PIM interference in C-Band Networks

SUMMARY

Auction 107 makes 280 MHz of new C-band spectrum available for 5G services in the 3.7 GHz to 3.98 GHz frequency range. Passive intermodulation (PIM) interference is a real concern in this band due to the many IM2, IM3 and IM5 products that can be generated by the existing low and mid-band downlinks at cell sites. These low-order IM products can elevate the noise floor reducing the speed and coverage of newly deployed C-band networks.

Solutions to mitigate external PIM generated by lower frequency downlinks are available now. While on site installing new 3.7 GHz radios and antennas, network operators have a unique opportunity to make other site modifications at minimal cost that can have a profound impact on PIM performance. This paper provides an overview of the PIM problems likely to be encountered in C-band systems and presents solutions operators can proactively deploy to improve network performance.

BACKGROUND

C-band is a generic designation given by the IEEE for radio frequency (RF) spectrum in the 4 GHz to 8 GHz frequency range. A major commercial use of this spectrum has been satellite communications with uplink frequencies between 5.925 GHz and 6.425 GHz and downlink frequencies between 3.7 GHz and 4.2 GHz. A portion of this spectrum has been re-purposed in the United States for 5G fixed and mobile services via FCC Auction 107. This auction makes 280 MHz of new spectrum available for 5G services in the 3.7 GHz to 3.98 GHz frequency range. Satellite operators have agreed to accelerated clearing to re-pack existing operations into the 4.0 GHz to 4.2 GHz frequency range. The first 120 MHz will be cleared in 46 Partial Economic Areas (PEA) by December 5, 2021 with the remaining spectrum to be cleared and available for 5G services by December 5, 2023.

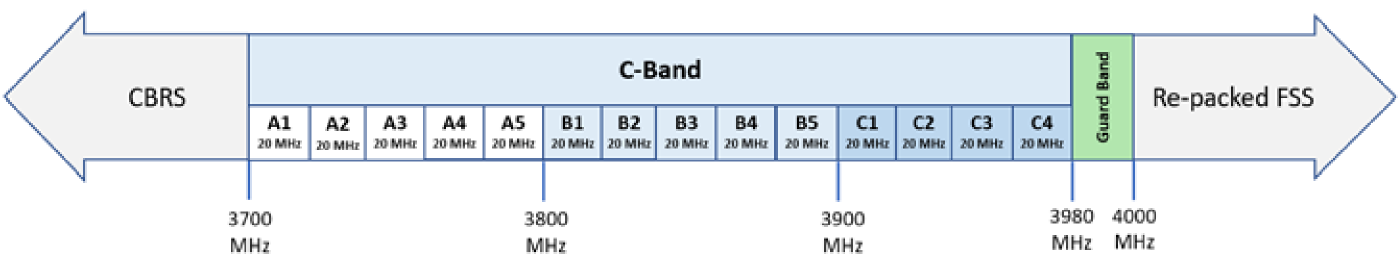

Figure 1: C-Band 5G Spectrum

The new C-band spectrum is divided into fourteen unpaired, 20 MHz frequency blocks as shown in Figure 1. Operators utilizing this spectrum will use Time Division Duplex (TDD) to multiplex uplink and downlink signals within their designated frequency blocks. TDD systems transmit and receive in different time slots with a guard time separating transmit and receive to prevent interference. The amount of time dedicated to uplink or downlink can be dynamically allocated based on varying demand. In some cases, operators may find it necessary to use fixed uplink / downlink ratios and to synchronize transmits with adjacent operators to prevent passive intermodulation (PIM) interference.

PIM occurs when the downlink signals at the site mix at passive, non-linear junctions in the RF path, creating new frequencies. If these new frequencies fall in an operator's uplink, they can elevate the noise floor resulting in reduced geographic coverage and reduced data rates. In the case of TDD systems, the PIM generated is only present when

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the radio is transmitting and not present when the radio is receiving. As a result, TDD systems operating in isolation are somewhat immune to PIM interference. However, TDD systems operating in adjacent frequency blocks must synchronize transmits to prevent PIM generated in one frequency block from interfering with an adjacent frequency block. An example of this is shown in Figure 2 where an operator utilizing the A1 block of C-Band would need to synchronize transmits with adjacent operators to prevent PIM interference.

