Confirm measurement resolution is set to a designated reference (e.g. 1024 points).

d. Enable an automatic PASS/FAIL criterion

Note: Recording and saving the data is important for future sweep tests.

4.2.4. Distance-to-Fault (DTF) using a SHORT (measure system cable length)

Configure the sweep test instrument for **DTF - RETURN LOSS** by either recalling the saved DTF setup for a frequency band of interest or start a new measurement procedure according to your testing instrument.

Note: always verify user calibration is valid and is displayed on the top of the display.

On the instrument in the main DTF screen, verify the following:

a. Cable type is correct (predominant cable type installed).

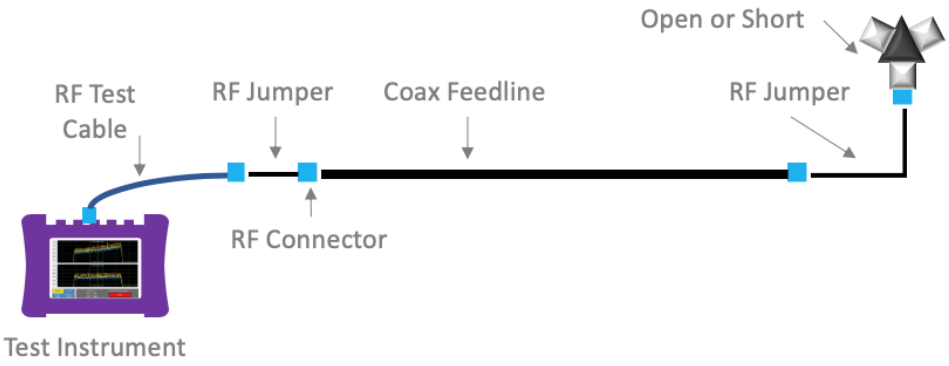
b. End Distance is at least 20% longer than the maximum line length to test.

c. Confirm measurement resolution is set to a designated reference (e.g. 1024 points).

Measure & record cable lengths by placing **M1** marker to peak and recording cable length into your Antenna System Site Submission Form. Should be at or near zero dB and is the length for the entire cable line as measured. Save the display to memory and record the value onto a submission form.

4.2.5. Feedline Loss (measure cable insertion loss)

This procedure is recommended for all feedlines (coaxial cable using short standard) by connecting a 50-ohm SHORT standard at one end of the coaxial cable, like shown here:



Any opens, shorts, or kinks will appear as high return loss when conducting this measurement.

Configure the sweep test instrument for CABLE LOSS by either recalling the saved Return Loss setup for a frequency band of interest or start a new measurement procedure according to your testing instrument.

Note: always verify user calibration is valid and is displayed on the top of the display.

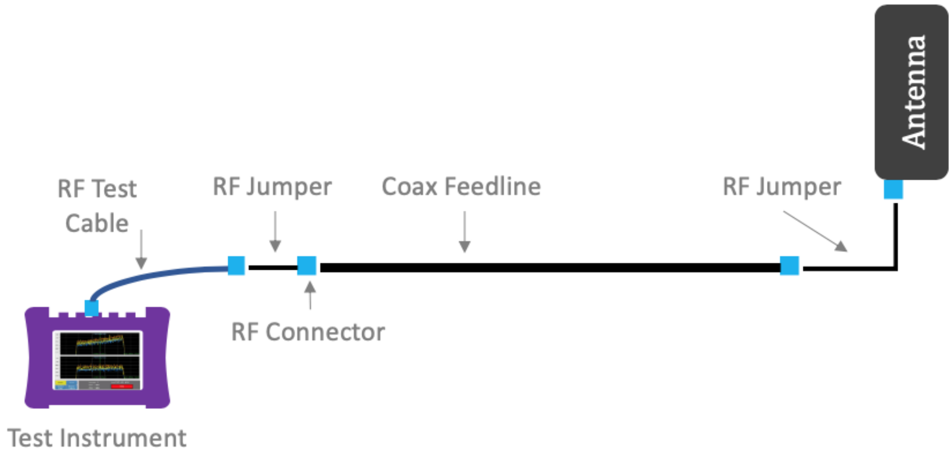
Place the SHORT at the end of the ANTENNA TOP JUMPER and measure CABLE LOSS. Select AUTO SCALE to optimize display. Using the Marker function, place M1 to PEAK and M2 to VALLEY.

Determine cable loss by adding M1and M2 markers and dividing by four if using RETURN LOSS, divide by two if using CABLE LOSS: (M1+M2)/2 = [one-way cable insertion loss for CABLE LOSS Measurement] or alternatively, check the “Average Cable Loss” value on the screen of the instrument.
.
Compare value obtained to any given limit specifications. A reference with typical cable attenuation values should be provided. If measurement passes proceed to next step. If measurement fails carefully inspect all connectors and cables for signs of damage or looseness. If cables and adapters are properly tight and no damage is apparent, contact cell-site management.

Save the display to memory and record the value on a submission form.

4.2.6. Complete System Return Loss Sweep

This is a measure of the complete transmission system quality.

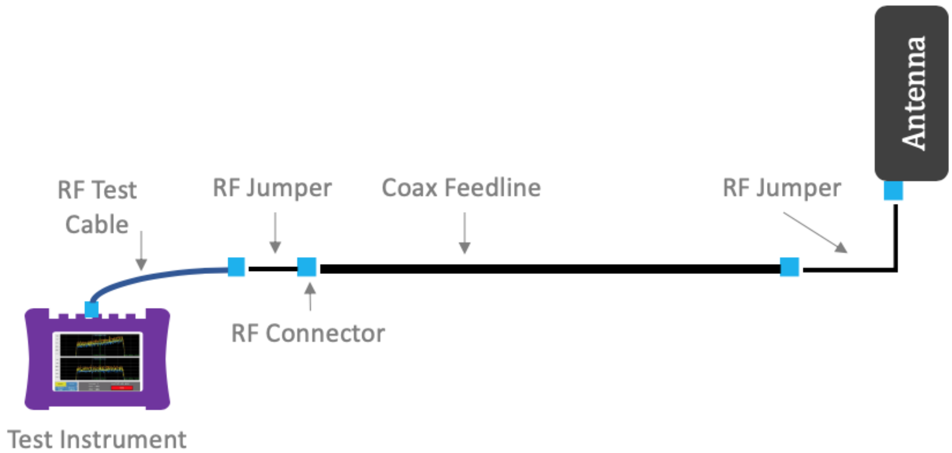


1. Connect the Antenna to the Top jumper.
2. Set LIMIT LINE to a designated value of reference (e.g. -15.5dB) across entire display.
3. Verify user calibration is valid and is displayed on the top of the instrument display.
4. Using the Marker function, place markers in selected frequency points – for example:

	900MHz	1800MHz	AWS
M1	924 MHz	1750 MHz	1710 MH
M2	949 MHz	1810 MHz	1755 MHz
M3	969 MHz	1850 MHz	2110 MHz
M4	994 MHz	1910 MHz	2155 MHz

Verify between Transmit markers (M3 and M4) and Receive markers (M1 and M2) that the displays are below the suggested -15.5 dB LIMIT LINE. Save the display to memory and record the value on a submission form.

4.2.7. Complete System DTF Sweep



This test may be used to identify any problems that may cause high loss in the system return loss test. There is no acceptance criterion for this test. This test provides a baseline for the loss associated with connectors and components in the transmission line. In the future, if the site performance has degraded, comparison of DTF-System plots can identify the problem.

Note each operator will typically set their own set of minimum values as a PASS reference criterion.

