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TELECOMMUNICATIONS INDUSTRY FOUNDATION

The Telecommunications Industry Foundation (TIF) is pleased to announce the publication of the following White Paper:

Navigating the Challenges of External PIM on Rooftop Sites

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Introduction

In urban environments, wireless infrastructure is increasingly deployed on rooftops due to limited space for macro communication towers. Rooftop sites offer a practical and cost-effective solution for enhancing coverage and capacity in densely populated areas. By leveraging existing structures, providers can strategically position antennas while avoiding the complexities of new macro tower deployments.

However, these benefits are accompanied by unique challenges, particularly the prevalence of external passive intermodulation (PIM). This phenomenon, if not addressed, can significantly degrade network performance. This Planning Advisory Notice (PAN) outlines the challenges of rooftop PIM and provides best practices for assessment and mitigation.

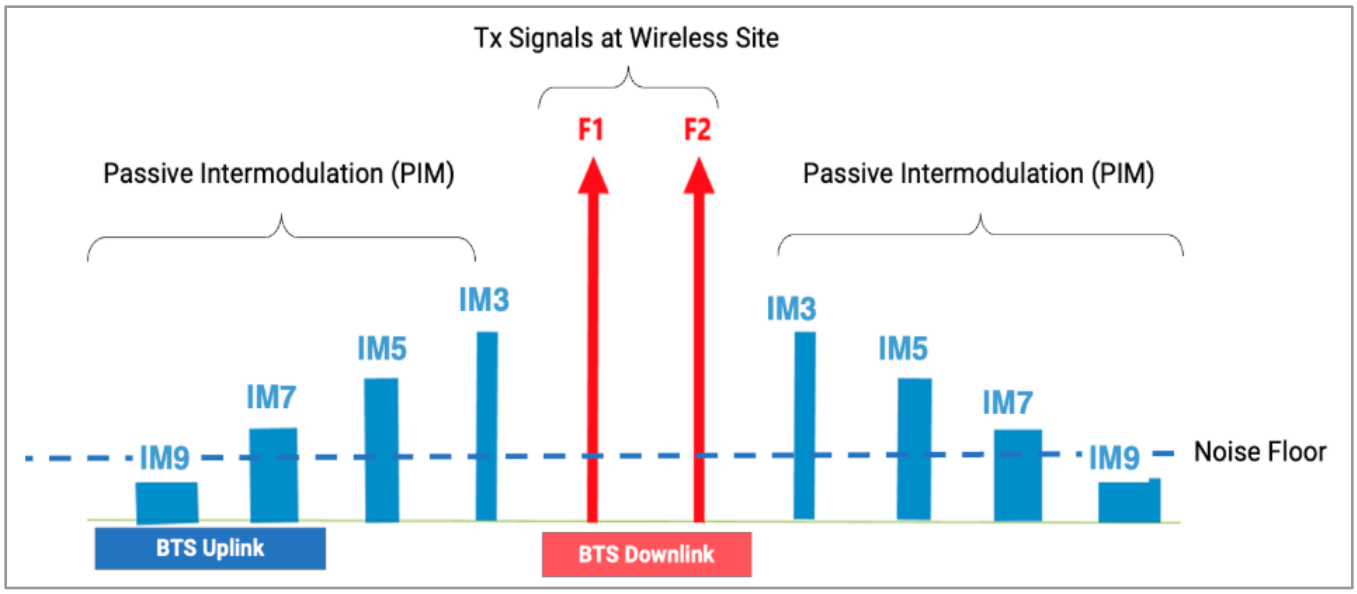
Objectives of This Paper

The objectives of this White Paper are to:

- Raise Awareness: Highlight the increasing challenges associated with external PIM on rooftop wireless sites and its impact on network performance.
- Provide Clarity: Differentiate between internal and external PIM sources to streamline troubleshooting processes.
- Share Best Practices: Offer actionable solutions for identifying, mitigating, and preventing PIM issues, including the use of specialized tools and structured methodologies.
- Promote Industry Standards: Encourage adherence to proven construction, maintenance, and design practices to minimize the prevalence of external PIM.
- Enhance Collaboration: Foster a coordinated approach among site acquisition, RF design, site construction, and RF optimization teams to address PIM holistically.