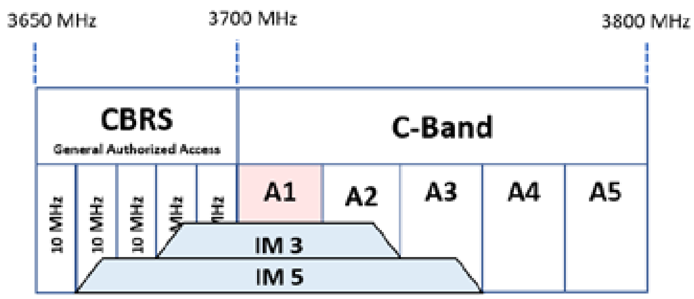

Figure 2: Tx synchronization required between adjacent operators to prevent PIM interference

Operators launching new C-band services are unlikely to deploy these systems in isolation. In most cases, the new services will be deployed on the same radio platform as existing 600 MHz, 700 MHz, 850 MHz, 1900 MHz, 2100 MHz and 2500 MHz mobile services. PIM interference generated by the other transmitters on the platform must be taken into consideration. As shown in Figure 3, multiple combinations of lower frequency services can generate low order intermodulation products falling in the C-band spectrum. Low order products such as IM2, IM3 and IM5 are significantly higher magnitude than the traditional IM7 or IM9 products commonly encountered at cell sites. IM3 is, for example, typically 35 dB (>3000x) higher magnitude than IM7 and 50 dB (100,000x) higher magnitude than IM9.

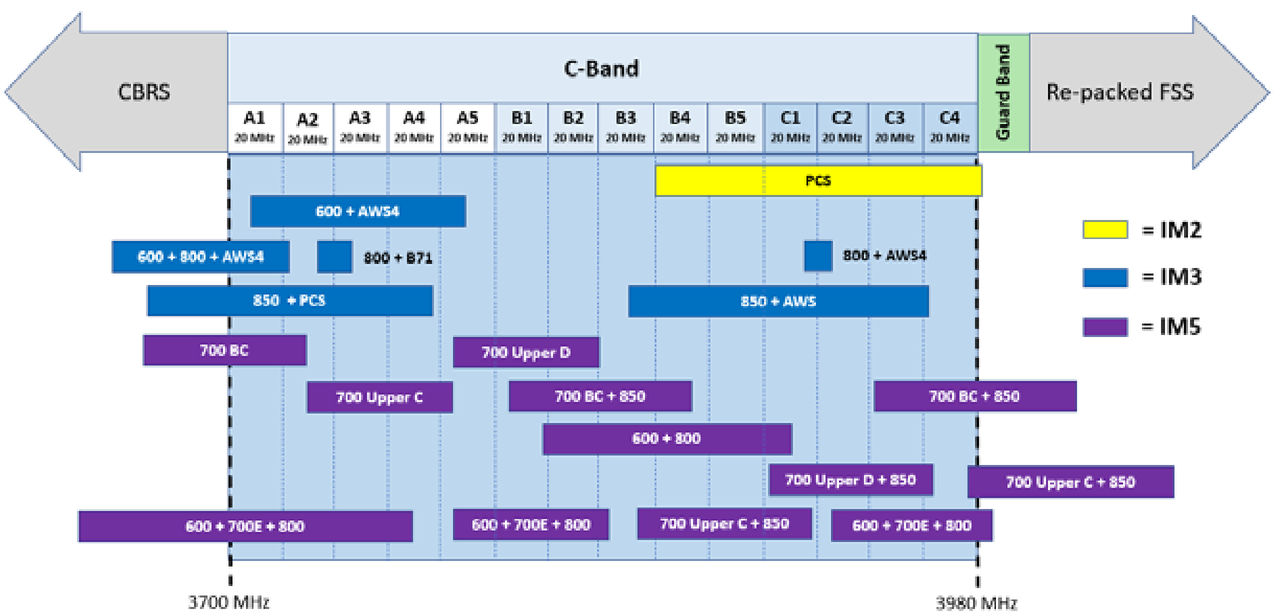

Figure 3: Low order IM products falling in 3.7 GHz spectrum

The lower frequency transmitters operating at cell sites are primarily Frequency Division Duplex (FDD) systems, meaning transmit and receive can occur simultaneously in separate uplink and downlink frequency blocks. As a result, synchronization is not a viable tool for mitigating PIM generated by these lower frequency transmitters. Two methods operators do have available for mitigating C-band PIM involve changing the way sites are constructed:

1. Reduce RF power arriving at PIM sources in the RF path. While this can be achieved by reducing the transmit power of the aggressor downlinks, site configuration changes are presented in this paper that can achieve the same result without reducing transmit power.

