Application Note

VIAVI Solutions

RF Interference Visualization

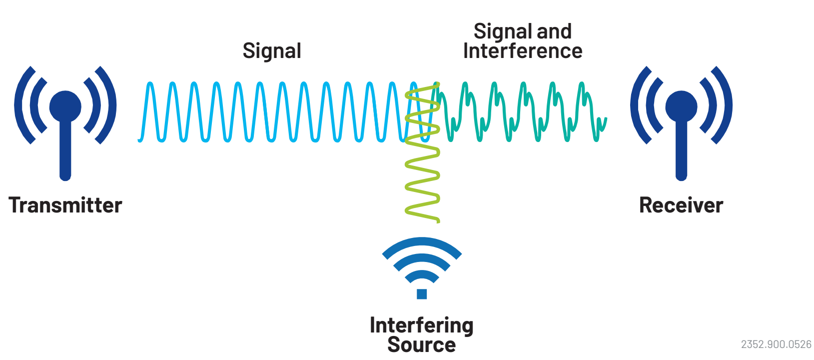
OneAdvisor 800 RF Viewer^P

RF Interference Overview

Radio waves enable communication, navigation and sensing, and covers a wide frequency range for multiple applications from broadcast services such as FM radio to highly complex and bandwidth intensive systems including cellular mobility, Wi-Fi connectivity, satellite communication, microwave links and mm-wave capacity.

Radio waves enable communication, navigation and sensing

Radio Frequency (RF) interference is one of the most critical limiting factors in the performance and reliability of these communication systems. It occurs when an unwanted electromagnetic signal disrupts the radio waves of the system, degrading signal quality or even preventing communication.



Communication System with RF Interference

RF interference can originate from a wide range of sources that are generally categorized as:

- Unintentional interference is often produced by malfunctioning or poorly designed electronic equipment, some examples are broadband amplifiers, power supplies, and video cameras.
- Inherent interference are nonlinear effects within RF hardware or infrastructure that generate passive intermodulation (PIM) created at metal junctions, corroded connectors, or dissimilar materials.
- Intentional interference in critical infrastructure and security-sensitive applications, such as deliberate jamming, and spoofing of navigational signals.

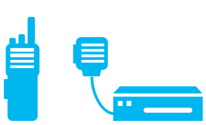
RF Interference in Wireless Networks

RF Interference disrupts radio communications in the downlink (DL) or uplink (UL) paths, causing network impairments. It can originate internally from the network infrastructure or externally from nearby transmitters. User devices are more susceptible to RF interference because their uplink transmission power is much lower than the radio's downlink power. Even low-power interfering signals in the uplink can cause retransmissions, capacity loss, and service disruptions, leading to dissatisfied customers and higher churn.

The key RF metrics associated with RF Interference include the following:

- Elevated Signal to Interference and Noise Ratio (SINR)
- High Error Vector Magnitude (EVM)
- Reduced modulation lowering throughput

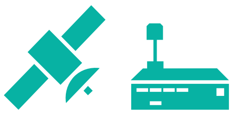
RF Interference in Mission-Critical Communications



Mission-critical communication systems are designed with stringent requirements for reliability, availability, and latency, often operating under life-or-death conditions. In these environments, RF interference is not merely a performance issue but a direct threat to operational continuity. Even moderate interference can disrupt voice, data or signaling channels, resulting in dropped calls, delayed dispatch information, or complete communication outages during emergencies.

A significant portion of RF interference in mission-critical networks originates from unintentional sources, particularly in-building systems such as improperly configured bi-directional amplifiers (BDAs), video surveillance systems, and electric motors.

RF Interference in GNSS



Global Navigation Satellite Systems (GNSS) are uniquely vulnerable to RF interference due to the extremely low power levels of the received signals. Consequently, even weak interfering signals can significantly disrupt operation. RF interference in GNSS can manifest in several forms, including narrowband signals that can corrupt specific frequency channels, wideband noise that raises the noise floor, and more sophisticated threats such as jamming and spoofing. Jamming results in the denial of services by overwhelming the receiver, while spoofing introduces false signals that can mislead the receiver into calculating incorrect position, velocity or timing.

The implications of such RF interference expand into several applications. In navigation, it can lead to position errors ranging from a few meters to several kilometers. In timing, can disrupt synchronization of cellular networks, financial systems, and power grids.

GNSS receivers are typical omnidirectional and operate in an open environment, making them highly susceptible to both intentional and unintentional interfering sources.

RF Interference in NTN

Non-Terrestrial Networks (NTN), particularly those based on Low Earth Orbit (LEO) satellites introduce a fundamentally different RF interference environment compared to terrestrial networks. This is primarily due to their large coverage areas, where a single satellite beam can receive signals from a vast number of user devices and interferers simultaneously, effectively aggregating interference over a wide geographical area. Unlike terrestrial radios, which are sectorized and with relatively localized interference sources, satellites must contend with cumulative uplink generated by many independent transmitters. This aggregated interference behaves like a spatially distributed noise floor, often becoming the dominant limiting factor of uplink performance.

A critical aspect of NTN interference is that user equipment typically transmits using quasi-omni directional antennas, meaning that interference does not need to be directed towards the satellite to have an impact. Instead, any transmission within the satellite's field of view contributes to the overall interference level. Additionally, the dynamic nature of satellite motion introduces time-varying Doppler shifts and propagation delays, complicating interference management and signal separation. As a result, a system can experience rapid degradation of uplink SINR, especially in the presence of external interferers. While large satellite antenna arrays and beamforming techniques proved some spatial filtering gains, they do not fully eliminate the challenge of aggregate interference.

RF Interference Analysis

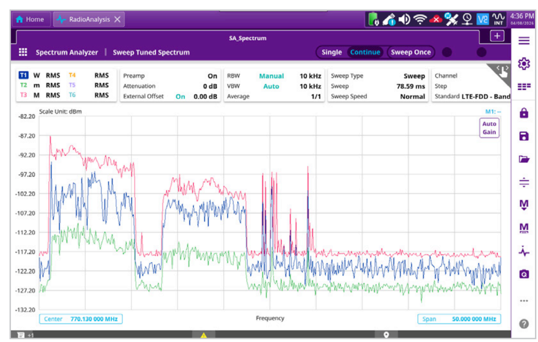
RF interference analysis is fundamental in wireless systems to identify, characterize and mitigate unwanted electromagnetic signals that are impacting the performance of the radio wave system.

Identification and Characterization

The initial phase of the RF interference analysis process is the identification and characteration of the interfering signal. This initial step is essential for the classification of the interference type and the applicable measurement techniques to mitigate it. The interference characterization includes the interfering signal power level, frequency, bandwidth and periodicity, for which, a combination of measurement functions is used that provides different attributes of the RF signals:

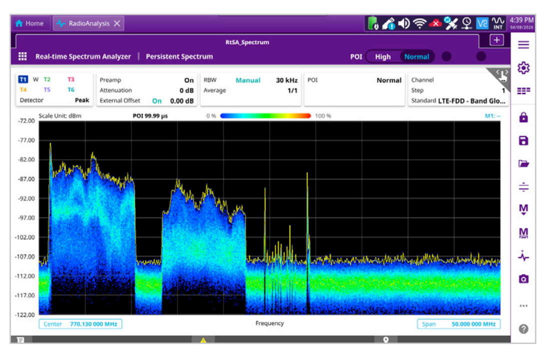
Swept-Tune Spectrum Analysis

A traditional method to characterize RF interfering signals, particularly effective for continuous and constant interferers. The use of multiple traces, such as max-hold and min-hold, captures the signal's power envelope providing a better visualization on the signal's power variation over time.