5. 5GNR RF signal validation for turn-up/maintenance

5.1. Verification of the 5GNR signal transmission

Validating the initial RF environment and signal transmission for new installations and commissioning of 5GNR cell sites can be achieved through a standardized number of measurements and performance indicators.

3GPP is providing a set of recommendations for over-the-air (OTA) tests through their TS38.104 and TS38.141 for *Base Station (BS) radio transmission and reception* **to verify actual 5GNR signals are in compliance**.

Here is a summary of the 3GPP recommended test cases*****:

5G Base Station Test Cases	3GPP 38.141 Sections	
	Conducted	Over-The-Air
Base Station Output Power	6.2	9.3
Output Power Dynamics	6.3	9.4
Transmission ON/OFF power	6.4	9.5
Transmitted Signal Quality (Frequency Error, Modulation Quality, Time Alignment Error)	6.5	9.6
Unwanted Emissions (Occupied Bandwidth, Adjacent Channel Leakage Ratio, Operating band unwanted emissions)	6.6	9.7
Transmitter intermodulation	6.7	9.8

***Source**: https://www.etsi.org/deliver/etsi_ts/138100_138199/138104/15.02.00_60/ts_138104v150200p.pdf

The test-cases in the table above for installation and regular maintenance of the new 5GNR radio-access, include performance indicators than are measured either over the 5GNR carrier channel or over the reference beams transmitted by each individual carrier. The following performance indicators should be validated to secure an optimal installation of new 5GNR cell sites and for troubleshooting/maintenance activities:

- Pre-validation of RF for **interference** / band clearing of designated 5G frequency bands / channels
- 5GNR pilot signals: confirm presence and location of **SSB** (Synchronization Signal Block)
- Power: **EIRP** (Effective Isotropic Radiated Power) and **RSRP** (Reference Signal Receive Power)
- **RSRQ** or Reference Signal Received Quality values
- **SINR** (Signal-to-Interference plus Noise Ratio) and SNR (Signal-to-Noise Ratio)
- **EVM** (Error Vector Magnitude) for signal propagation and signal attenuation issues
- Over-the-air synchronization: **Time Error** and **Frequency Error** vs. 3GPP specified tolerances

These RF tests become of particular importance in scenarios where 2 or more carriers are co-located in the spectrum adjacent to each other due to the TDD nature of 5GNR signals and particularly when using Dynamic Spectrum Sharing where 4G/LTE and 5GNR carrier channels share same spectrum.

Coverage and propagation analysis should be done with drive-test or walk-test modes based on indoor/outdoor cell area to certify the commissioning of a 5GNR radios. This certification shall include path loss validation, signal fading, non-coverage spots and signal attenuation in ingression (outdoor to indoor) or egression (indoor to outdoor) scenarios.

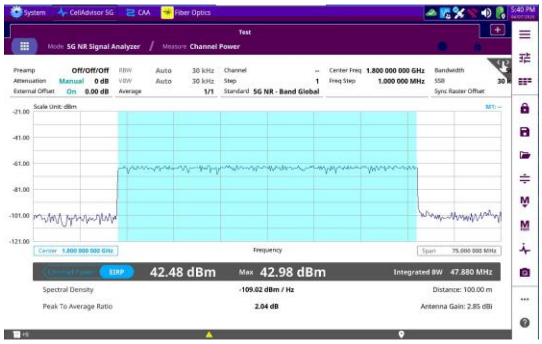
In addition to the 3GPP conformance tests, it is required to conduct spectrum clearance, and in case of interference, conduct interference analysis and mitigation of external signals transmitting in the frequency bands of operation for the 5GNR radio. This may be a recurrent activity during the network life cycle.

5.2. Basic radio conformance tests

5.2.1. Channel Power

The Channel Power measurement is a common test used in the wireless industry to measure the total transmitted power of a radio within a defined frequency channel. Channel power measurements can also indicate spectrum density (dBm/Hz) values in a user specified channel bandwidth, e.g. for each 5GNR carrier.

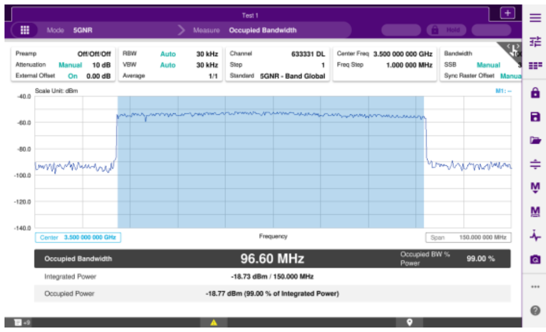
EIRP or Effective Isotropic Radiated Power is a recommended power measurement to determine transmitter power and beam verification of a 5G base-station since it is a reliable indicator of signal strength anywhere in a cell sector with beam-based coverage once path loss and distance to the cell-site is taken into consideration.



Channel Power

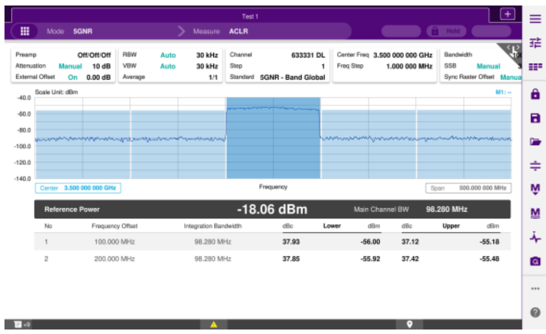
5.2.2. Occupied bandwidth

Occupied Bandwidth measures the total frequency bandwidth occupied by 99% (typically) of the transmitted power within that specified bandwidth, to determine the amount of spectrum used by a modulated signal. This measurement validates that a given signal is not occupying more bandwidth than originally allocated to that channel and required for normal operation.



5.2.3. Adjacent Leakage Power

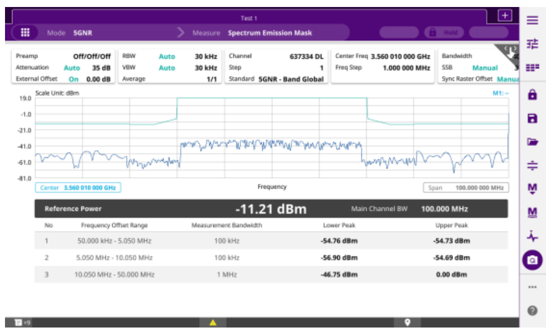
Adjacent Channel Power Ratio (ACPR) is also designated by 3GPP specifications as the Adjacent Channel Leakage Power Ratio (ACLR). This indicator measures the amount of RF power leakage in adjacent channels and its ratios and is particularly relevant in test-scenarios where mobile operators have multiple carrier adjacent to each other with tight guard-band spaces or even no band-guards at all to validate these are not leaking power into each other.



Adjacent Leak Power

5.2.4. Spectrum Emission Mask

The Spectrum Emission Mask (SEM) measurement is to identify and determine any out-of-band spurious emission outside the channel bandwidth and modulated signal. It compares the total power level within the defined carrier bandwidth and offset frequencies to pre-defined mask limits for automatic pass/fail results.



Graphical captures of measurements like examples above should automatically be added to predefined report models for new cell site commissioning and for troubleshooting purposes during regular maintenance activities.