2. Improving the inherent linearity of the site. This involves physical changes to site hardware to reduce the magnitude of interference generated by known PIM sources.

ROOFTOP SITES

In most cases, the IM products impacting C-band will be generated by low and mid-band signals originating from separate antenna ports at the site. As a result, these signals are only able to combine and generate PIM at sources located beyond the antennas. On rooftop sites where antennas are recessed from the edge of the building for aesthetic purposes, many PIM sources are likely to be illuminated in front of the antennas. Overlapping metal flashing at the parapet wall as well as metal fasteners unseen below the roof membrane are common PIM sources encountered at rooftop sites. Since PIM is power sensitive, the highest magnitude PIM sources are often located within the area illuminated by the half-power beamwidth of the antenna. Depending on the frequency of operation and on how non-linear the PIM source is, external PIM sources located hundreds of feet beyond the antenna can be service impacting. The good news for C-band systems is that testing conducted by ConcealFab indicates that the area of concern for this band will likely be limited to PIM sources found within 30 FT of the antenna. Site designers can use one or more of the following methods to reduce power arriving at rooftop PIM sources to mitigate interference:

- **A** MOVE SECTORS CLOSER TO THE BUILDING EDGE
- **B** REDUCE ELECTRICAL BEAM TILT OF INSTALLED ANTENNAS
- **C** ALIGN SECTORS WITH THE BUILDING FACE
- **D** INSTALL RF BARRIER MATERIALS

A MOVE SECTORS CLOSER TO THE BUILDING EDGE

One way to reduce PIM interference at rooftop sites is to physically relocate antennas closer to the edge of the building. As seen in Figure 4, relocating typical 65° azimuth beamwidth antennas from 20 FT to 10 FT reduces the roof + parapet wall area illuminated within the half-power beamwidth by 289 sq. ft (62% reduction.) The closer antennas can be placed to the edge of the building the better. Reducing the area exposed to the antenna's main beam reduces the number of non-linear objects exposed to high RF power and reduces PIM interference.

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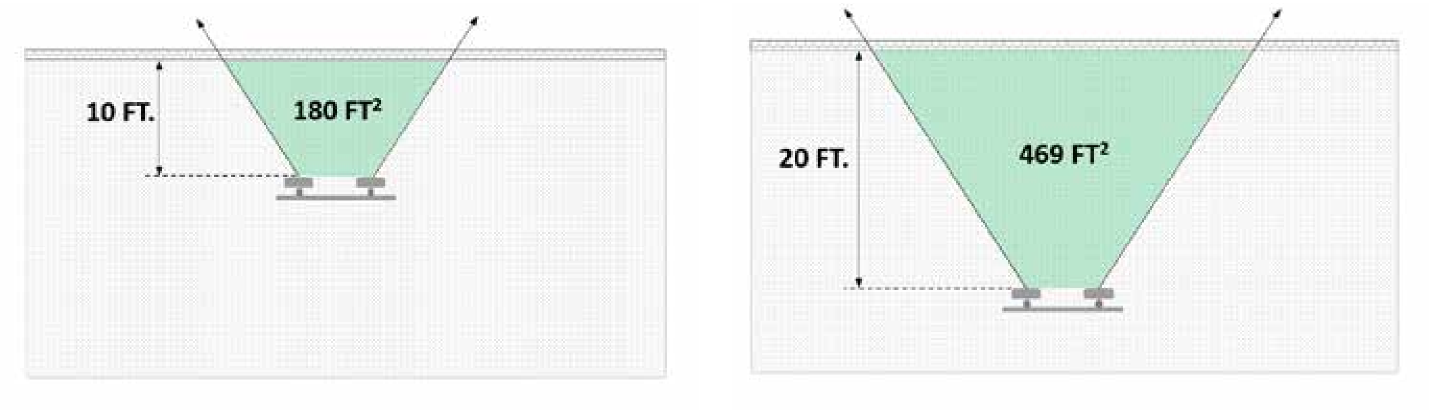

