White Paper

Cross-Band PIM Generation in Co-located Cellular Base Stations

Rev 4

Introduction

PIM testing in cellular base stations has traditionally focused on *intra-band* PIM problems. This refers to situations in which downlink signals from a base transceiver station (BTS) generate PIM in the uplink band of the same system.
A less well-known but increasingly more common type of PIM is *cross-band* PIM. This occurs when downlink signals from two or more BTSs operating in different frequency bands mix together to produce PIM in the uplink band of one or more of those systems. This problem is set to intensify as spectrum is reframed for use in the 600 MHz, 700 MHz, 2500 MHz and 3500 MHz bands, thereby creating opportunities for mixing between entirely new combinations of downlink signals.
An insidious feature of cross-band PIM faults is that they do not reveal themselves when only one BTS is operating. This means that, depending on its traffic configuration, a BTS can be PIM-free when tested in isolation but still experience a large PIM-induced noise- floor rise when all co-located BTSs are transmitting simultaneously.

Cross-Band PIM Generation Mechanisms

Co-located RRU Units with External PIM Faults

A common cross-band PIM scenario arises when multiple remote radio unit (RRU) units are co-located in close proximity to each other on the same tower or rooftop. In such cases, the transmitting signals from two or more RRU units can illuminate an external PIM source which is then re-radiated back towards the cell site and into the RRU receivers. This scenario is depicted in Figure 1.

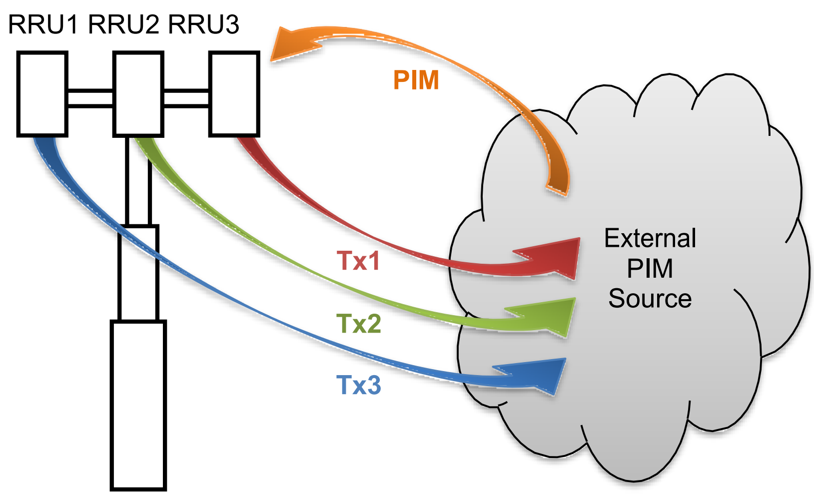


Figure 1. Illustration of cross-band PIM scenario involving 3 co-located RRU units. Downlink carriers Tx1, Tx2 & Tx3 illuminate an external PIM source, which then re-radiates PIM back towards the cell site.

For an external PIM source to cause cross-band PIM problems, it must usually be located within a few metres of the sector antennas.

Below is a photo of a typical rooftop site. A complex base station system has been installed. The visual inspection of the site suggests there could be 11 potential external PIM sources at this rooftop site. Examples of external PIM sources include chain link fences, electrical plant, air conditioning units, rooftop sheeting & guttering, structural steel beams and metal water tanks.