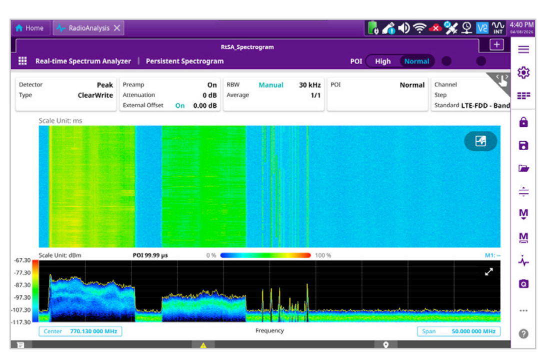
Real-time Persistent Spectrum

Real-time spectrum instantaneously captures the entire spectrum within a defined bandwidth, without any gaps. The addition of persistent spectrum allows visualization of how often the signal's power varies over time, detecting fast or bursty signal.



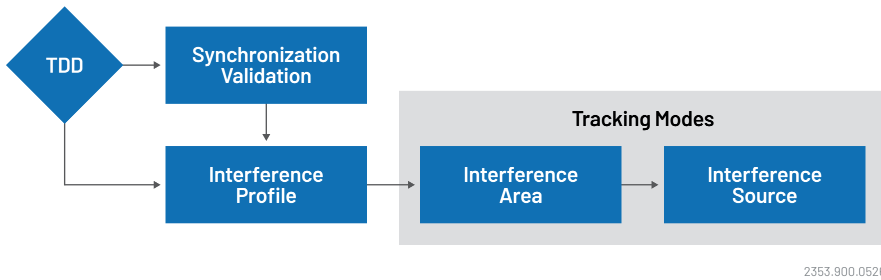
Spectrogram

The spectrogram provides a time-correlated view of the spectrum, effectively mapping the power level of the spectrum over time. This is essential for identifying frequency-hopping signals, or periodic interference patterns.



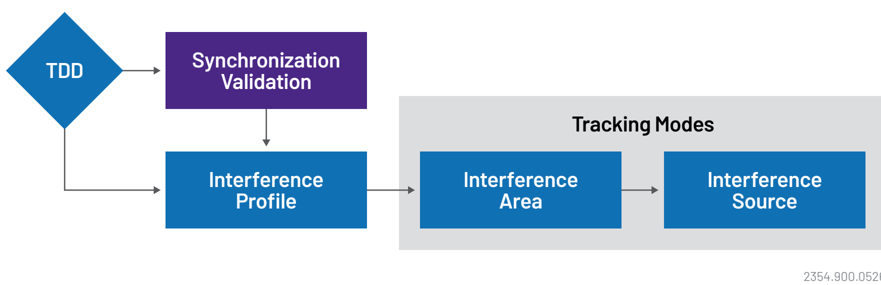
RF Interference Mitigation

The RF interference mitigation process covers three main aspects for localizing the interference source:



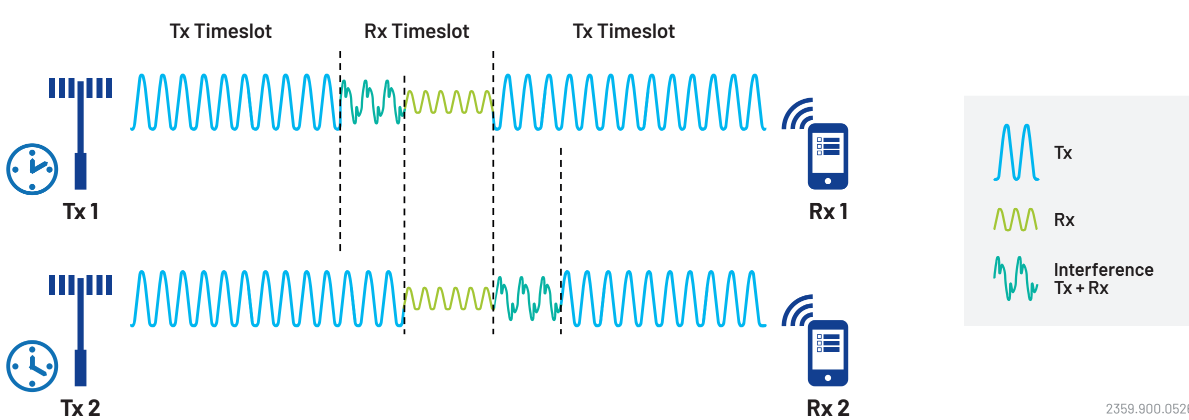
Interference Mitigation Process

Synchronization Validation

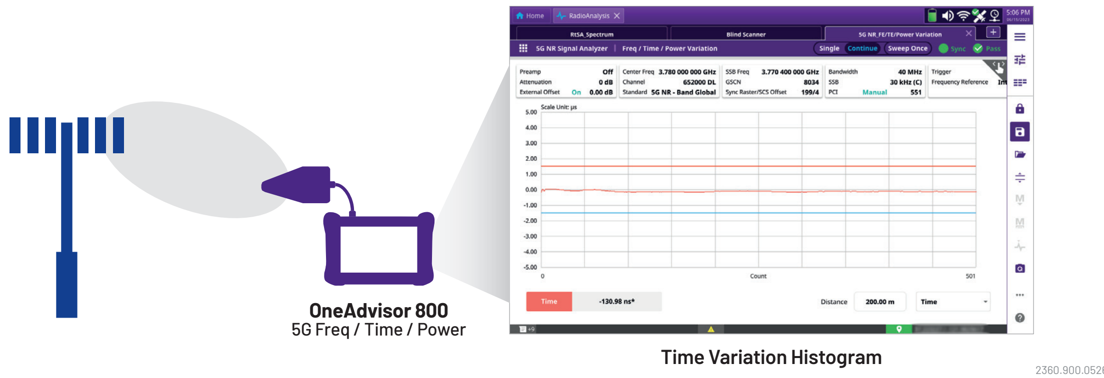


Synchronization Validation

Synchronization in communication systems based on time division duplex (TDD) is critical to maintain proper transmission and reception timing, otherwise if adjacent radios have different synchronization base it'll create intra-network interference. Therefore, it is important to first validate proper synchronization in TDD networks before proceeding to the Interference Profile stage.