Figure 4: Area of illumination vs. distance from building edge

B REDUCE ELECTRICAL BEAM TILT

Another method to reduce PIM at rooftop sites is to reduce the electrical beam tilt of the installed antennas. Changing electrical tilt from 10 degrees to 2 degrees allows more RF energy to radiate over the parapet wall vs. into the roof surface. Along with the tilt change a reduction in transmit power may be necessary to control signal propagation. Reducing transmit power provides further reduction in power arriving at rooftop PIM sources, resulting in additional interference mitigation.

C ALIGN SECTORS WITH THE BUILDING FACE

A third option that operators should seriously consider is to align all rooftop sectors with building faces. With a typical 3-sector site installed on a rectangular building it is possible to align one sector with a building face, but the other two sectors are usually skewed 30° to maintain 120° sector spacing. As shown in Figure 5, sector skew causes a much larger area of the roof + parapet wall to be illuminated within the antenna's half-power beamwidth. For a sector placed 10 FT from the building edge, the area of rooftop plus parapet wall illumination increases by 136 sq ft (76 %) for a sector skewed 30° vs. a sector aligned with the building face.

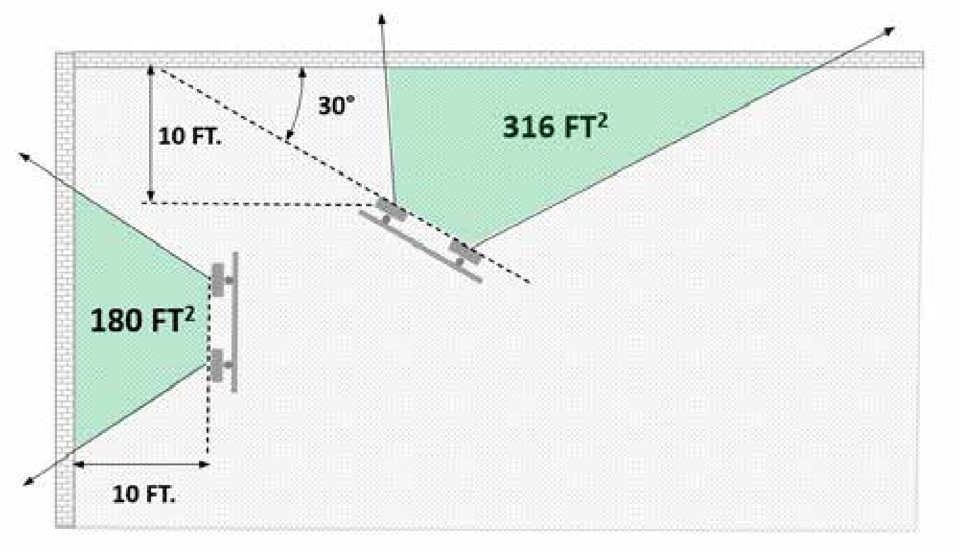

Figure 5: Area of illumination vs. skew with building edge

Aligning sectors to match the building edge may require a 4th sector to achieve coverage and capacity objectives. The CAPEX cost of the additional sector will likely be justified by the performance improvements alone. However, as shown in Figure 6, adding the 4th sector could be justified by OPEX savings achieved by reducing the lease footprint.