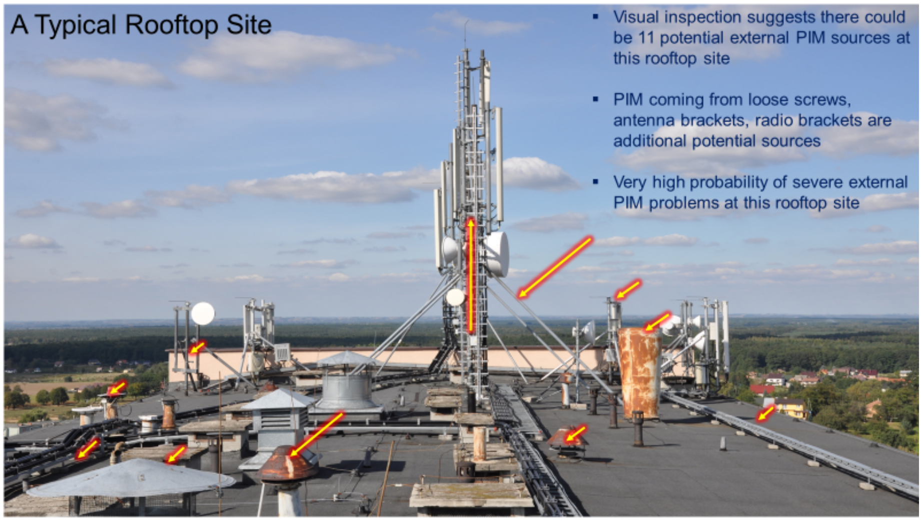


Figure 2: a typical rooftop site

Multiple Base Stations with Shared RF Infrastructure

Another well-known cross-band PIM scenario arises when multiple base stations share common RF infrastructure. This approach is often used in passive DAS installations, wherein two or more BTSs are multiplexed onto a common coaxial cable network, as shown in Figure 3. When a PIM fault is created somewhere in the cable network, downlink signals from the BTSs mix together to produce a potentially large number of PIM products. These PIM products then propagate back through the network, towards the BTSs and into the receiver of any system whose uplink band they happen to land in.

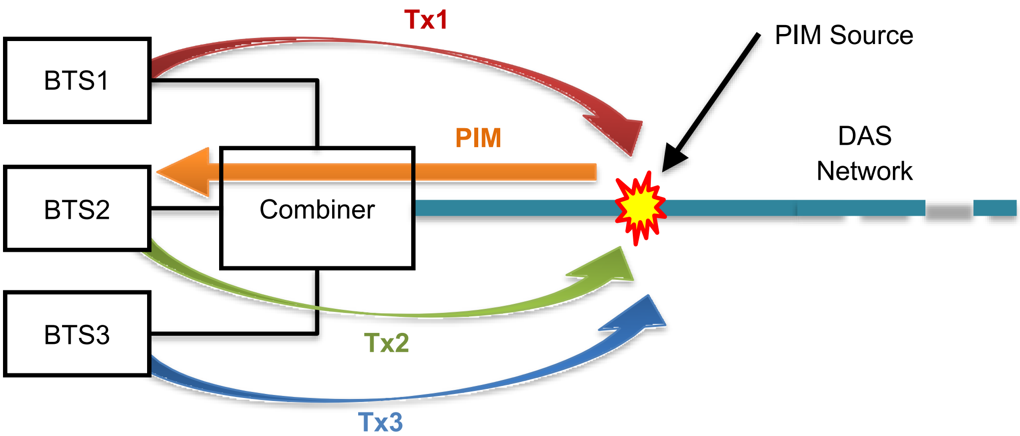


Figure 3. Illustration of cross-band PIM scenario in a passive DAS installation with three BTSs. Downlink carriers Tx1, Tx2 & Tx3 excite a PIM source in the common RF path, which then emits a PIM signal back towards the BTSs.

The root causes of PIM faults in DAS installations are many and varied. They include the usual suspects such as loose connectors, damaged cable assemblies, defective filters, couplers and antennas. Additionally, DAS installations are vulnerable to external PIM sources located in close proximity to the system's antennas, similar to the scenario involving multiple co-located RRUs described previously.

Prediction of Potential Cross-Band PIM Scenarios

Before deciding to collocate a new BTS beside an existing one, it is prudent to investigate whether cross-band PIM can cause problems. This can be predicted mathematically. However, the number of PIM products increases dramatically with the number of downlink bands used at a cell site. Thus, the calculation becomes a laborious task. Various tools are available on the internet to perform those calculations; contact Kaelus for details.

Case Study

As an example, consider a cell site that contains two RRU units co-located on the same tower. RRU1 operates in Band 20 (800 MHz band), while RRU2 operates in band 8 (900 MHz band). Both systems use a 10MHz bandwidth signal and have been tested to pass an IM3 level of -140dBc with 2x20W signals. The plots shown in Figures 5 and 6 are mathematical approximations performed by modelling a nonlinearity model to fit the measured IM3, IM5, IM7 and IM9. We are also assuming that the system noise figure is 2dB and will be using a resolution bandwidth of 10kHz.