5.3. 5GNR Radio Validation

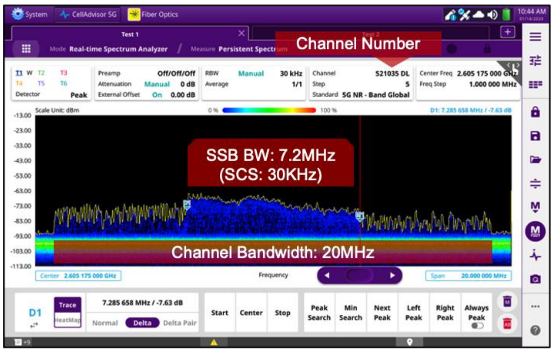
5GNR radio validation shall be performed after the radio has been commissioned to ensure proper configuration and transmission over the air.

5.3.1. 5GNR Signal Characterization

5G **NR-ARFCN** carrier channel is defined by 3GPP TS38.140 section 5.4 Channel Arrangement, and its channel number it is composed of 6 to 7 digits that correspond to a specific center frequency of the carrier.

Channel bandwidth and Sub-Carrier Spacing (SCS) configuration must be verified according to the deployment guidelines to ensure proper signal bandwidth and numerology to ensure connectivity with UEs.

Beamforming verification requires confirming the presence and location of the **SSB** (Synchronization Signal Block) for each 5GNR carrier, including the specific SSB center frequency and SSB bandwidth.

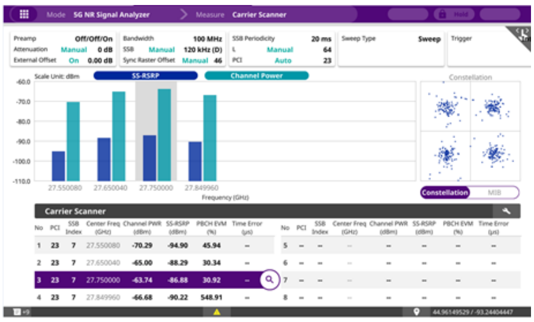


5GNR Characterization (Channel, Bandwidth & SSB)

5.3.2. 5GNR Carrier Aggregation and Transmission Quality

Carrier Aggregation: 5GNR radios can be configured to transmit multiple carriers in the same band in the form of carrier aggregation, where it shall be verified the linearity of the transmitted channel power of all the component carriers.

Error Vector Magnitude (**EVM**) shall be done of the PBCH (physical broadcast channel) which has a modulation format QPSK (quadrature phase-shift key) transmitting 4 symbols and within the modulation error or EVM defined by 3GPP 38.104 section 6.5.2 Modulation Error.



EIRP or Effective Isotropic Radiated Power provides a reliable indicator of signal strength anywhere in a cell once path loss and measuring antenna gain are taken into consideration. For an accurate measurement, it requires to **enter the approximate distance** between the measurement location position and the 5G radiating antenna including any gain of the measuring antenna.

EIRP has become a critical measure to determine transmitter power and beam verification of a 5G cell sites since it is able to discriminate the gain of directionally transmitted signals like 5GNR ones through each individual reference beam, compared to prior 4G sectors radiating isotopically with equal power in all directions.

5.3.3. Channel Synchronization Over-the-Air (OTA)

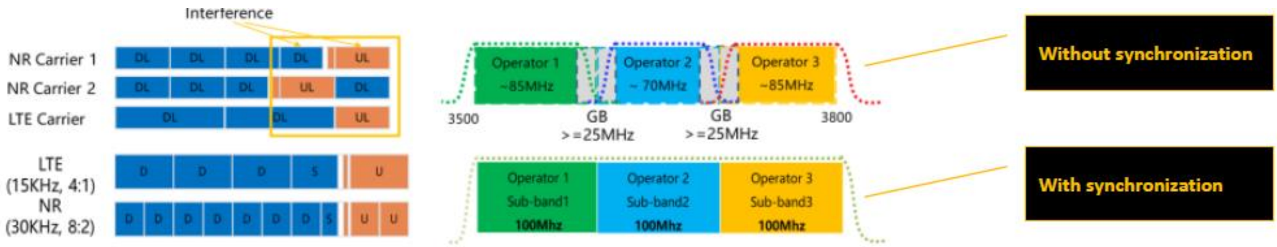
Time error validation for commissioning of 5GNR new sites and for regular maintenance must be performed to avoid inter-channel interference on adjacent channels (reason to verify ACLR as described in section 4.2.3.).

For 5GNR (*also for 4G/LTE-TDD*) 3GPP specifies:

- A Frequency Synchronization: 50ppb
- A Time Synchronization (time alignment error): TAE 3µs [co-site]

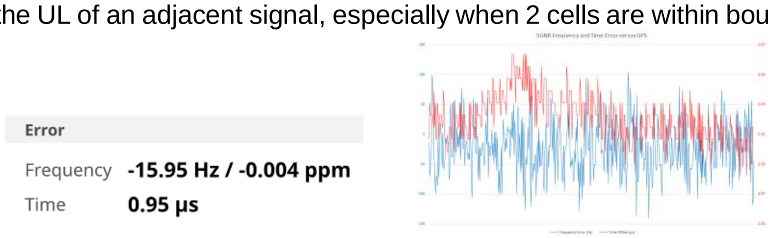
A Time Alignment Error (TAE) ≤ 3µs for TDD means that signals arriving from 2 cells shall arrive within less than 3µs of mutual alignment. Note stricter network synchronization based on GPS or PTPv2 may be required.

Also, for mobile operators within the same country or region, GSMA recommends using the same synchronization for adjacent 5G carrier channels.



*Source: https://www.gsma.com/futurenetworks/wiki/5g-implementation-guidelines/

Given 5GNR is TDD technology, UL and DL share the same channel. Any DL spectral misalignments may create interference in the UL of an adjacent signal, especially when 2 cells are within boundaries of each other.



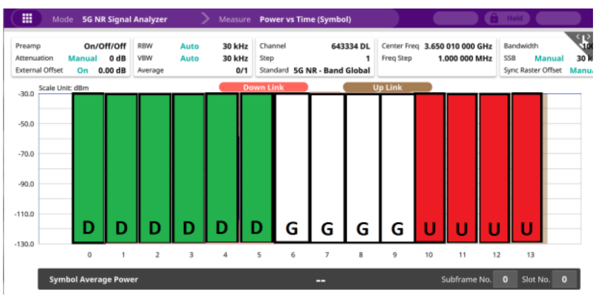
Expected values per site sector should be:

- Frequency Error < +/-.05 ppm versus GPS
- Time Error < +/-1.5µs versus GPS

Note proper co-site synchronization is also important when transmitting multiple signals from the same cell-site and the Mobile Operator chooses a given UL/DL distribution among signal frames and time slots. To avoid issues, country regulators may force the same reference synchronization frame for all Mobile Operators following directives like 2019/235/UE for the European Union members or similar like ECC Report 296.

*Source: https://www.gsma.com/spectrum/wp-content/uploads/2020/04/3.5-GHz-5G-TDD-Synchronisation-QA.pdf

Also, a Power versus Time checkout per Frame or per Symbol can help quickly identify UL/DL synchronization compliance issues by using a simple mask corresponding to the slot format of choice by the mobile operator:



5.4. Validation of Reference Beams transmission quality and coverage

5GNR site installation and maintenance validation can be achieved by using performance indicators measured either over the 5GNR carrier channel or over the reference beams transmitted by each carrier channel.

Validation over reference beams may include a **quality analysis of beam transmission** to identify any potential issues **and a coverage analysis** to confirm the radio sector to commission or troubleshoot is providing reliable network access to end-users located in the that area.