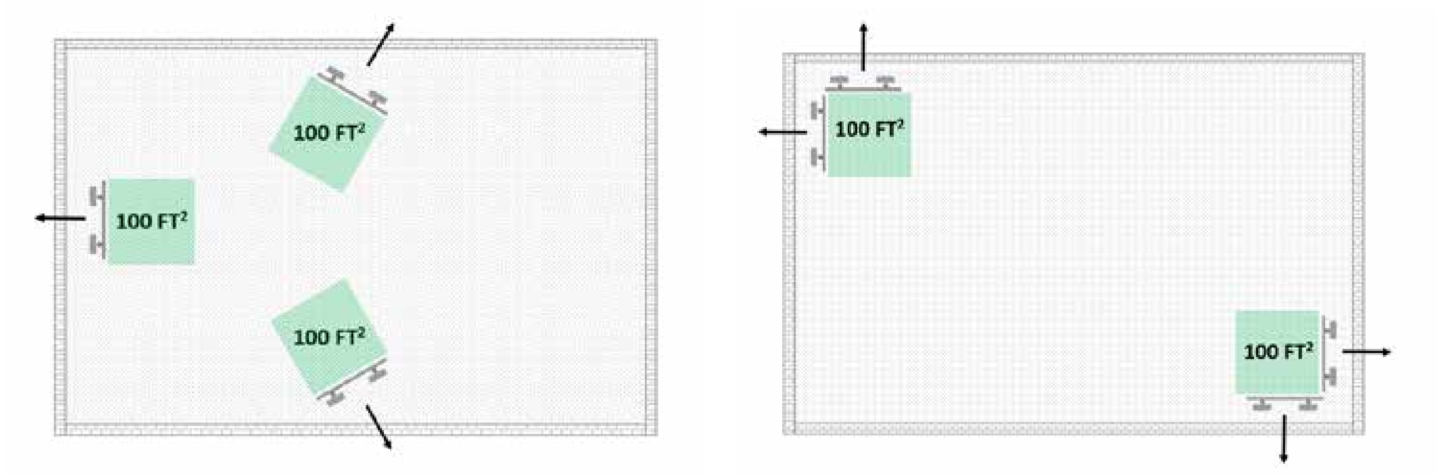

Figure 6: Lower PIM and reduced footprint with 4-sector configuration

D INSTALL RF BARRIER MATERIALS

Even with the forementioned techniques, additional mitigation may be required in some areas to reduce power arriving at rooftop PIM sources. One method is to deploy RF barrier materials on the roof surface to block the aggressor downlink signals from reaching PIM sources. PIM Shield® Roofing membranes and PIM Shield® Tape are two such RF barrier products available from ConcealFab that can be installed at rooftop sites to block the downlink signals. ConcealFab joined forces with Johns Manville, a leading roofing materials manufacturer to develop RF barrier materials that are reliable as well as compatible with existing roofing systems.

Figure 7: PIM Shield® Roofing membrane and PIM Shield® Tape RF barrier materials

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ALL SITES (ROOFTOP AND TOWER)

In addition to the area in front of antennas, PIM sources located in the reactive near field behind, above, below, and beside base station antennas can also generate high levels of PIM interference. This region has come to be known as the “High-Risk PIM Zone.” Even though this region is outside the main beam of the antenna, enough RF energy is present to excite non-linear objects and generate PIM. Field measurements have shown that loose metal-to-metal contacts located within the first several wavelengths of the antenna are more likely to generate service impacting PIM than sources located farther away. For low frequency systems (600 MHz, 700 MHz, 850 MHz) the high-risk PIM zone is generally the area within 3 to 5 feet of the antenna. For mid-band systems (1900 MHz, 2100 MHz, 2500 MHz) the high-risk PIM zone is generally the area within 1 to 2 feet of the antenna. To reduce the magnitude of PIM generated in the high-risk PIM zone, the following actions should be taken:

- **A** USE LOW PIM CABLE SUPPORT HARDWARE
- **B** VERIFY THE PIM PERFORMANCE OF RADIO AND ANTENNA MOUNTING HARDWARE
- **C** ELIMINATE ANTENNA SKEW

A LOW PIM CABLE SUPPORT HARDWARE

Common PIM sources found close to antennas are the large number of metal clips and brackets used to support RF cables, remote electrical tilt (RET) cables, power cables and fiber optic cables. These cables must be supported periodically along their length to prevent movement in the wind. The galvanized steel antenna support frame (located in the high-risk PIM zone) provides a convenient location for this support. A shockingly large number of stainless-steel hose clamps, support brackets, beam clamps and snap-in style cable hangers are attached to this frame to support the ever-increasing number of cables deployed at cell sites.

Figure 8: Traditional hardware used to secure the growing number of cables at cell sites

Multiple sources of PIM are present with the existing cable support designs.