PIM product	Test limit (dBc) @2x43dBm
IM3	-140
IM5	-158
IM7	-183
IM9	-215

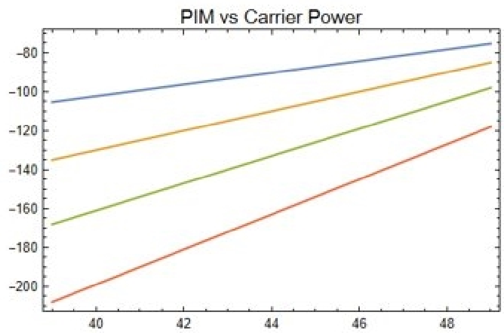


Figure 4: PIM vs Carrier Power model

As per figure 5, when RRU1 & RRU2 transmit simultaneously, no noise floor rise is observed, indicating that the current site configuration is unaffected by any cross-band PIM problems. It is also important to note that the *intra-band* IM order for each system being only a 9th order (as per Table 1), the installer can "get away" with a high IM3 level when commissioning the site.

Table 1 . Integrated Power measurement for RRU and RRU2.

Integrated Power measurement		
Frequency band	852 - 862MHz	888-898MHz
PIM per 10MHz	-201.07dBm	-190.36dBm
Thermal Noise per 10MHz	-101.86dBm	-101.85dBm
PIM + Thermal noise per 10MHz	-101.74dBm	-102.00dBm
Noise rise per 10MHz	~0dB	~0dB