Understanding Passive Intermodulation (PIM)

Passive Intermodulation (PIM) occurs when transmit signals at a cellular site interact with non-linearities in the RF path, like loose connections or damaged components, resulting in the generation of new frequencies. These undesired PIM signals can overlap with the uplink frequency band, increasing the noise floor and causing interference. The impact of this interference can be severe, leading to network challenges such as call drops, connection failures, and slower data speeds, all of which degrade the overall user experience and compromise network reliability.

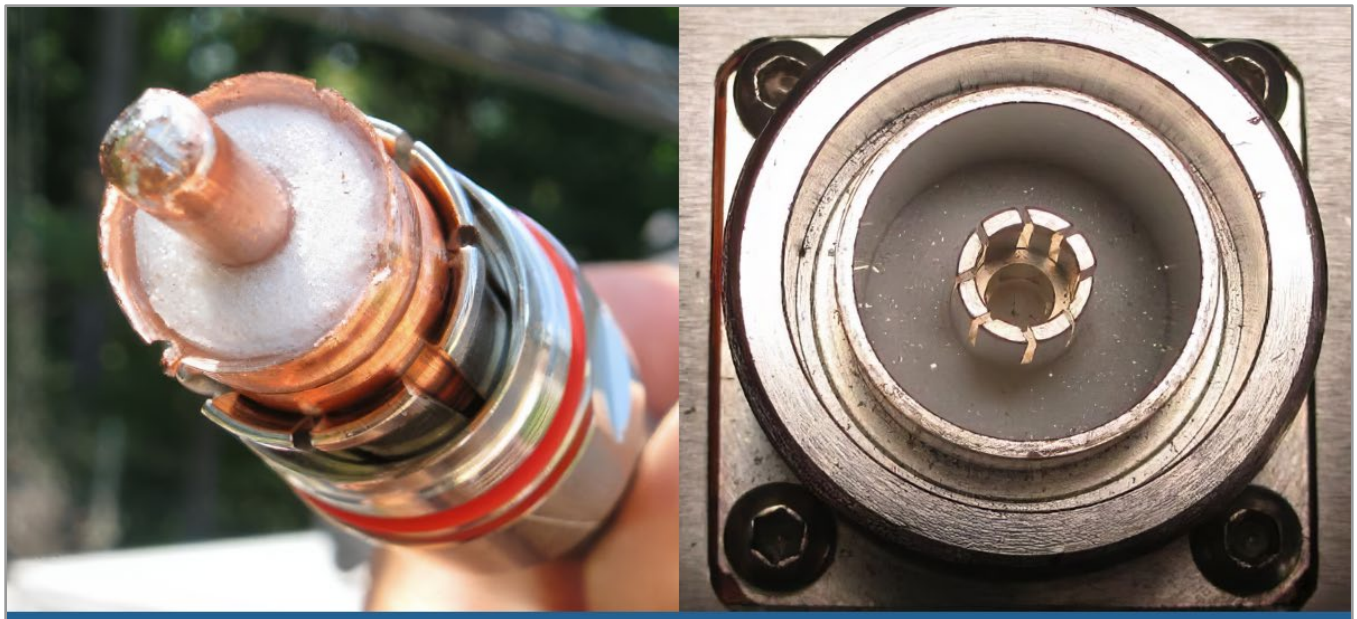


Passive Intermodulation (PIM) problems often arise due to poor construction or maintenance, resulting in metal-to-metal non-linearities or galvanic corrosion. These challenges are generally classified into two types: Internal PIM and External PIM, with examples including:

Internal PIM

Originates within the feed system, including the antenna, and is commonly caused by:

- Improperly torqued RF connectors
- Contaminants such as metal shavings inside coaxial cables
- Inadequate surface preparation during assembly
- Broken solder joints disrupting electrical continuity



Internal Passive Intermodulation (PIM)

External PIM

External PIM occurs beyond the antenna and is often the result of:

- Rusty metal surfaces
- Loose hardware
- Lightly touching metal surfaces
- Galvanic corrosion from dissimilar metals in contact

External Passive Intermodulation (PIM)

Proper site construction and maintenance are critical to mitigating both internal and external PIM.