5.4.1. Validate quality transmission of reference beams

5GNR reference beams are transmitted through the SSB and operate a similar role as the reference signals in 4G/LTE with the consideration there may be multiple of these being transmitted by the same radio sector, up 4 in bands <3GHz, up to 8 in bands ranging from 3GHz to 7GHz and up to 64 when operating mmWave frequencies between 24GHz and 52GHz. Hence, a common case when operating in the C-band or mid-band (3.5GHz) is to transmit up to 8 simultaneous reference beams distributed in a semi-circle configuration.

Key metrics to help operators qualify the performance of reference beams are the following:

- **RSRP** [Reference Signal Receive Power]
- **RSRQ** [Reference Signal Received Quality]
- **SINR** [Signal-to-Interference-plus-Noise Ratio]
- **SNR** [Signal-to-Noise Ratio]

These metrics provide a ratio between the beam channel and any unwanted signal or potential noise in the beam channel bandwidth. These also measure the received signal quality derived from detected error rates.

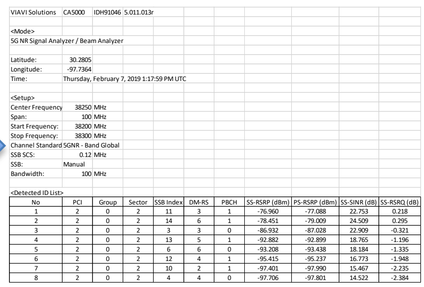
The above metrics are typically sourced from the Primary or Secondary Sync Signals (**PSS/SSS**) of the SSB.

As discussed in section 4.3.2., **EIRP** is also considered a suitable 5G power measurement per each beam.

Testing the reference beams for a new site commissioning brings also the following valuable information:

- ➢ Making sure all intended beams (1, 4, 8…64) are all actively transmitting.
- ➢ Quickly validate the N (e.g. 8x) strongest beam indexes detected at any designated geographical point around the cell-site sector.
- ➢ Confirm beam dominance at a given location of interest around the cell-site sector, as per planning and design, so the intended **Beam Index** is the actual stronger one at that location vs. other beam indexes.
- ➢ Validate any beam signal/indexes arrivals from other different PCI's or antenna sectors (group/sector).

Site record validating beam transmission and quality metrics can be created for commissioning purposes:



VIAVI Solutions CA5000 IDH91046 5.011.013r

<Mode>
5G NR Signal Analyzer / Beam Analyzer

Latitude: 30.2805
Longitude: -97.7364
Time: Thursday, February 7, 2019 1:17:59 PM UTC

<Setup>
Center Frequency 38250 MHz
Span: 100 MHz
Start Frequency: 38200 MHz
Stop Frequency: 38300 MHz
Channel Standard 5GNR - Band Global
SSB SCS: 0.12 MHz
SSB: Manual
Bandwidth: 100 MHz

<Detected ID List>

No	PCI	Group	Sector	SSB Index	DM-RS	PBCH	SS-RSRP (dBm)	PS-RSRP (dBm)	SS-SINR (dB)	SS-RSRQ (dB)
1	2	0	2	11	3	1	-76.960	-77.088	22.753	0.218
2	2	0	2	14	6	1	-78.451	-79.009	24.509	0.295
3	2	0	2	3	3	0	-86.932	-87.028	22.909	-0.321
4	2	0	2	13	5	1	-92.882	-92.899	18.765	-1.196
5	2	0	2	6	6	0	-93.208	-93.438	18.184	-1.335
6	2	0	2	12	4	1	-95.415	-95.237	16.773	-1.948
7	2	0	2	10	2	1	-97.401	-97.990	15.467	-2.235
8	2	0	2	4	4	0	-97.706	-97.801	14.522	-2.384

5.4.2. Validation of coverage for beams by sector/PCI

Coverage testing is conducted in drive-test or walk-test mode (for outdoor or indoor testing locations) and requires adding GPS and timing stamps to all samples collected. Information is displayed over a mapping view during collection in real-time. Data can also be exported to 3rd party tools for offline post-processing or analysis.

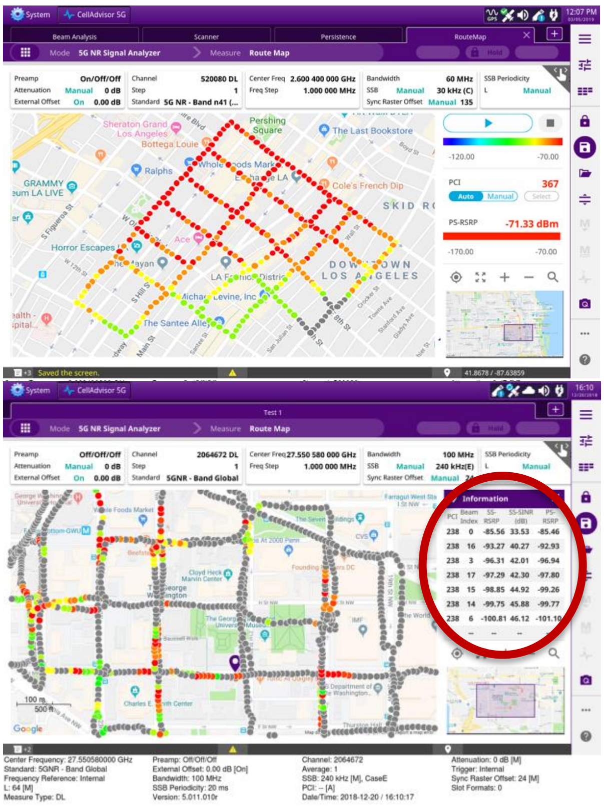
Coverage testing requires the use of omni-directional antennas to effectively capture signals levels and other channel information from signals coming from multiple sectors (PCI's) or through different reflection paths.

The use of a band-pass filter is recommended for coverage testing in mid-band range from 3.4GHz to 3.5GHz.

For coverage testing in mmWave ranges like 26GHz or higher it is recommended the use of special mmWave omni-directional antennas with an integrated Low-Noise Amplifier (**LNA**) module to help capture appropriately these type of high-frequency signals that may feature significant path loss and other propagation challenges.

*Pictures: examples of magnetic mounted omni-directional antennas for FR2 (mmWave) and FR1 (<6GHz) ranges and a 3.3GHz to 3.8GHz band pass filter, which increases measuring sensitivity for coverage testing.

Coverage testing tools can display network information in real-time as collected and consolidated at the end of the drive-test or walk-test designated route:



Mobile operator designated color schemes can show different power levels including metrics like **RSRP, RSRQ, SINR or SNR** in different colors by value thresholds and provide an immediate picture of signal propagation and quality of servicer available in a given location.

A critical feature for effective coverage testing is to discriminate dominant beam indexes coming from **multiple PCI sectors at once** to identify coverage gaps and/or any sector overlapping.

Coverage testing for 5G differs from previous 3G/4G technologies in that multiple reference signals so-called reference beams are being transmitted from the same site sector or antenna. These reference signals can be identified by their corresponding Beam Index number (e.g. from #0 to #7 for 8 reference beams in the same radio), so another important piece of coverage information is to confirm the dominant Beam Index available in every given location point and confirm it corresponds to the original designated Beam Index during the network planning and design stage. Note the same Beam Index number may repeat from different sectors in a given location if there any sort of overlapping issues.

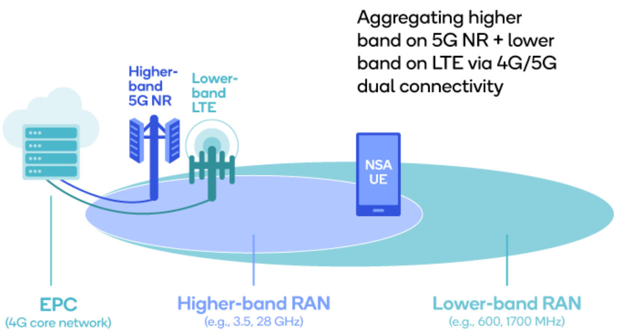
Coverage testing is recommended around the sector of interest as part of the commissioning report after installation and for regular maintenance or troubleshooting of any network issues after the roll out of 5G sites.