- Metal snap-in style cable hangers generate PIM at the loose metal-to-metal contacts between hangers and at the support bracket interface.
- Steel hose clamps generate PIM when not tightened sufficiently or when the free end of the band makes contacts other metal objects.
- Beam clamps generate PIM where the setscrew digs into the beam surface creating metal burrs and where the edge of the clamp contacts the angle flange.
- Stainless-steel brackets touching galvanized steel support structures produces galvanic corrosion. Since galvanized steel and stainless steel are dissimilar metals at opposite ends of the galvanic series, highly non-linear pockets of white, powdery corrosion forms over time where these dissimilar metals touch. PIM from these sources may form quickly in some regions or may develop after the installation warranty period is over in others depending on environmental conditions.

Figure 9: Galvanic corrosion found on stainless-steel site hardware

A wide variety of low PIM cable support solutions are now available that eliminate the problems associated with the previous designs. High strength, UV stable plastic support brackets have been designed that eliminate metal-to-metal contacts and prevent galvanic mismatches. These new brackets can be secured to the antenna mounting frame using high strength, weather resistant Acetal straps for a reliable, non-metal mounting solution. Acetal straps in accordance with Telcordia TR-TSY-000789 have been used in the wire-line industry for decades to secure fiber optic cables in the communications space between utility poles. Straps meeting this specification are designed to provide >20-year outdoor service life and to provide >250 lbs. loop tensile strength per strap; more than enough strength to secure cables at a cell site. In addition, plastic as well as hybrid metal/plastic snap-in style cable hangers are available that eliminate the PIM issues associated with metal snap-in cable hangers.

Figure 10: Low PIM cable support solutions available from ConcealFab

B PIM PERFORMANCE OF RADIO AND ANTENNA MOUNTING HARDWARE

In addition to cable support brackets there are many radio and antenna mounting brackets present in the high-risk PIM zone. As with the cable support brackets, dissimilar metal contacts should be avoided in antenna and radio bracket designs. Galvanized steel construction is preferred, but aluminum may also be used given its proximity to galvanized steel on the galvanic series. Stainless steel mounting hardware should be avoided with both galvanized steel as well as aluminum brackets.

Equipment mounting brackets should be designed to eliminate the possibility of any loosely touching metal surfaces. Metal touching metal is not a problem if the metals are galvanically similar and the connection is designed to maintain high contact pressure. This can be achieved by including washers or raised contact surfaces at bolted connections or by providing insulation between parts if high contact pressure cannot be assured. Metal chains and clips of any type should be avoided.

A new test procedure is being released by the IEC to provide a standardized method to validate the radiated PIM performance of mechanical equipment. The new test procedure, IEC 62037-8, requires objects to be radiated by two high power test signals while applying a dynamic stimulus to the device under test (DUT). The DUT is radiated on four sides using two different polarization transmit signals for a total of eight dynamic PIM tests. Any object designed to be installed within the high-risk PIM zone near antennas should be tested and verified to be low PIM in accordance with this specification.

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C ANTENNA SKEW

RF energy in the reactive near field behind an antenna is high, but the RF energy in front of an antenna is even higher. For panel antennas the maximum radiated energy is in the 0° boresight direction. At 90° from boresight for a typical 65° beamwidth panel antenna, the signal level is lower by approximately 15 dB compared to the boresight direction. While reduced by more than a factor of 30, there is still a significant amount of power radiated into adjacent equipment installed on the sector frame.

If the antennas on a sector are skewed 15 degrees relative to the support frame, the adjacent equipment will be radiated by the signal level 75° from antenna boresight. For a typical 65° beamwidth panel antenna the signal level at 75° from boresight is usually only 12 dB lower than the boresight direction. This small amount of skew doubles the RF power radiating into adjacent equipment.

If the antennas on a sector are skewed 30 degrees relative to the sector frame, the adjacent equipment will be radiated by the signal level 60° from antenna boresight, which is usually only 8 dB lower than the boresight direction. Thirty degrees of antenna skew increases the RF power radiated toward adjacent equipment by a factor of 5 compared to sectors with no antenna skew.