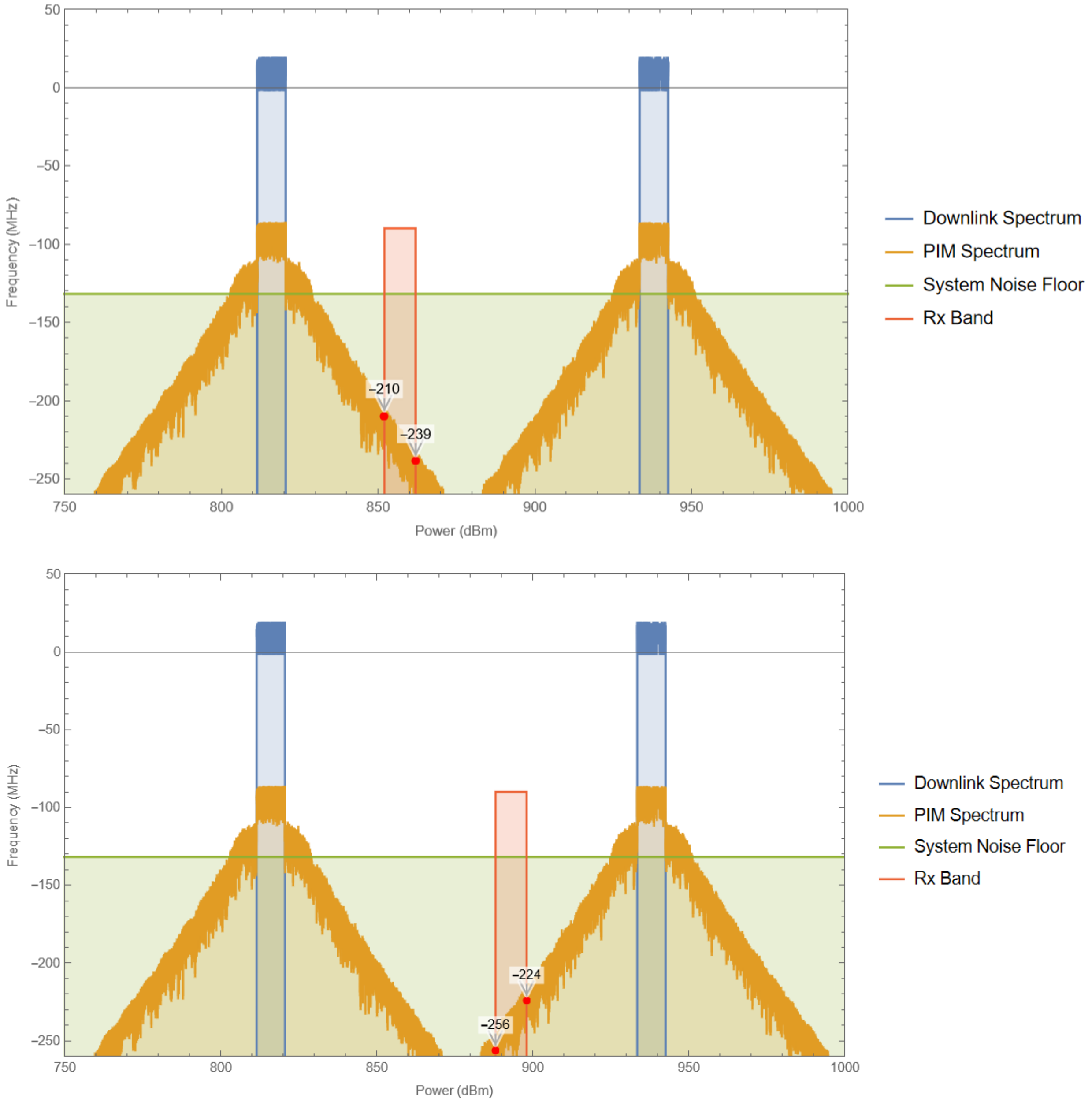


Figure 5: Signal Spectra for RRU1 and RRU2

Now suppose that a new RRU unit is installed on the same tower in close proximity to RRU1 & RRU2, similar to the arrangement depicted in Figure 1. The new system, RRU3, operates in the Band 28 (700 MHz band). The proposed site configuration is summarized in Table 1.

Table 2. Operating bands of three co-located RRU units.

System	**Band Name**	**Uplink Frequencies (MHz)**		**Downlink Frequencies (MHz)**		**In Band IM order**
RRU1	B20	852	862	811	821	9th Order
RRU2	B8	888	898	933	943	9th Order
RRU3 (NEW)	B28	763	773	708	718	11th Order

The question is, will the installation of RRU3 create a risk of cross-band PIM problems at this site?

Through some simple calculations, we obtain the list of IM3 scenarios in uplink bands as shown in Table 2. The reported results have been restricted to IM3 only, because this is usually the PIM product with the highest amplitude, and therefore most likely to degrade receiver performance if it lands in a system's uplink band. However, the other products of intermodulation (i.e. IM5, IM7 etc.), will also contribute to the noise floor rise, as depicted in Figure 5 and 6.

Table 3. Potential cross-band IM3 scenarios arising from collocation of 700 MHz, 800 MHz and 900MHz RRU units.