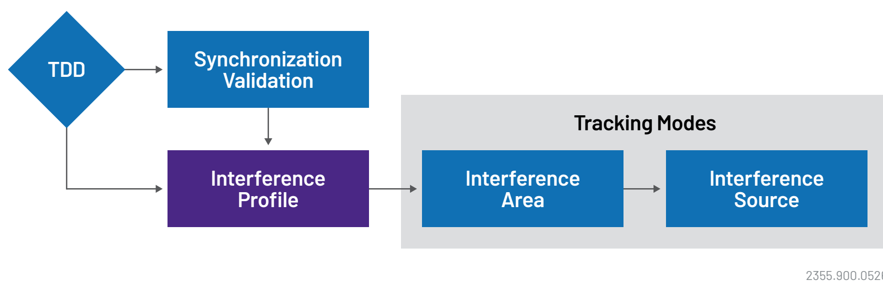


Synchronization and Interference in TDD



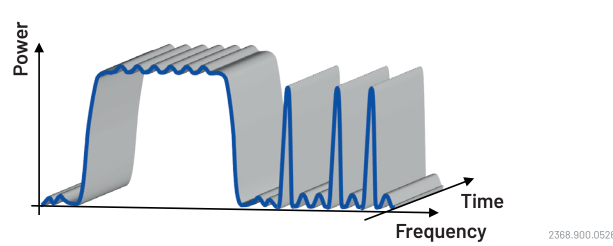
OneAdvisor 800 Wireless | TDD Synchronization Validation

Interference Profile



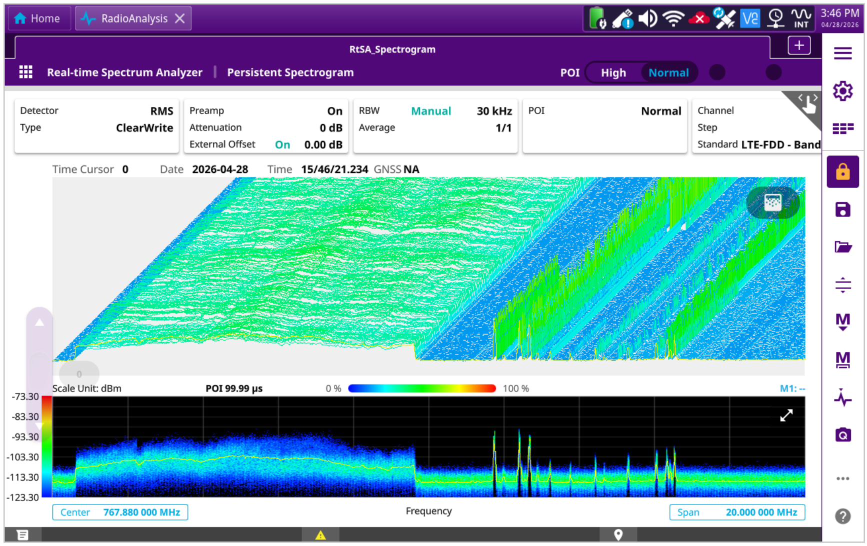
Interference Profile

RF signal profile refers to the comprehensive characterization of an interfering signal based on its spectral, temporal, and statistical properties. Spectral characterization includes parameters such as frequency, bandwidth and power distribution. Temporal characterization captures how the signal change over time, including its duration, duty cycle, and burst behavior. Statistical characterization provides insight on the variability of the signal, such as amplitude distribution, occurrence probability, and persistence.

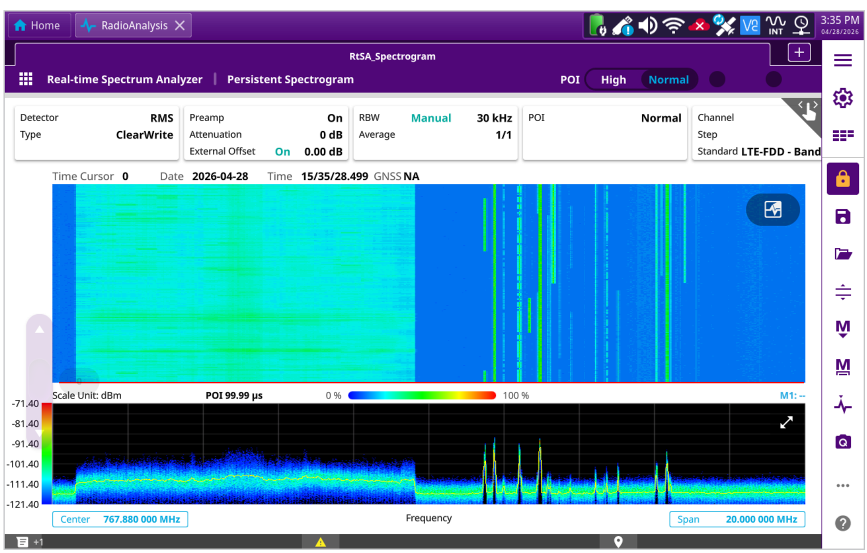


RF Signal Profile (Power, Frequency, Time)

In practice, RF profiling is primarily done using real-time spectrogram analysis, which provides a time-correlated representation of frequency and power. This enables simultaneously observe frequency, amplitude and time dynamics of the signal under test, making it particularly effective for identifying intermittent, frequency-hopping, or low-duty-cycle interference. Additionally, real-time persistent spectrum further enhances this profiling by revealing signal occupancy and recurrence patterns.



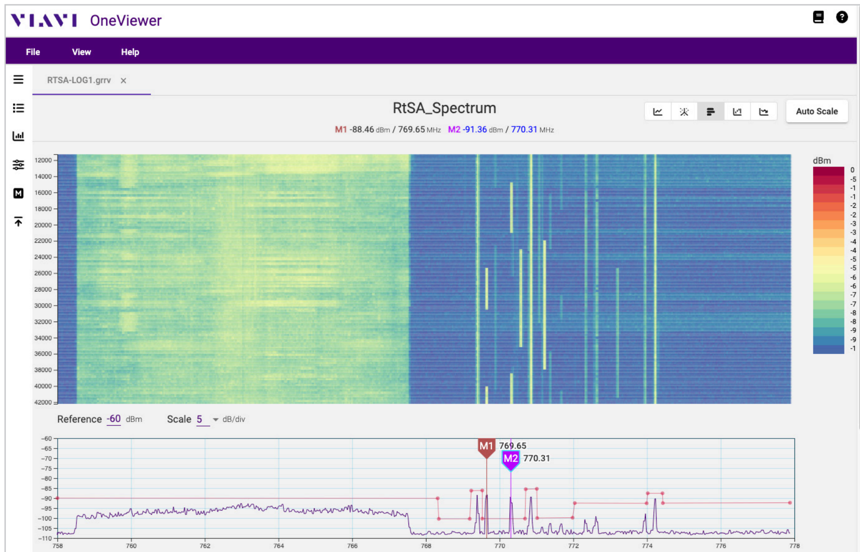
OneAdvisor 800 Real-Time Spectrum Analysis | Spectrogram 3D



OneAdvisor 800 Real-Time Spectrum Analysis | Spectrogram 2D

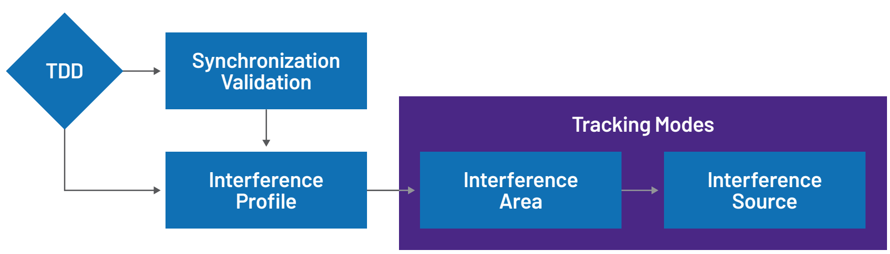
In case RF interference conditions are not constant, it is necessary to log spectrum measurements over an extended period of time to capture intermittent, or low duty-cycle interference. Real-time observations alone may miss transient events, making long-duration recording essential for accurate signal profiling.