Challenges of Rooftop Sites

External PIM is significantly more common at rooftop wireless sites than at tower or monopole sites. This disparity stems from the inherently uncontrolled nature of rooftop environments, which contrasts with the highly regulated infrastructure of macro tower sites. Key factors include:

- Unpredictable Surroundings
  Rooftops are part of existing buildings and are exposed to various external factors that can't always be managed. Unlike macro sites, which have fewer surrounding interferences, rooftops are surrounded by objects such as HVAC units, power lines, billboards, piping, railings, and unrelated deployments.

- Metal-to-Metal Contacts
  External PIM is often caused by corrosion on metal surfaces and shifting components due to environmental factors like wind or temperature changes.

- Distance of Interference Sources
  Many site surveys have revealed unexpected PIM sources located hundreds of feet from the antenna which include parapet walls, roof flashings and fasteners, drain covers and power lines.

The combination of these factors makes rooftop sites more prone to PIM issues, presenting unique challenges in managing interference and maintaining optimal performance.

Troubleshooting External PIM

Diagnosing PIM issues can be complex, often requiring crews to revisit sites multiple times for the same unresolved problem. These repeat trips lead to hours spent swapping out hardware like radios, jumpers, and antennas, only to discover that the issue persists because it stems from external interference. This trial-and-error approach results in unnecessary equipment replacement and wasted time and money for both contractors and carriers.

Many of these challenges can be minimized with the right tools and a structured troubleshooting process. It is recommended to designate specific crews for this work - folks with some technical background paired with those who enjoy an occasional challenge, when most days are different versus the repetitive aspects of some projects.

The primary difficulty lies in determining whether the problem originates within the antenna itself or from external environmental factors. To address this, one of the most effective tools is an absorber kit. By installing an absorber kit directly onto the antenna, this isolates the antenna from the external environment without introducing excessive reflections or additional PIM. This approach simplifies the diagnostic process, helping crews quickly determine if the antenna or the external surroundings are the root cause of interference, ultimately saving significant time and resources.