Ideally sectors should be deployed with no antenna skew. When skew is unavoidable, energy radiating toward adjacent antennas, radios, cable support hardware and the frame itself increases significantly. As a result, the linearity of the frame and equipment mounted to the frame becomes more critical.

ConcealFab conducted tests to evaluate the impact of antenna skew at CBRS frequencies (3.5 GHz). The test involved transmitting 700 MHz and 2100 MHz test tones through a 10 dBi, 60° beamwidth panel antenna and measuring the magnitude of the IM3 generated in the CBRS band. A diode PIM source was positioned outside the antenna and moved in 1 FT increments away from the antenna in directions corresponding with antenna skew. The tests confirmed that low and mid-band signals combining at cell sites can generate significant PIM interference at CBRS frequencies. In addition, the tests confirmed the impact antenna skew has on PIM generation. While these measurements were conducted at 3.5 GHz due to equipment limitations, results are expected to be the same for C-band (3.7 GHz.)

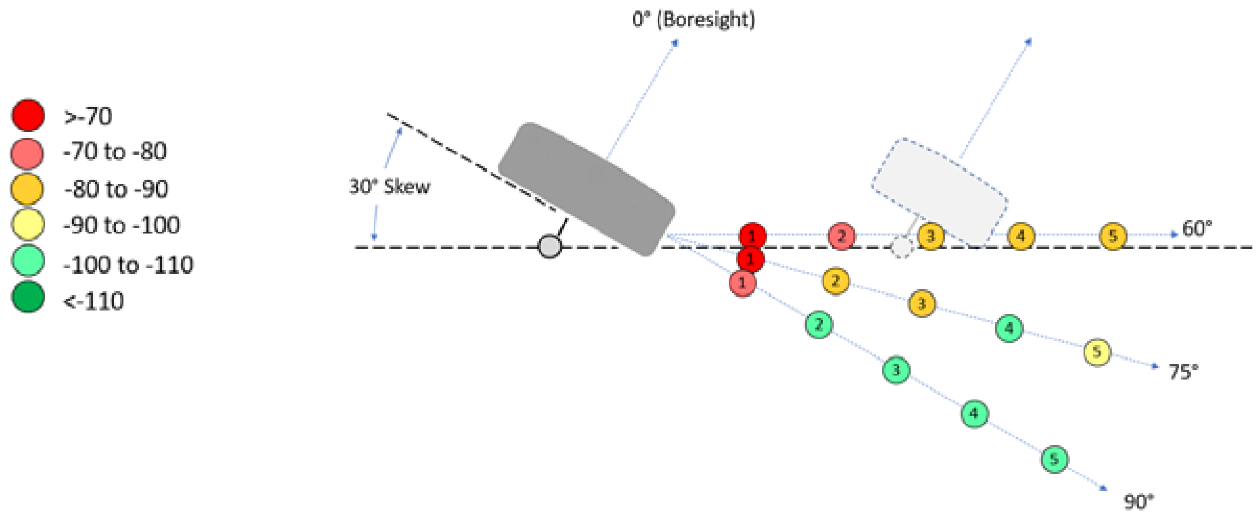

Figure 11: PIM test data showing IM3 magnitude at 3.5 GHz vs. antenna skew

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CONCLUSIONS

External PIM is a problem that is here to stay. Each time a new frequency band is added to a cell site, additional intermodulation product frequencies are created. It is only a matter of time before an operator is impacted by an unfortunate frequency combination that generates low order PIM in one or more uplink bands. Adding C-band systems to existing cell sites is no exception. Many IM2, IM3 and IM5 products can be generated by the existing low and mid-band downlinks at the cell site. These low-order IM products can elevate the noise floor reducing the speed and coverage of newly deployed C-band networks.

Solutions to mitigate PIM impacting C-band are available now. Designers should proactively address PIM at the start of new deployments rather than building in problems for someone else to repair post launch. Paying tower crews for additional climbs to identify and correct PIM problems that could have been prevented is expensive. Minor materials that were once thought inconsequential to site performance have been shown to have significant impact on PIM interference. Eliminating these known PIM sources close to antennas is a simple first step. Relocating and reorienting antennas requires more effort but will pay off in the long term due to the gains in network performance across multiple frequency bands.

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