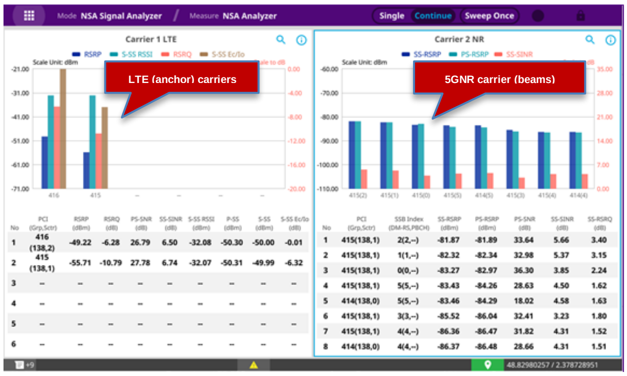
5.4.3. Validation of 4G and 5G combined coverage

Currently the most common 5G deployment mode is the so-called NSA or **Non-Standalone** where 5GNR radios require support of an **anchor 4G/LTE signal** to provide control signals to mobile devices.

In this operational mode may be required to compare 4G and 5G radio access networks together to validate for example the coverage available in the 4G legacy network vs. the coverage offered by the new 5GNR one.

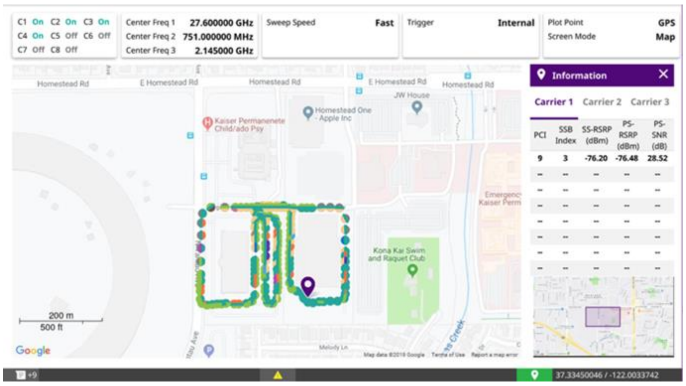
This may require measuring multiple 4G/LTE channel carriers along with one or more 5GNR channels in the same location around the new 5GNR cell site (similar for regular maintenance or troubleshooting activities).

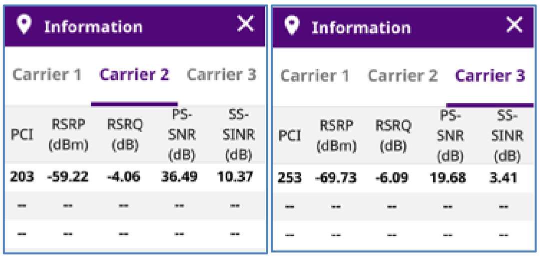




*Source: Qualcomm

Concurrent 4G/LE and 5G coverage testing is needed for new 5GNR commissioning reports to fully realize the performance and propagation of the 5GNR in the new frequency bands compared to the existing LTE/4G.





Information — Carrier 1 | **Carrier 2** | Carrier 3

PCI	RSRP (dBm)	RSRQ (dB)	PS-SNR (dB)	SS-SINR (dB)
203	-59.22	-4.06	36.49	10.37
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Information — Carrier 1 | Carrier 2 | **Carrier 3**

PCI	RSRP (dBm)	RSRQ (dB)	PS-SNR (dB)	SS-SINR (dB)
253	-69.73	-6.09	19.68	3.41
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Example of a 4G/5G combined coverage testing involving 3 concurrent carriers, one 5GNR and tow 4G/LTE ones in 700MHz and 2.1GHz.

Coverage tests in NSA combined mode should include logged records for post-processing and offline analysis:

Time	Latitude	Longitude	Attenuation	Preamp 1	Preamp 2	DNC Preamp	Carrier No	Center Frequ	Technology (
05:40:49.480 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	3	2.145	LTE FDD
05:40:49.710 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	4	0.8875	LTE FDD
05:40:50.143 AM UTC	37.3344632	-122.00338	0	On	On	On	1	27.6	5G NR
05:40:50.531 AM UTC	37.3344632	-122.00338	0	Off	Off	On	2	0.751	LTE FDD
05:40:50.765 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	3	2.145	LTE FDD
05:40:51.005 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	4	0.8875	LTE FDD
05:40:51.442 AM UTC	37.3344631	-122.00338	0	On	On	On	1	27.6	5G NR
05:40:51.828 AM UTC	37.3344631	-122.00338	0	Off	Off	On	2	0.751	LTE FDD
05:40:52.070 AM UTC	37.3344631	-122.00338	0	Off	Off	Off	3	2.145	LTE FDD
05:40:52.323 AM UTC	37.3344631	-122.00338	0	Off	Off	Off	4	0.8875	LTE FDD
05:40:52.752 AM UTC	37.3344631	-122.00338	0	On	On	On	1	27.6	5G NR
05:40:53.138 AM UTC	37.3344631	-122.00338	0	Off	Off	On	2	0.751	LTE FDD
05:40:53.374 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	3	2.145	LTE FDD
05:40:53.605 AM UTC	37.3344632	-122.00338	0	Off	Off	Off	4	0.8875	LTE FDD

Recommended performance metrics for 4G and 5G carrier's comparison are **RSRP, RSRQ, SINR and SNR** on all reference signals (4G) and reference beams (5G) present in the location of choice with PCI stamps.

5.5. Dynamic Spectrum Sharing (DSS) operation mode

Signal performance validation should be made when operating aggregated carriers in-band, contiguous or non-contiguous or when a 5G channel operates in Dynamic Spectrum Sharing mode in combination with an LTE channel carrier.

DSS implementation modes may vary from Time and Frequency sharing to Time Division sharing and presents numerous challenges to secure optimal 4G/LTE and 5GNR signal co-existence, integrity, and performance.

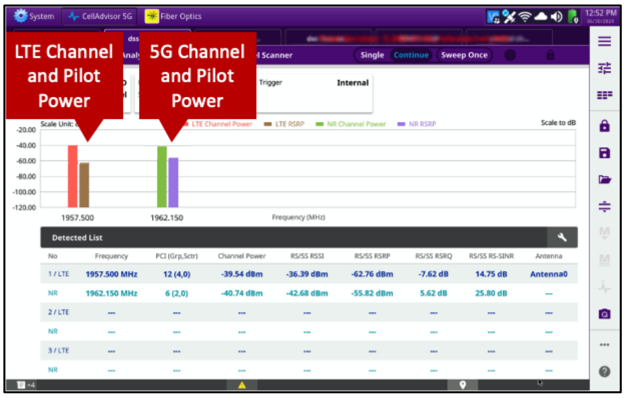
*Source: Qualcomm

DSS requires signal integrity verification of LTE and 5G carriers that are transmitted on the same frequency, and concurrently perform a coverage assessment for commissioning 5G service delivery in DSS mode.