Using RSSI Monitoring to Identify PIM Sources

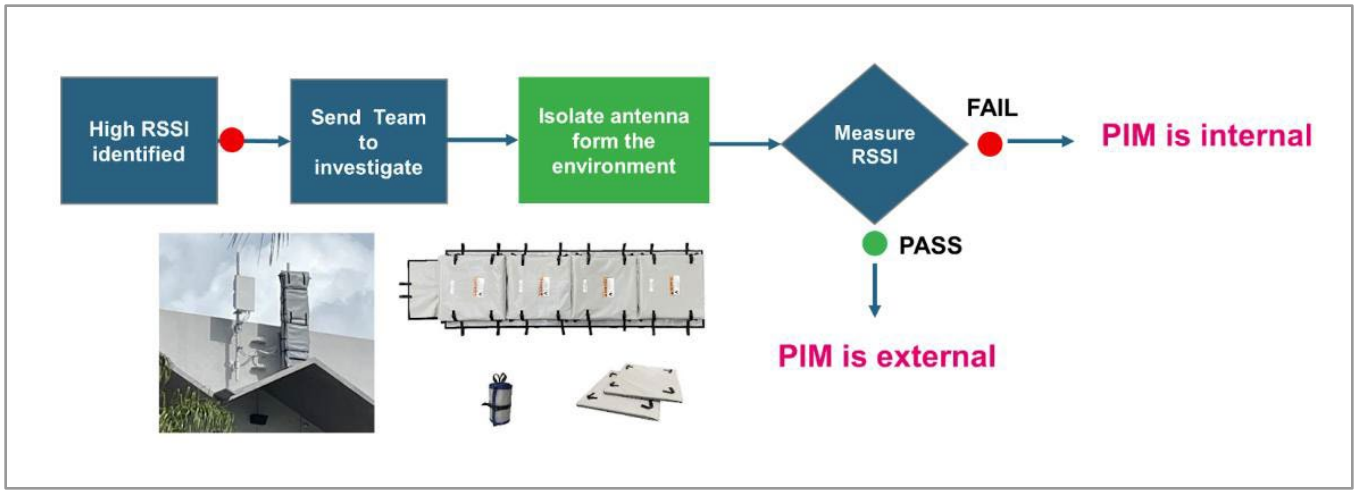
Receive Signal Strength Indicator (RSSI) monitoring is a reliable method for distinguishing between external and internal PIM issues, particularly when combined with 100% artificial loading on the radio. This method requires network access and prompt feedback of RSSI data; therefore, close cooperation between contractor and carrier personnel is needed. While this level of cooperation may be new in the industry, it has been proven effective in successfully and efficiently troubleshooting sites with PIM. Alternatively, a CPRI analyzer can be used to monitor RSSI changes in real-time. By tapping into the fiber via an optical splitter between the RRU and the BBU, the contractor can see RSSI fluctuations instantly, eliminating any wait time for results. An added benefit of using a CPRI analyzer is the ability to observe external interference signals at the same time.

The testing process involves observing changes in RSSI levels before and after installing an absorber kit:

- External Interference Indicated
  If the noise disappears when the absorber kit is installed, the issue is external, originating from the surrounding environment rather than the hardware.

- Internal Fault Identified
  If the noise remains high (or increases) after the absorber kit is installed, the problem is internal, likely involving the antenna, jumper, or radio.

ConcealFab® PIM Shield® Blanket



This method is very efficient because it allows all cables and connections to remain in place during testing, all ports/bands can be tested at the same time, and the sector can carry traffic during the process.

PIM Hunting Process

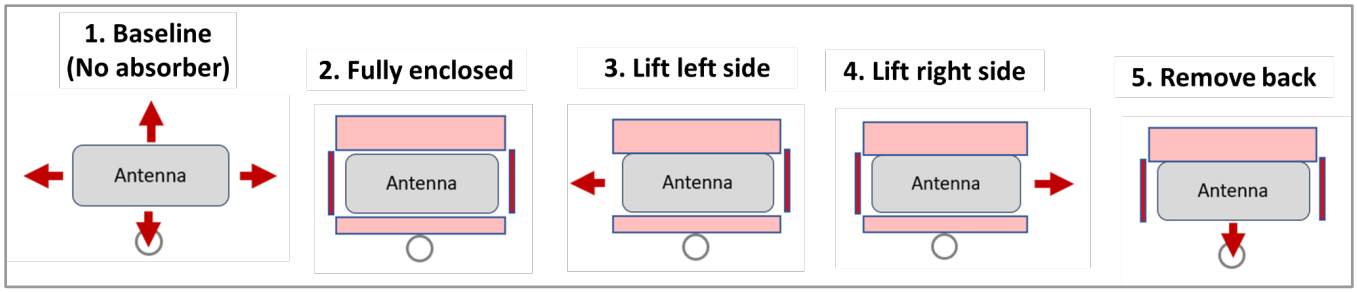
Troubleshooting internal PIM issues is relatively straightforward. By systematically isolating components, technicians can pinpoint the source of the problem:

- Attach a Low PIM Load to the failing jumpers, starting at the antenna end.
- Gradually move the Low PIM Load back toward the radio while monitoring RSSI levels, ideally with 100% artificial loading activated on the radio.