This is achieved by logging spectrum using the OneAdvisor 800 Wireless, the recorded data can be post-processed using VAIVI's post analysis application OneViewer, enabling deeper analysis through tools such as spectrograms, markers, traces, and spectrum masks.



OneViewer Post-Analysis Application

Interference Tracking Mode



Tracking Modes

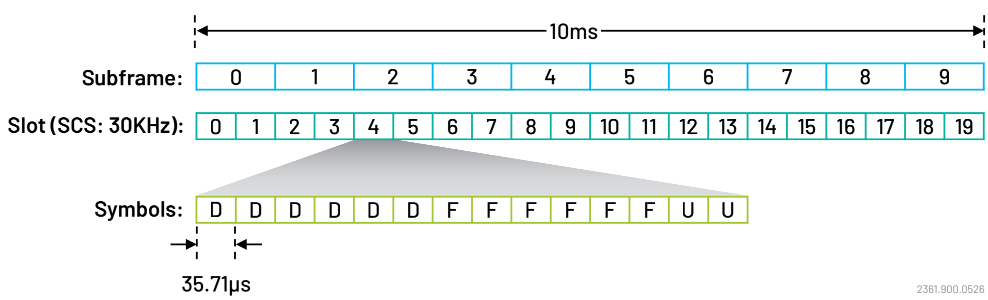
The interference profile will indicate the most effective tracking and measurement technique to effectively detect the interference source. In general, these tracking modes can be classified as follows:

Tracking Mode	Description	Interference Source
Channel Power Measurements	Channel power is used for wideband interfering signals, typically with bandwidths greater than 1MHz. It measures the total integrated power over a specified frequency bandwidth.	Broadband amplifiers, and wideband emissions from PIM, among others
Received Signal Strength Indicator (RSSI)	RSSI is used for narrowband interfering signals, generally with bandwidths below 1MHz. It measures power at a specific frequency.	Video cameras, and smart grid devices, among others
Peak Power Measurements	Peak power is used for frequency-hopping signals that are not constantly present in a specific frequency.	Industrial machinery, and switching systems, among others.

Interference in TDD

For systems based on time division duplex (TDD), such as 4G-TDD and 5G-TDD, after validating proper radio synchronization, the interference analysis requires time-selective or gated interference measurements to isolate specific timeslots, particularly in the transition or receiver (uplink) periods to ensure that measurements do not contain signals from the transmitter (downlink) period. For example, 5G-TDD frames typically have 14 symbols per slot, and the symbol types are:

- Downlink, for the transmission of radio resources
- Flexible, for guard period between downlink and uplink
- Uplink, for the transmission of mobile resources

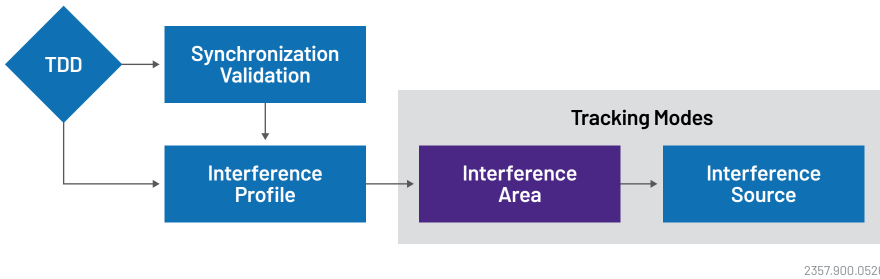


5G Frame Configuration

The OneAdvisor 800 has the capability to perform TDD Auto-Gated Spectrum (TAGS[P]) which is a patented algorithm that automatically detects the configuration of the transmission frame, including downlink and uplink slots and symbols; and subsequently set interference analysis in the flexible symbols.

OneAdvisor 800 Wireless | TDD Auto-Gated Spectrum (TAGS[P])

Interference Area

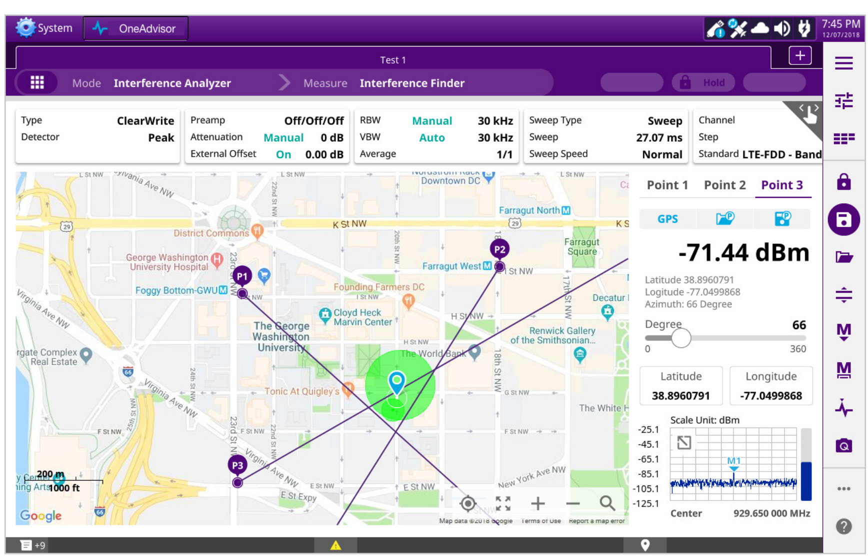


Interference Area

Based on the characterized RF signal profile, the corresponding signal tracking mode should be used to find the location area of the interference. This interference area can be identified using two primary methods:

- **Triangulation Method:** this conventional approach estimates the direction of arrival of the interference signal from multiple test points at different locations. It requires an antenna system composed of a directional antenna, a global navigational satellite system (GNSS) receiver for geo-referencing, and an electronic compass to determine the direction or azimuth of the interference. Multiple directional test points from different locations produce an intersection of bearing lines indicating the location area of the interference.