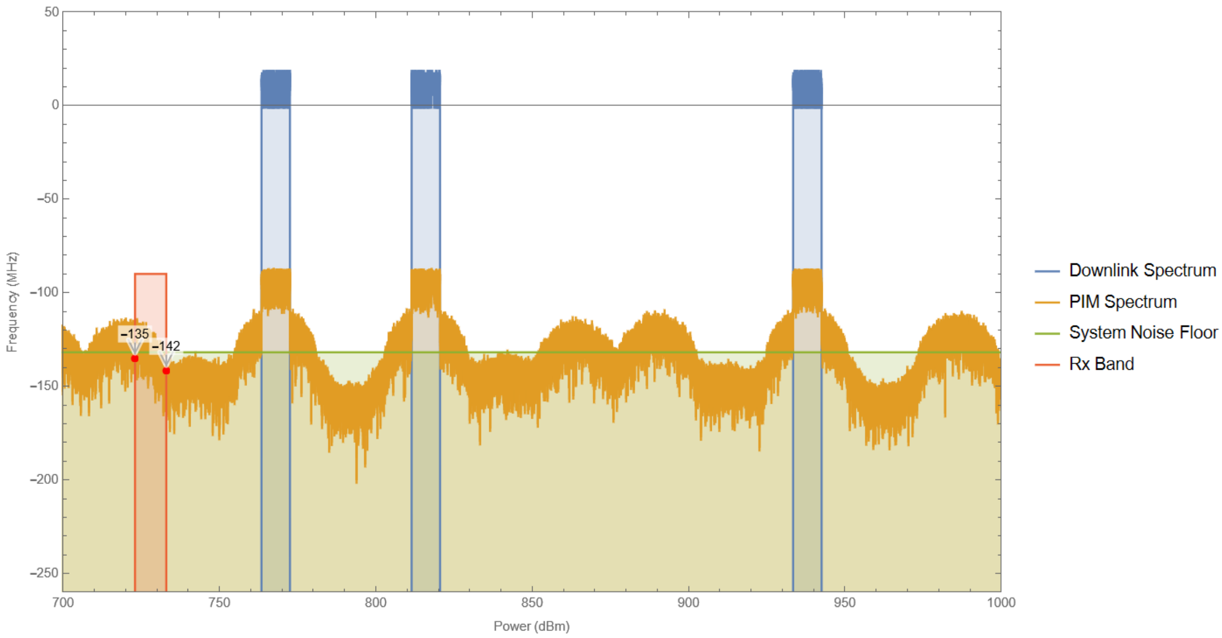
System	Transmit Signal designation	Receive band (MHz)	IM3 scenario **before** RRU3 is introduced	IM3 scenario **after** RRU3 is introduced
RRU1	F1	852 - 862	**No IM3**	**IM3**: 2xF1 – F3
RRU2	F2	888 - 898	**No IM3**	**IM3**: F3 + F2 – F1
RRU3	F3	763 - 773	N/A	**IM3**: 2xF3 – F1

From Table 3 it is evident that all three RRU systems are at risk of cross-band PIM interference when RRU3 is installed.

As shown in Figure 6 and Table 4, if the residual PIM level remains at –140dBc with 2x20W, when collocating the 700MHz radio, we can expect a severe noise rise of **11.5dB** in 900band. This will significantly impact the site ability to generate revenue: **the uplink coverage will be reduced by 74%.**

Table 4. Integrated Power Measurement for RRU1, RRU2 and RRU3

Integrated Power measurement			
Frequency band	723 - 733 MHz	852 - 862MHz	888-898MHz
PIM per 10MHz	-97.02dBm	-96.69dBm	-90.58dBm
Thermal Noise per 10MHz	-101.86dBm	-101.85dBm	-101.85dBm
PIM + Thermal noise per 10MHz	-95.79dBm	-95.63dBm	-90.27dBm
Noise rise per 10MHz	**6.06dB**	**6.32dB**	**11.58dB**
Cell coverage decrease	**51%**	**52%**	**74%**