When the issue is confirmed to be external, the process becomes more intricate but also more engaging. Directionality can be determined using the modular design of the absorber kit:

- Monitor and record RSSI levels as parts of the absorber kit are lifted or removed.
- Narrow down the PIM source by identifying whether the interference originates to the left, right, behind, or in front of the antenna.

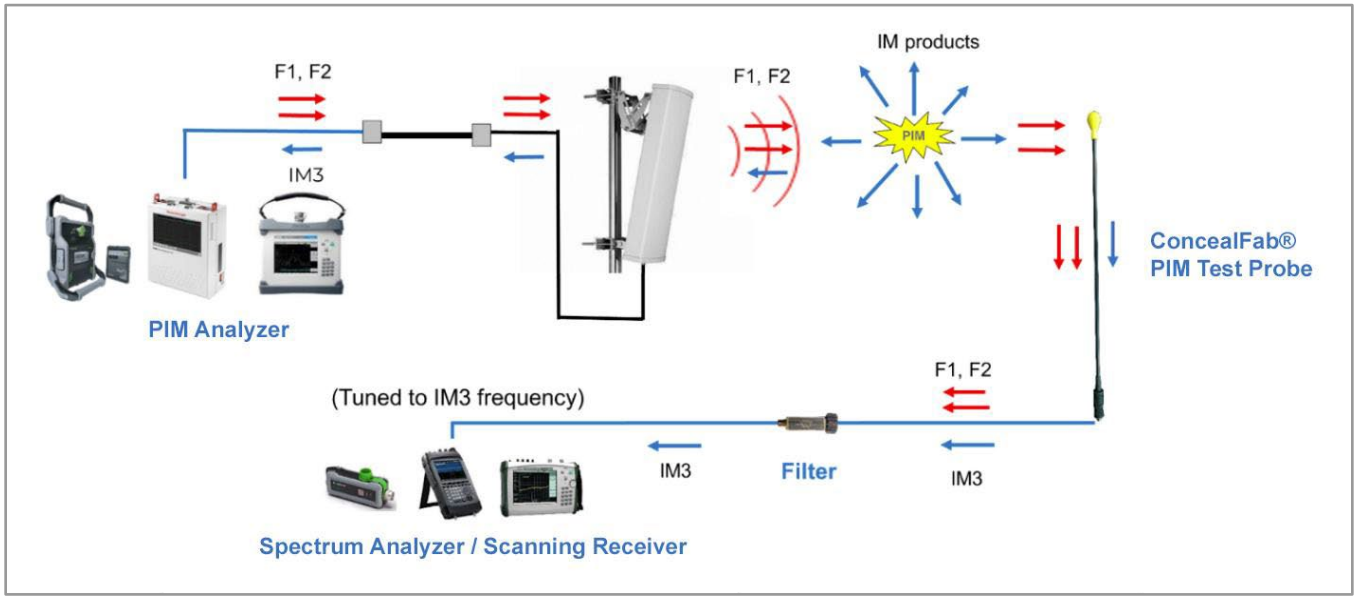
This methodical approach dramatically accelerates the process of locating external PIM sources, saving time and reducing guesswork in the field.



Once the general direction is identified, potential PIM sources can be systematically tested by covering them with RF barriers, such as blankets or absorbers, while continuing to monitor RSSI levels. Again, having the instant feedback of RSSI levels via a CPRI analyzer allows one to try a lot of things quickly.

This process often helps pinpoint the primary sources of interference. However, when multiple PIM sources exist at similar signal levels, the RSSI may not change when only one source is covered, making it challenging to isolate all contributors.

In cases where this approach fails to identify the PIM source, a more advanced method can be employed. This involves utilizing a PIM analyzer alongside a handheld spectrum analyzer paired with a PIM probe for precise detection and measurement, which can be a substantial investment for the contractor if they do not already own such equipment.