DSS Channel and Pilot Power

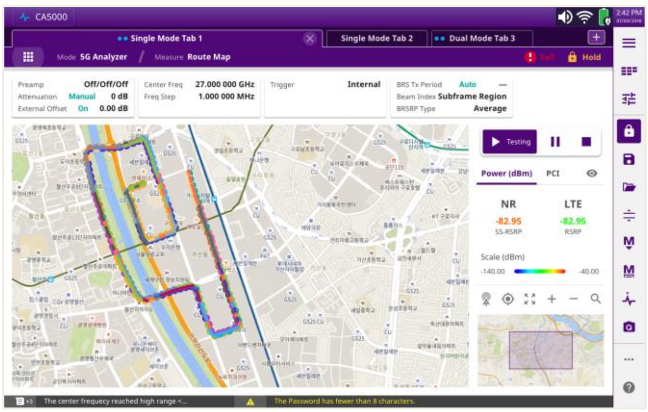
DSS channel power and corresponding pilot power of LTE and 5G signals should be verified, for adequate transmission power and availability of LTE and 5G pilot signals over the same DSS channel.

Control channel verification allows for effective **DSS performance validation** to make sure both 4G/LTE and 5GNR control and synchronization channels are within the radio vendor recommendations regarding channel power levels, EVM, modulation code schemes and other 3GPP compliance metrics.



DSS Network Coverage

DSS network coverage is required to perform concurrent LTE and 5GNR coverage assessment to ensure both signal radio resources that are sharing the same frequency channel remain consistently available throughout the area within the DSS cell site sector.

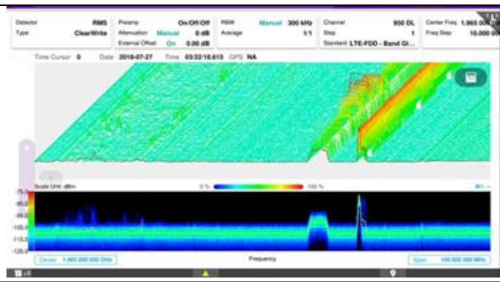


APPENDIX A. RTSA tools for 5G field use-cases

Real-time Spectrum Analysers (**RTSA**) differentiate from traditional sweep tuned spectrum analysers in two main aspects: ability to measure a full extended analysis bandwidth (e.g. 100MHz) instantaneously without the need to 'sweep' and through very fast, continued FFT functions plus visualization of the spectrum using a persistence display that can show different power levels for the same frequency point depending how often a given power level occurs at that frequency. RTSA tools are very effective for 5G rollouts and troubleshooting.

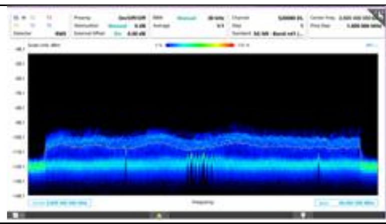
The following test-cases are typical examples for using RTSA in the field during 5GNR roll outs:

Band clearing and interference analysis

5G is operating in new frequency ranges like mmWave (~27GHz) and the mid-band (~3.5GHz) in that may require the traditional spectrum clearance and interference analysis jobs before deployment to make sure the spectrum bands are free and no alien signals are messing with the brand new 5G services. Validating a low noise floor is also a recommended verification as part of a 5G roll out preparation.	

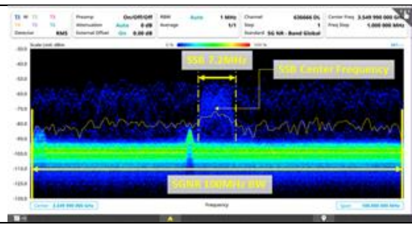
RTSA tools allows identify spurious and other interference signals more effectively, including the possibility to visualize alien signals inside a channel carrier occupied bandwidth, something near impossible for other tools.

Characterize 5GNR TDD signals like a broadband carrier

RTSA tools allow to observe 5GNR TDD signals like actual whole carriers instead of the on/off time slots. With the persistence display function any time slots are visualized in a more steady fashion since they take place often enough for the RTSA to capture and report that power activity as long as it occurs above the POI (probability of interception) specification.	

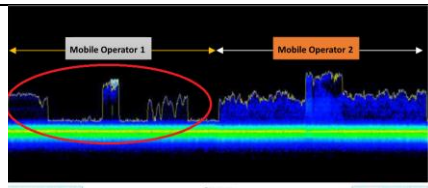
RTSA tools allow to quickly validate the correct channel number or center frequency and signal bandwidth of any given 5GNR channel carrier, along with any potential alien signals or spurious located through the carrier.

Validate presence and location of SSB (sync signal block)

3GPP does not mandate any fix location for the SSB through the 5GNR channel carrier. Due to network planning and other considerations, the SSB can be in different frequency positions which requires field technicians the ability to confirm the presence and actual location of the SSB in the carrier to extract most performance indicators or RF measurements.	

RTSA tools are very effective to automatically highlight the presence and location of the SSB in the 5G carrier, given the SSB can be in fact the most persistent part of the 5GNR signal vs. the time slots within the channel.

Adjacent 5GNR carriers between different mobile operators

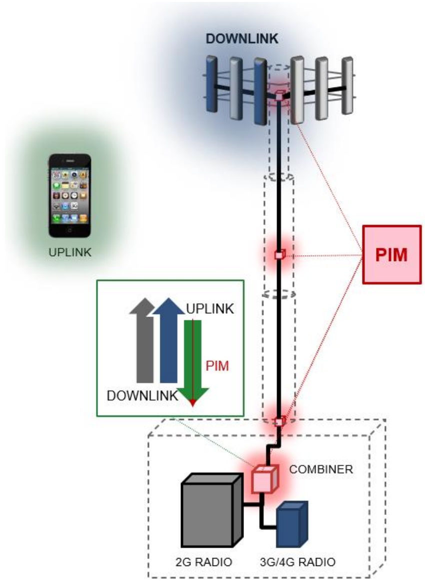
With the increasing presence of multiple 5G networks in the same location it is possible to see 5G carrier channels adjacent next to each other creating adjacent leakage interference and other compliance issues. RTSA tools also provide an effective analysis to troubleshoot these situations.	

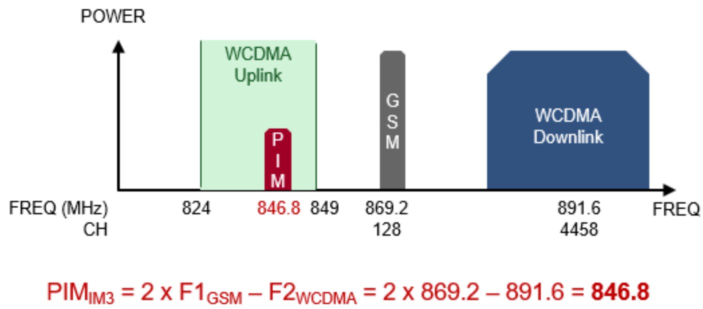
APPENDIX B. PIM Detection vs. PIM Analysis

What is PIM?

Passive-Intermodulation (PIM) is a form of interference originating internally in cellular base-station systems.

Typically, PIM is interference in the Uplink caused by signals derived by the combination of two or more carriers in the Downlink that are being transmitted on a single nonlinear coaxial feedline. These nonlinearities in the feedlines can be the result of poor cable terminations or improper connections, material breakdowns within the cable/connector parts, contaminants, partial discontinuities (cracks or dissimilar metal joints) or presence of improper material (e.g., ferromagnetic such as iron, nickel, cobalt) and other similar causes.





With the arrival of FTTA in cell sites, a lot of the coaxial and other passive elements have been replaced with optical fiber, and the overall impact of PIM in cellular system performance has been somewhat mitigated. Yet many coax-based elements remain concentrated in shorter feedlines between the radios and antennas where the occurrence of PIM is still possible, due to larger combinations of carrier channels, often including any mix of 2G, 3G and 4G in multiple frequency bands, all being transmitted through the same broadcasting system.