The following is an example of the triangulation methodology performed by the OneAdvisor 800 Wireless, Interference Finder:

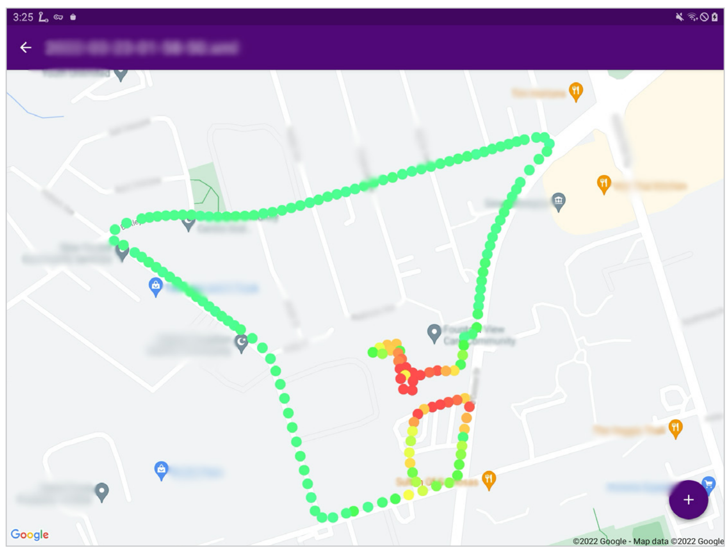


OneAdvisor 800 Interference Finder | Triangulation

It is recommended that measurements at each test point be conducted in locations with minimal or no obstruction to limit reflections and scattering, which can introduce bearing errors. Clear line-of-sight conditions improve direction accuracy increasing confidence of the intersection area.

- **Drive Test Method:** this method involves continuous measurement of interference power levels while moving through the environment. It requires a GNSS receiver, an omnidirectional antenna, and a system capable of logging RF power correlated with the location data, producing a geo-reference heat map of the interference, where the higher power levels indicate the location area of the interference.

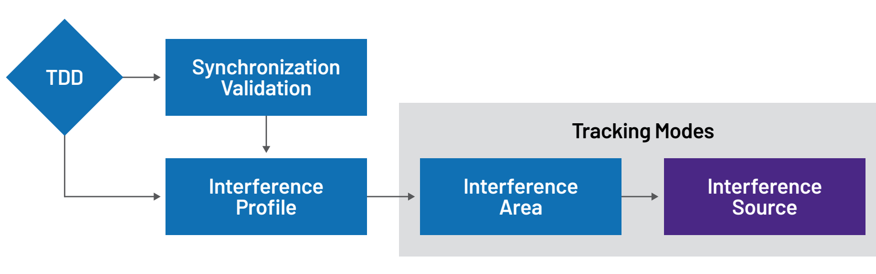
The following is an example of the drive test methodology performed by VIAVI's Interference Advisor in conjunction with the OneAdvisor 800:



Interference Advisor | Drive Test

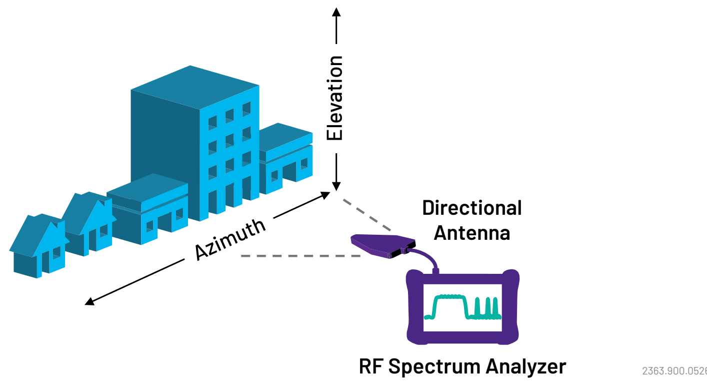
It is recommended to collect a sufficient relevant number of data samples surrounding the interference area to reduce the impact of reflections, this improves the reliability of the resulting geo-reference heatmap with a better approximation of the true location of the interference area.

Interference Source



Interference Source

The last step of the process is to find the interference source, which is typically done by an RF spectrum analyzer combined with a directional antenna. This process is based on direction finding and signal strength maximization.



Interference Source Finding | RF Spectrum Analysis and Directional Antenna

The spectrum analyzer is configured accordingly to the RF signal profile, including center frequency, frequency range, resolution bandwidth, sensitivity, and tracking mode. This will ensure stable and repeatable measurements of the interfering signal.

A directional antenna is used to measure the direction or angle of arrival of the interfering signal by sweeping the antenna in azimuth and elevation, locating the area where the maximum signal power is received, indicating the bearing toward the interference source. By moving closer to the source and repeating measurements at multiple positions, the search area is progressively reduced.

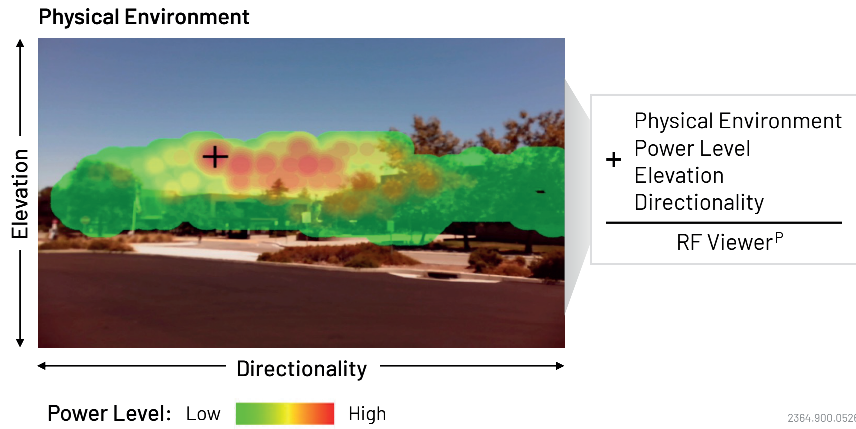
There are different challenges with this conventional approach due to the limited correlation of the power levels in the spatial environment, including the following:

- It does not provide a direct indication of the interference direction or origin
- It relies on manual measurement correlation of power in the environment
- Localization becomes cognitive and iterative
- Reflections and scattering from buildings and structures can produce false positives
- A strong signal level does not necessarily indicate the true direction of the source
- Requires repeated measurements and experimentation to differentiate direct paths from reflections

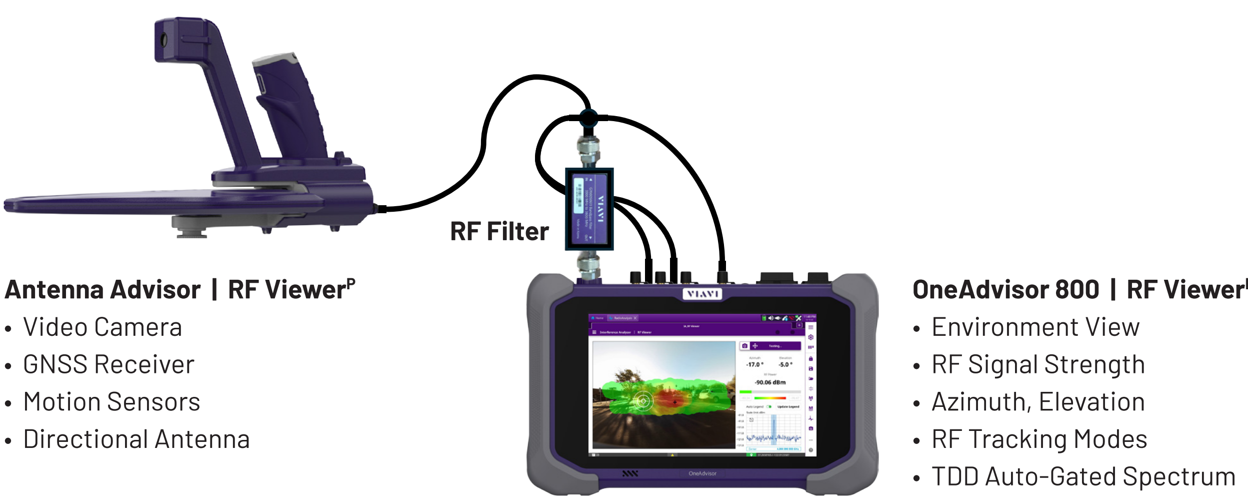
These challenges have been significantly reduced with the OneAdvisor 800 RF Viewer^{P} which provides visualization of the RF signals in the spatial environment.