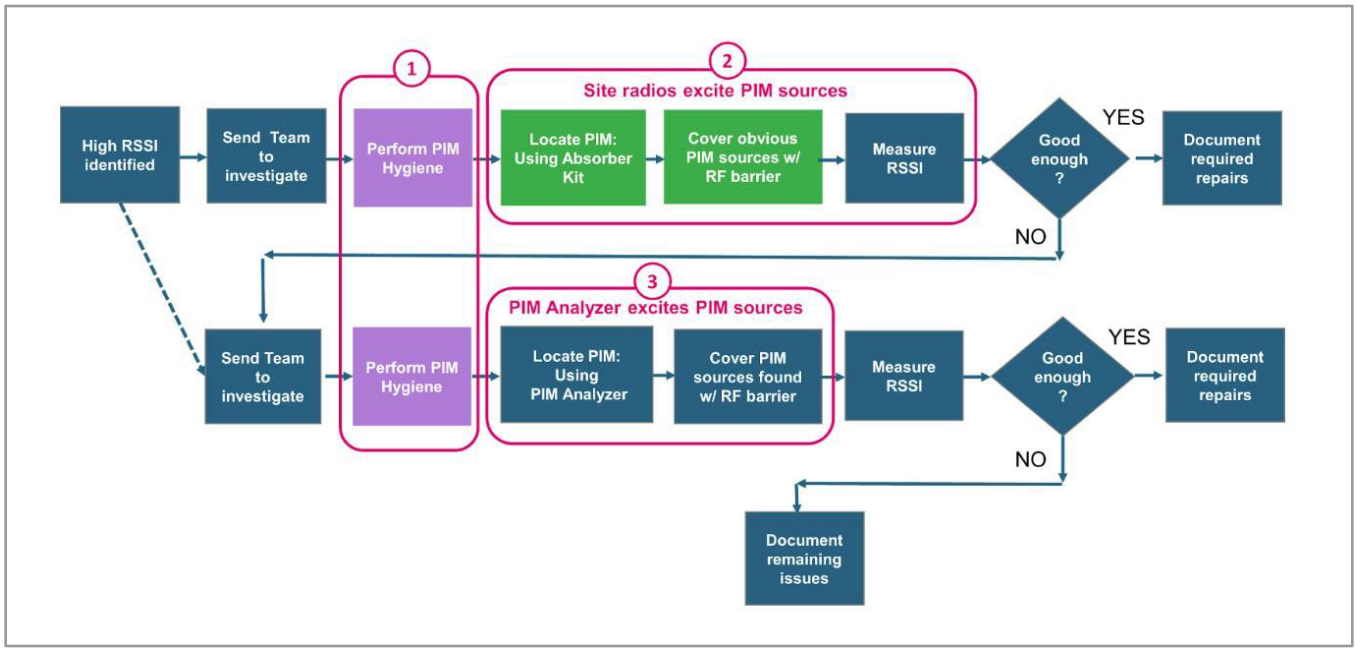
The PIM analyzer helps locate PIM sources by illuminating them, measuring the magnitude of PIM generated, and providing a Distance to PIM (DTP) measurement to guide the process. A secondary mobile receiver, tuned to the same IM3 frequency as the PIM analyzer, is connected to a PIM probe. As the probe tip nears a PIM source, the signal from the receiver becomes stronger, enabling precise identification of interference points. This approach is comparable to using a metal detector to locate items.

To ensure accurate results, a bandpass filter is required between the PIM probe and the spectrum analyzer. This prevents the mixing of the transmit tones (F1 and F2) in the receiver, which could otherwise produce misleading PIM readings and obscure the actual sources.

With the right tools and training, crews can use this process to systematically identify all PIM sources contributing to elevated uplink noise at the site.

Prioritizing PIM Hygiene

Regardless of the method used for PIM hunting, the initial step for any crew upon arriving at a site is to address PIM hygiene. Maintaining effective PIM hygiene not only accelerates the troubleshooting process but, in some cases, resolves the issue entirely without expensive equipment. Many PIM hygiene problems are straightforward to identify and fix with thorough inspection and basic tools. This cost-effective practice ensures efficient resolution and contributes to the site's long-term reliability.