PIM Detection vs. PIM Analysis

Regarding PIM testing procedures in cell sites, it is important to differentiate PIM Detection vs. PIM Analysis.

PIM Detection is a simpler procedure that indicates if there is a noticeable level of PIM in a given cell site, based on a PIM signature that raises the noise floor of the uplink and if so, how sever that may be, although it does not identify the particular location or element in the feedline from where that level of PIM may originate.

PIM Analysis on the other hand, includes the ability to identify the location or feedline element where the PIM may originate, and usually does it by indicating a “Distance-to-PIM” reference from the testing point.

PIM Analysis however is a testing procedure that requires the use of highly specialized, heavy test equipment which is typically very costly and limited to a reduced number of frequency bands, which often means different toolsets are required for different frequency ranges thus further increasing the overall cost of testing.

Despite the limitation of not supporting a “distance-to-PIM” reference, PIM Detection brings some operational advantages for a more cost-effective testing procedure when only a PIM-free report is required or for a simpler, preventive testing procedure during regular maintenance routines.

PIM Detection can be done with portable, common base-station / spectrum analyzers able to do also other sort of related cell site tests (coax, fiber, RF) and does not bear the band limitations that PIM Analyzers have.

Thus, any PIM mitigation strategy must carefully compare the pros and cons of PIM Detection vs. PIM Analysis, considering also factors such as FTTA technology has significantly reduced the number of feedline elements that produce PIM, and these are now typically concentrated at the very top end of cell sites in macro towers, between the antenna panels and radios, still connected through coaxial jumpers, but between the remote radio heads and the base-band units connected through optical fiber the possibility of PIM is no longer major issue.

Here is a comparison matrix for PIM Detection vs. Analysis:

	PIM Detection	**PIM Analysis**
Equipment required	General purpose base-station / spectrum analyzers with other functions	Dedicated PIM Analyzers with limited band segmentation.
Testing point required	Flexible, including ground level and over CPRI (fiber) in FTTA cell sites.	Requires bulky equipment lifted to the tower top for FTTA cell sites.
Cost of testing	Lower cost of equipment required.	Higher cost of dedicated equipment / different toolsets per band needed.
Technician expertise	Lower level of technician expertise and training required.	Higher level of technician expertise and training/certification required.
PIM free reports for site commissioning	Supported.	Supported.
PIM presence detection / PIM levels assessed	Supported.	Supported.
Distance to PIM	Not Supported.	Supported.
Time of site service disconnection during testing procedure	Typically, shorter period.	Typically, longer period.

Given the current proliferation of FTTA new cell sites in the industry today, it has become more common for mobile operators to require only a PIM Free report at the time of commissioning a new cell site, and later on have only regular checkups based on a more cost-effective PIM Detection procedure that allows to identify which cell sites may eventually reach to more noticeable PIM levels – Also note this problem can often simply be fixed by replacing the coaxial jumpers and other feedline elements between the antennas and radios, which can be under certain circumstances, a cheaper alternative than ordering a full PIM Analysis testing procedure to identify the single culprit element that may be causing the higher PIM levels at the top of the cell site tower.

A cost-effective PIM mitigation strategy may combine regular PIM Detection procedures, leaving PIM Analysis only for those situations where high levels of PIM have been detected and the root-cause is difficult to identify.

PIM Detection over Coaxial procedure (non-intrusive method)

The process for detecting PIM over the RF uplink interface on a coaxial feedline is performed in 4 main steps:

- **Pre-analysis of suspected victim RF channels**

  Test equipment like VIAVI CellAdvisor include a PIM calculator that predicts the possible victim receive band that may be impacted by the other RF bands been used in each base-station. This is used to highlight the potential sources of PIM and no other knowledge of the antenna system is requires at this stage.

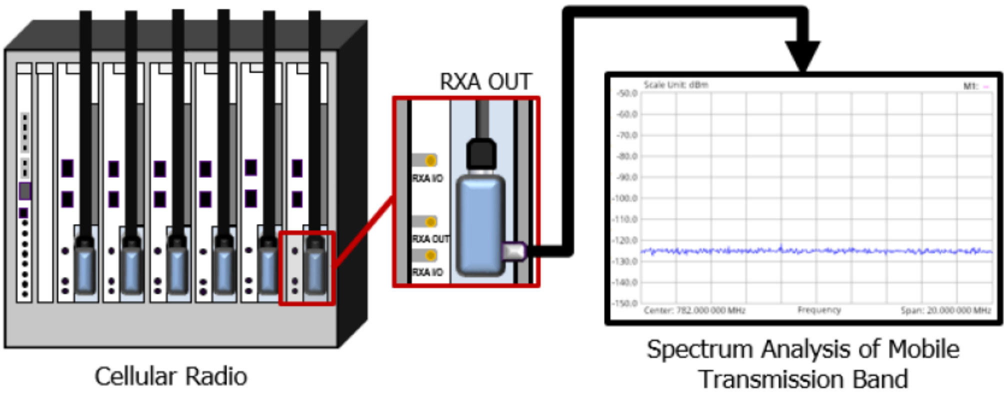
- **Test configuration setup**

  Access to the base-station receiver port is required – this is generally accomplished by connecting directly to a receiver monitoring port (when available) or via an RF coupler. The RF receiver port is then connected to the RF spectrum analyser port or to a base-station analyser instrument like the VIAVI Celladvisor.

- **Measurement of victim receiver noise floor with a single transmitter (DL) enabled**

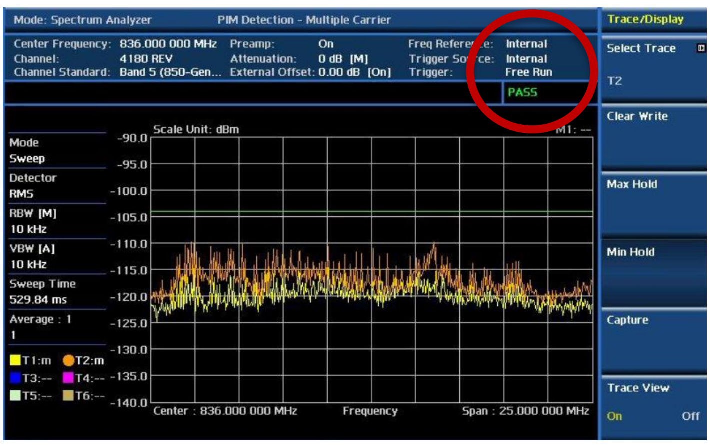
  With the base-station hardware connected to the test set, a tool-guided PIM Detection application can be run from the instrument supporting a PIM Detection automated function. The RF frequency band and span to be monitored for PIM is configured in the instrument GUI and a description of the setup for the transmitter is given. During this first step the user is required to enable only 1 of the connected base station transmitters ensuring the rest of transmitters are turned off. This step is to establish the noise floor in the monitored receiver band with only 1 transmitter signal enabled.

  The PIM Detection application then measures the noise floor as shown in the following picture example:



- **Measurement of victim receiver noise floor with all other connected RF transmitters (DL) enabled**

  For the next step, the remaining base station transmitters connected to the antenna system are then enabled and the same measurement re-run. At this point the PIM Detection automated function measures the same noise floor again but overlaying the trace taken from the previous step and the testing instrument simply indicates to the user a PASS/FAIL indication for PIM Detection, similar to the following example using a VIAVI CellAdvisor tool set indicating no significant levels of PIM have been detected in this site:



PIM Detection over Optical Fibre [CPRI] procedure (non-intrusive method)

The process for detecting PIM over the RF uplink interface on a fiber feedline is performed in 4 main steps:

- **Pre-analysis of suspected victim RF channels**

  Test equipment like VIAVI CellAdvisor include a PIM calculator that predicts the possible victim receive band that may be impacted by the other RF bands been used in each base-station. This is used to highlight the potential sources of PIM and no other knowledge of the antenna system is requires at this stage.