OneAdvisor 800 RF Viewer^{P}

The OneAdvisor 800 RF Viewer^{P} provides an augmented reality (AR) approach to RF interference detection and analysis. Designed to deliver intuitive, real-time visibility of RF signals within the physical environment, RF Viewer^{P} overlays RF signal strength data directly onto an image of the physical environment. This allows field technicians and engineers to quickly identify the location, intensity, and spatial distribution of RF emissions, accelerating root-cause analysis and improving the resolution of uplink interference issues.



The OneAdvisor 800 RF Viewer^{P} is designed for field testing applications integrating a comprehensive set of tracking modes and TDD Auto-Gate Spectrum (TAGS^{P}) capabilities of the OneAdvisor 800 wireless instrument. It is further enhanced by the Antenna Advisor solution, which incorporates a directional antenna along with motion sensors, GNSS receiver and a video camera.



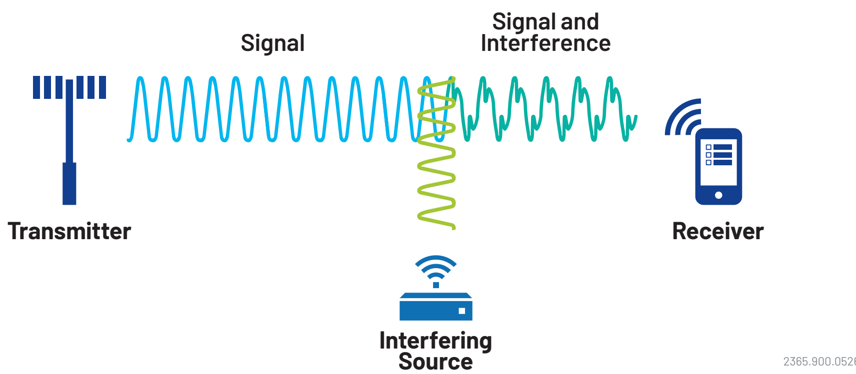
OneAdvisor 800 RF Viewer^{P} | Augmented Reality with RF Visualization

This combined system captures the RF conditions within the physical environment by correlating, in real-time, signal strength, azimuth (directionality), and elevation with a visual image of the physical environment. The result is an augmented reality (AR) view that overlays RF emissions onto the environment, enabling intuitive visualization of RF signals.

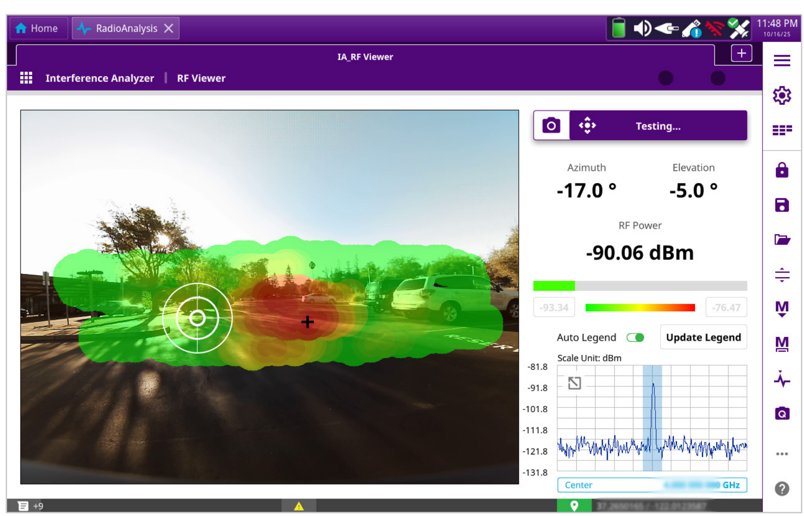
The OneAdvisor RF Viewer^{P} enables intuitive localization and identification of interference sources, significantly improving the efficiency and accuracy of RF interference analysis in complex field environments.

Radiated External Interference

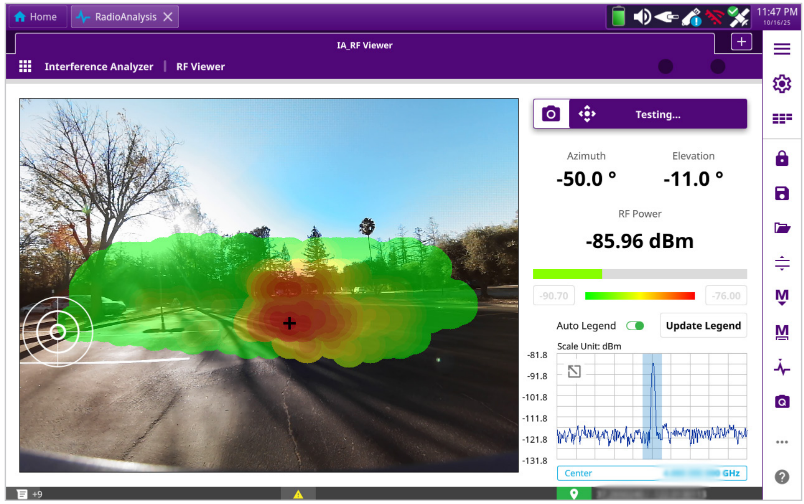
Radiated interferences originate from external emitters that transmit signals disrupting the radio waves of an RF system. These external emitters may be intentional such as jammers, or unintentional such as malfunctioning electronics.