PIM hygiene focuses on eliminating "known" sources of passive intermodulation near antennas. This process follows a straightforward framework: Remove, Repair, and Replace:

- Remove
  - Clear unnecessary hardware, debris, or trash within the "high-risk PIM zone," which typically spans 10 feet behind, below, and above the antenna in low and mid-band deployments.

- Repair
  - Tighten loose hardware.
  - Adjust or eliminate lightly touching metal surfaces to prevent contact.

- Address rusty or corroded areas by:
- Removing loose metal and burrs.
- Wiping surfaces clean with a solvent to remove dust.
- Applying cold galvanizing spray or paint for protection.
- Prevent dissimilar metals from touching, especially stainless steel against galvanized steel, as this combination can create galvanic mismatches that generate PIM.

ConcealFab® PIM Shield® Snap-Ins

- Replace
  - Upgrade traditional components, such as metal snap-ins and hose clamps, with low-PIM alternatives to minimize interference risks.

By systematically applying this framework, crews can significantly reduce PIM risks and improve site performance, ensuring long-term reliability and efficiency.

REMOVE	Unnecessary hardware or trash that may cause PIM
REPAIR	Existing PIM sources that are fixable
REPLACE	Traditional components with low-PIM alternatives

By following this structured approach, crews can effectively identify and mitigate PIM sources, ensuring a more reliable and efficient network. Additionally, operators should mandate these practices to enhance site performance, reduce the likelihood of future issues, and maintain optimal operational standards over the long term.