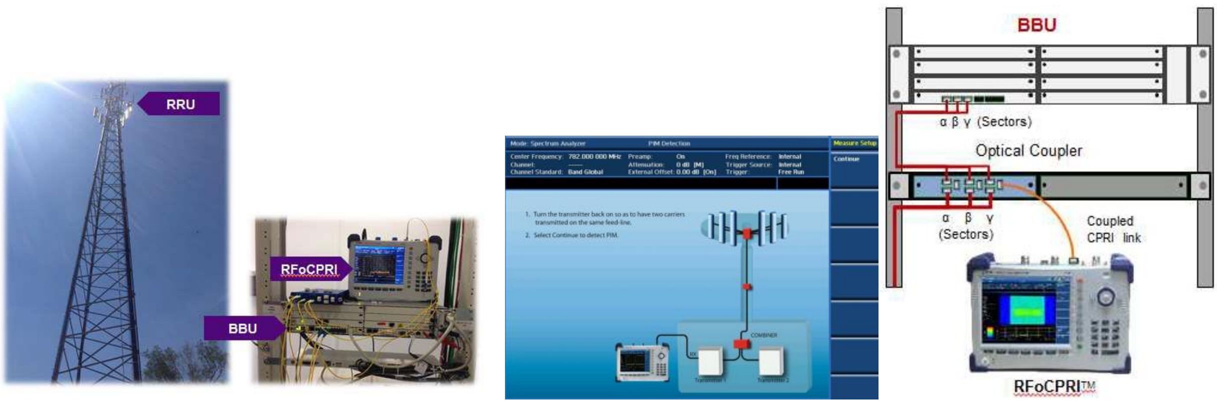
- **Test configuration setup**

  Access to the base-station receiver port is required – this is generally accomplished by connecting directly to a receiver CPRI test port (when available) or via an external optical coupler. The receiver port is then connected to the spectrum analyser port with RF over Fiber testing capabilities like the VIAVI Celladvisor.

- **Measurement of victim receiver noise floor with a single transmitter (DL) enabled**

  With the base-station connected to the test set via the CPRI link, a tool-guided PIM Detection application can be run from the instrument supporting a PIM Detection automated function. The RF frequency band and span to be monitored for PIM is configured in the instrument GUI and a description of the setup for the transmitter is given. During this first step the user is required to enable only 1 of the connected base station transmitters ensuring the rest of transmitters are turned off. This step is to establish the noise floor in the monitored receiver band with only 1 transmitter signal enabled.

  The PIM Detection application then measures the noise floor as shown in the following picture example:



- **Measurement of victim receiver noise floor with all other connected RF transmitters (DL) enabled**

  For the next step, the remaining base station transmitters connected to the antenna system are then enabled and the same measurement re-run. At this point the PIM Detection automated function measures the Uplink spectrum again but overlaying the trace taken from the previous step and the testing instrument simply indicates to the user a PASS/FAIL indication for PIM Detection, similar to the following example using a VIAVI CellAdvisor tool set that shows a noticeable PIM signature level detected in this site:

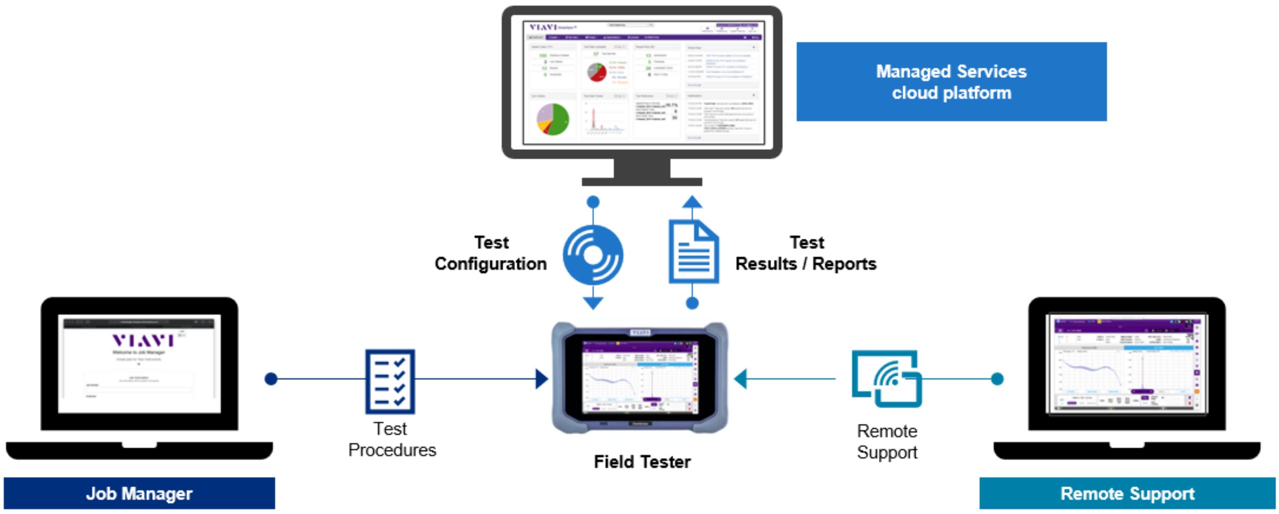
APPENDIX C. Workflow automation for field testing

Cost reduction in Methods of Procedure is recommended through **adoption of a workflow automation plan** for testing activities during installation, commissioning and regular maintenance or troubleshooting of cell sites.

Workflow automation enables management control over the correct execution of field test workflows, thereby delivering results consistently and reliability by ensuring the process of testing and creating reports for site commissioning and other use-cases is fully integrated and automated as a default function of the testing tools.

Such capability facilitates all the field-testing activity – for example tools can be operated by experienced users but also by entry-level technicians – saving in operational costs, while improving time to market and the overall quality assurance of the network.

Following is an example of a workflow automation process recommendation:



- Jobs are defined as a set of individual test-scripts coordinated by tasks, objectives, or regions
- Tests-scripts can be pre-defined by management covering the different cell site areas to validate
  - Fiber / Coax / Transport / Radio
- Web-based tools allow to customize test-scripts and load into required field tools or technicians
- Testing tools display step-by-step instructions to field technicians, show test progress and results
- Test tool automatically consolidates all results (incl. fiber, coax, radio…) into a One Report
- Test tool automatically uploads the reports into a cloud service of choice or managed services platform
- Cloud services include the ability to manage an install base of test tools in the field, known-location, license management, tests configuration repositories, data results and reports storage by technician or instrument
- Workflow automation includes the ability to remote support and monitor field technicians progress with the ability to operate and monitor the test tool online by management or expert-level users from anywhere

Workflow automation takes full advantage of software tools and utilities easy to use and effective in the field. A **Job Manager** allows to pre-define a set of specific tests that technicians in the field simply need to follow as the instrument indicates the next steps. All the information and test results can be automatically stored in a C**loud Service of choice** without manual intervention of the technician. Latest generation of **Remote Access** utilities allow for access and control of any tool in the field anywhere in the world, even when using non-public IP addresses, useful when additional troubleshooting of problems is required by experts in a different location.