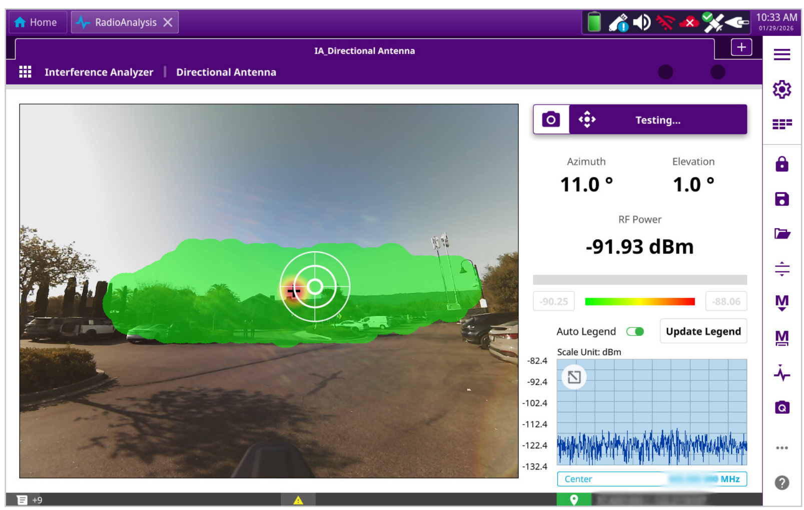
The following are some RF Viewer[P] examples demonstrating the location of external RF interference:



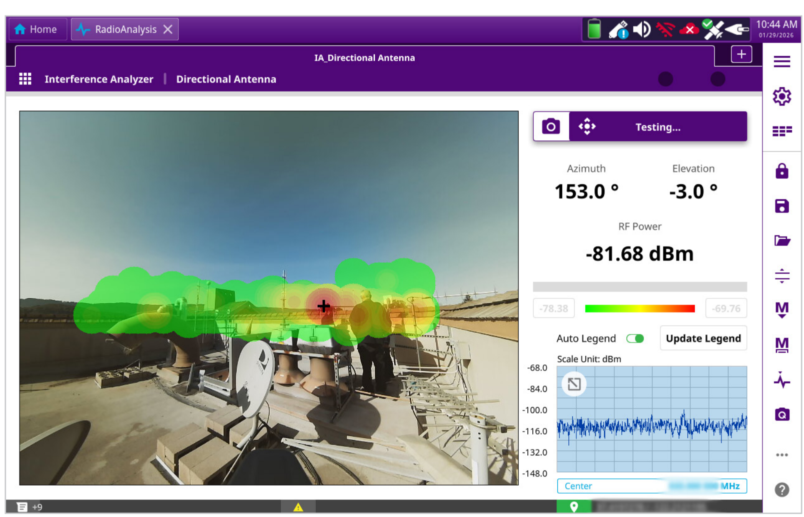
RF Viewer[P] | Radiated External Interference | Case 1 at 386ft (118mts)



RF Viewer[P] | Radiated External Interference | Case 1 at 204ft (62mts)



RF Viewer[P] | Radiated External Interference | Case 2 at 212ft (65mts)

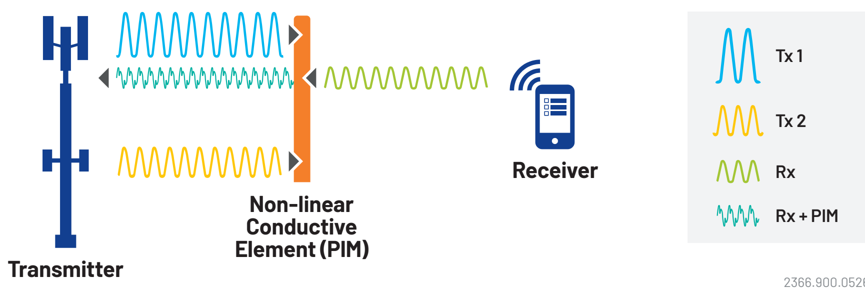


RF Viewer[P] | Radiated External Interference | Case 2 at 22ft (6.7mts)

PIM Generated External Interference

PIM generated interferences are created from passive non-linear conductive elements where multiple RF signals mix and generate new signals as intermodulation products derived from the original RF signals.

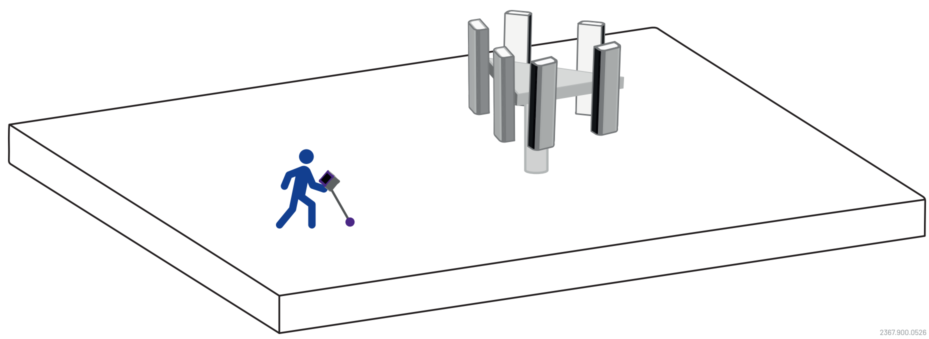
Unlike radiated interference from active transmitters, PIM is locally generated and can be an in-band interferer if the resulting intermodulation products fall within the receiver's operating frequency, for example the uplink. It is typically dependent on transmit power levels and may vary with environmental conditions such as temperature and mechanical stress.



The following are some third intermodulation products (IM3) generated by radios that interfere with mobile devices:

Frequency 1 Downlink (MHz)		Frequency 2 Downlink (MHz)		PIM (IM3) Uplink (MHz)	
Band 5	869	Band 5	894	Band 5	844
				Band 41	2632
				Band 41	2657
Band 5	880	Band 2	1950	Band 77	3710
Band 2	1930	Band 2	1990	Band 2	1870
Band 2	1930	Band 12	730	Band 42	3510
Band 5	880	Band 13	750	Band 41	2510
Band 4	2120	Band 5	880	Band 77	3880
Band 4	2120	Band 12	730	Band 42	3510
				Band 42	3580
Band 4	2120	Band 12,17	740	Band 42	3500
				Band 42	3600
Band 4	2120	Band 13	750	Band 42	3620
Band 12	730	Band 13	750	Band 12	710
Band 12	736	Band 14	763	Band 12	709
Band 12,17	740	Band 14	760	Band 13	780
Band 5	880	Band 14	760	Band 41	2520
Band 2	1950	Band 13	750	Band 42	3450
Band 2	1950	Band 12,17	740	Band 42	3430
Band 12	730	Band 71	620	Band 5	840

Traditional methods of locating sources of external PIM consider the use of a spectrum analyzer and an antenna probe, allowing technicians to walk around suspect areas such as roof-tops while monitor signal levels from suspected PIM generated structures.