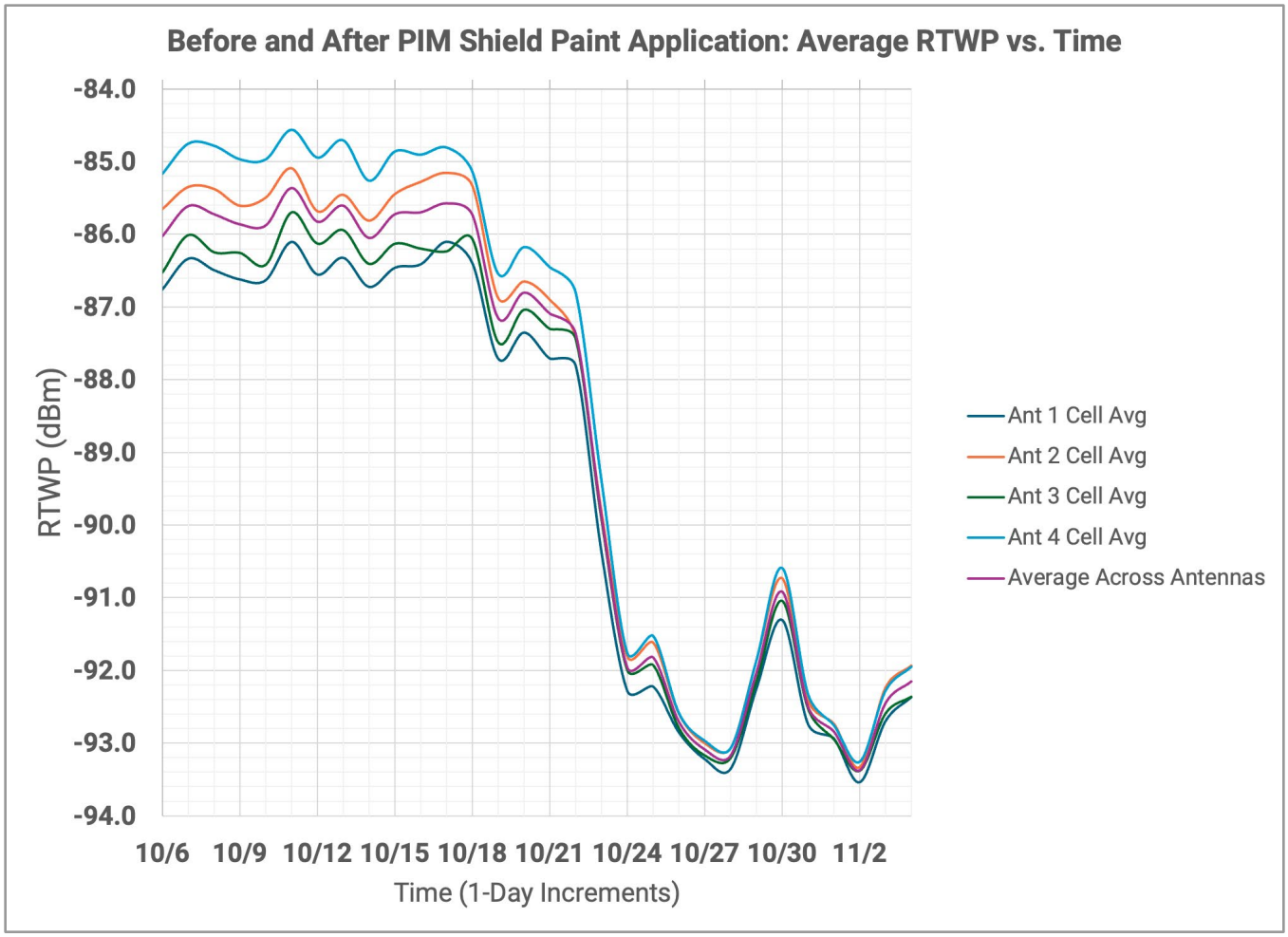
PIM Mitigation Options

On many rooftop sites, some PIM sources are unavoidable, especially those located in front of antennas. Even when operators or contractors adhere to build standards, utilize low-PIM hardware, and implement comprehensive PIM hygiene practices, they often have limited control over external factors. These factors

include building structures outside the leased area, such as roofing materials, HVAC systems, skylights, solar panels, and other nearby elements. Additionally, zoning restrictions on height and visibility may necessitate concealment solutions that further complicate the RF environment near antennas. Once a PIM source is identified in such scenarios, the challenge shifts to mitigating or eliminating it.

PIM Paint has become a reliable solution for reducing interference from many common sources, including parapet walls, roof flashings, the roofing structure itself, and smaller structural elements.

By applying two coats of PIM Paint, it is common to achieve over 17dB of RF attenuation. This significant reduction in uplink noise can lead to major performance improvements for carriers, such as better data throughput and fewer access failures. PIM Paint is particularly effective for covering large surface areas but is versatile enough for use on smaller structures as well, making it a valuable tool in mitigating PIM in challenging rooftop environments.



Future Recommendations to Ensure Network Reliability

As the demand for wireless connectivity grows and networks expand to incorporate new frequencies, external PIM will continue to be a persistent challenge. Tackling these issues directly is crucial for maintaining the reliability, efficiency, and performance of wireless networks. By leveraging the right tools, proper training, and a disciplined troubleshooting approach, rooftop PIM can be effectively managed.

Looking ahead, the industry must adopt a proactive stance. This includes refining site selection processes, optimizing antenna placement, adhering to strict material standards, and ensuring meticulous attention to detail during installation. Achieving this will require a coordinated effort across multiple disciplines within the carrier, from site acquisition and RF design to construction and optimization teams, as well as contractor training on the latest, most efficient and cost-effective methods for troubleshooting and mitigation of PIM.

Conclusion

The growing complexity of modern wireless networks demands a more strategic and integrated approach to PIM mitigation. By addressing these challenges at every stage, including planning and installation as well as maintenance and optimization, operators can maximize spectrum efficiency and significantly enhance

network performance. A commitment to innovation and collaboration will be key to delivering the reliable, high quality wireless experience that users expect in an increasingly connected world.

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- Drew Martin
- Rodger Williams
- Justin Huggins

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