External PIM Finding with Spectrum Analyzer and Antenna Test Probe

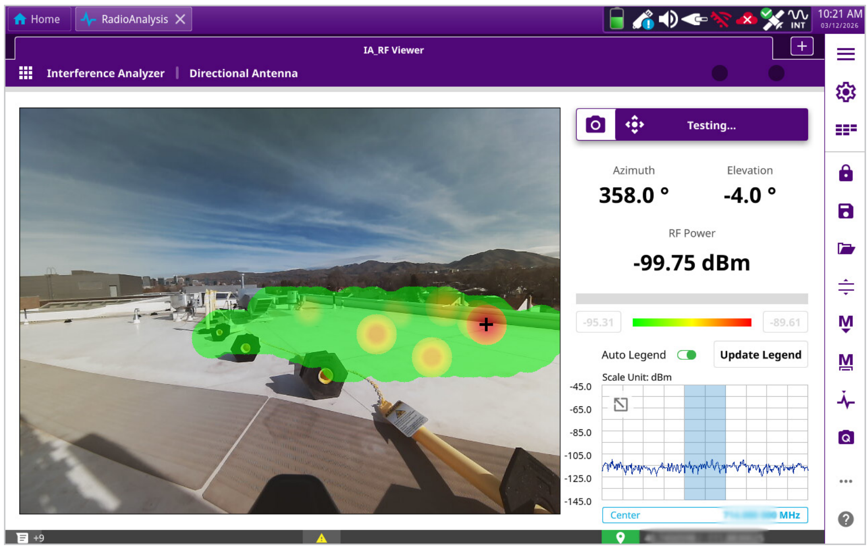
There are several limitations of this methodology, including the following:

- Measurements are discrete and localized
- Not an entire view of the PIM generated distribution
- Sometimes PIM generated sources are not visible structures, such as infrastructures with hidden construction materials
- Operator must mentally map signal levels to physical structure
- Requires continuous movement and assessment
- False positives of reflections from the true PIM generated source
- Operator can change the conditions of the PIM generated source by blocking signals or stepping on metal materials that are generating PIM products
- Operator can generate PIM products due to the presence of metallic elements, such as keys or test instrumentation

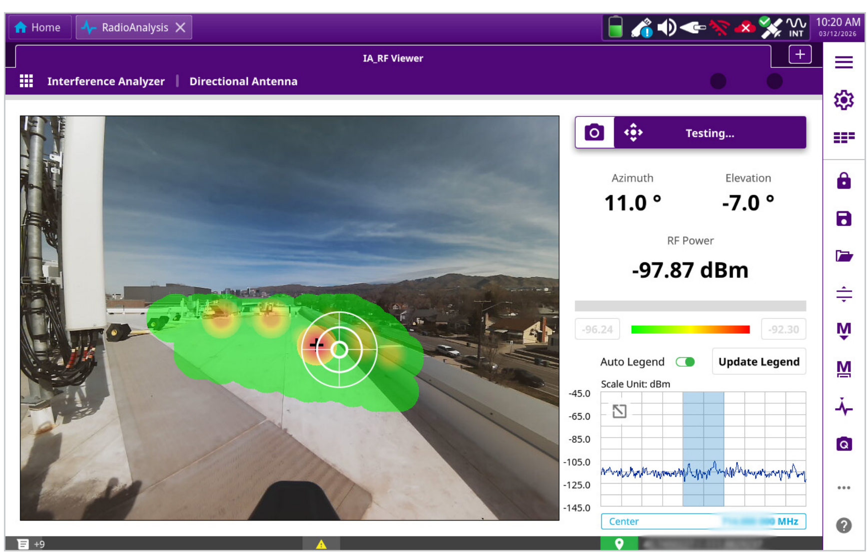
These challenges have been significantly reduced with the OneAdvisor 800 RF Viewer[P] which provides visualization of the RF signals in the spatial environment. Some of its benefits include:

- Provides a site-wide view of the PIM-generated energy distribution
- Highlights hotspots associated with true PIM sources
- PIM reflections appear diffuse or inconsistent and lower-level signal levels
- True PIM sources appear stable and localized in high intensity regions
- Eliminates the need of mental reconstruction of signal levels with the environment
- Reduces test time and PIM mitigation material
- PIM sources can be identified without extensive walking, thereby reducing the risks associated with walking on roof-tops

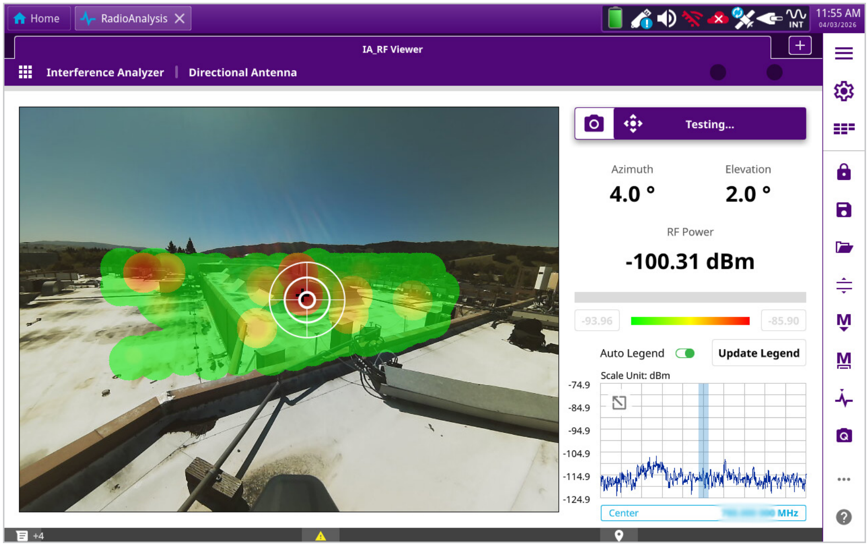
The following are some RF Viewer^{P} examples demonstrating the location of PIM generated interference:



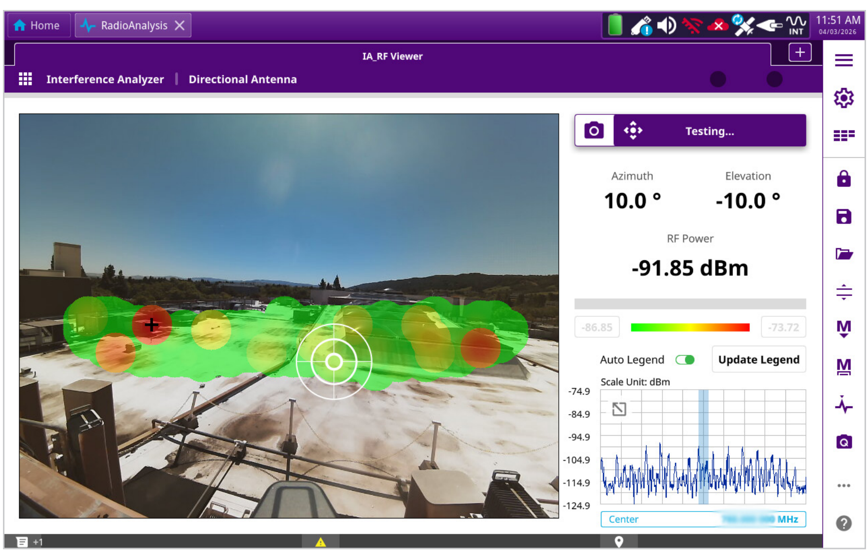
RF Viewer^{P} | PIM Generated Interference | Case 1 Sector Left



RF Viewer^{P} | PIM Generated Interference | Case 1 Sector Right



RF Viewer[P] | PIM Generated Interference | Case 2 Sector Top NE



RF Viewer[P] | PIM Generated Interference | Case 2 Sector Top E

Contact Us: +1 844 GO VIAVI | (+1 844 468 4284). To reach the VIAVI office nearest you, visit viavisolutions.com/contact

oneadvisor800-rf-inter-visual-an-nsd-nse-ae
30195098 900 0626