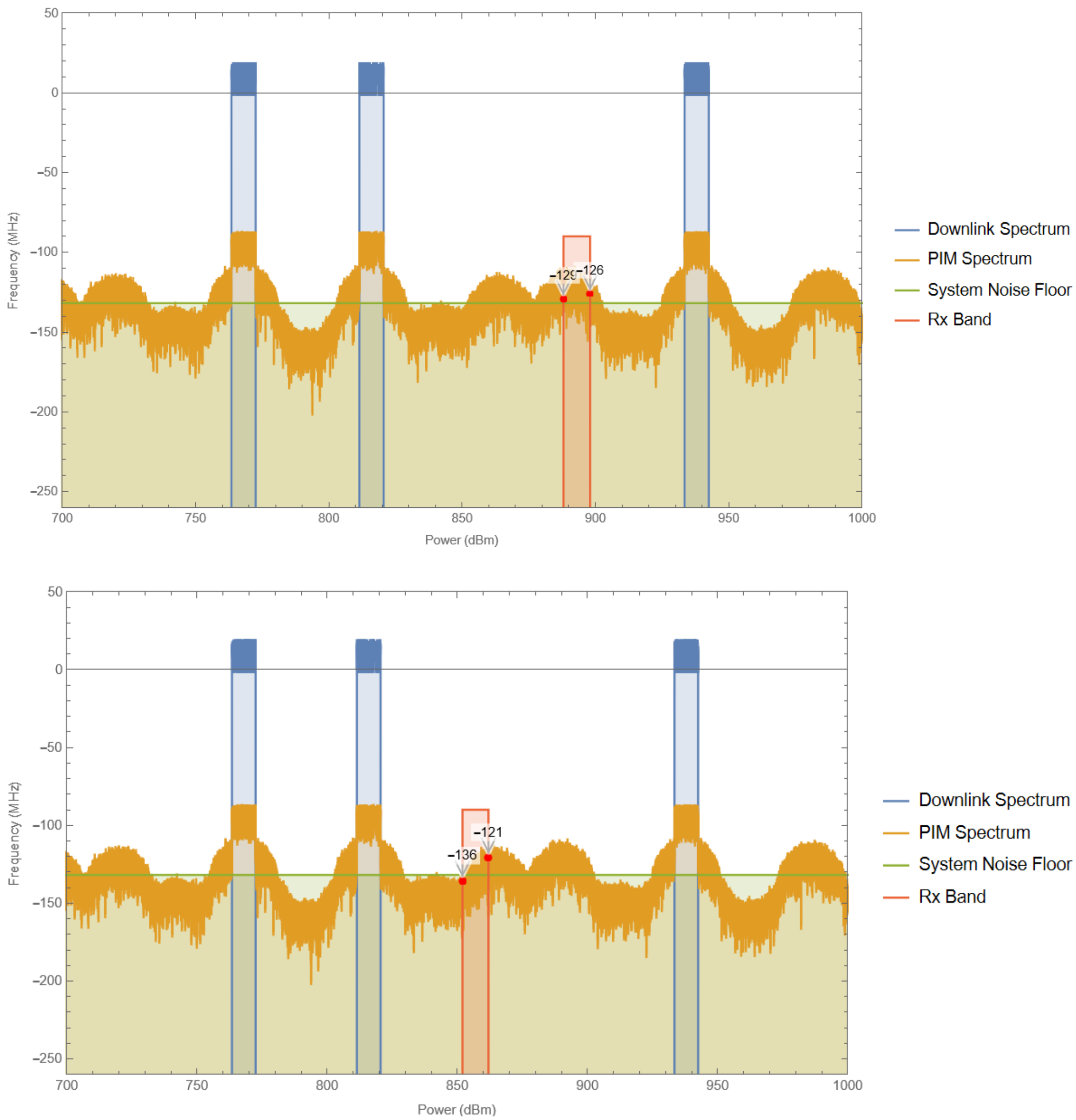


Figure 6: Signal Spectra when RRU3 is introduced

It is important to remember that this problem could not necessarily be anticipated by performing noise floor rise tests on the individual RRU units. That is, even if RRU1, RRU2 & RRU3 each had perfect noise floors when operated separately (by virtue of their individual traffic configurations), it is still possible for all three systems to experience a PIM-induced noise floor rise when they are transmitting simultaneously.

As additional radios are added to the site, ensuring a good 3rd order PIM level is critical to minimize cross band PIM issues. Ideally, the measurement should be performed using PIM testers in place of the radio to simulate the site configuration.

Mitigation of Cross-Band PIM Issues

The steps to mitigating cross-band PIM problems are as follows:

- **Step 1:** Identify those combinations of downlink bands that have the potential to generate cross-band IM3 PIM products in the respective uplink bands. This can be predicted mathematically. If no cross-band PIM scenarios are identified, then technically, no further action is required. However, it is still advisable to perform intra-band PIM testing as per Step 2 below to reduce the risk of cross-band PIM problems occurring with future RRU deployments at the site.

- **Step 2:** Test each RRU individually with a PIM analyzer and confirm that no intra-band PIM problems exist. Note that any narrowband filters in the Antenna system or device under test that could prevent the PIM product of interest from being measured should be bypassed before the commencement of testing. In most cases, Step 2 is sufficient to guarantee that no cross-band PIM problems will arise when all RRUs are turned on and transmitting simultaneously. However, there may be rare exceptions where this is not the case. To rule out cross-band PIM issues completely, we must continue to Step 3.

- **Step 3:** Perform a cross-band PIM test on the entire cell site. This can be as simple as turning on all base stations together and monitoring the change in noise floor in each uplink band. Alternatively, the site can be tested by replacing each RRU with a PIM analyser, as shown in Figure 7, and configuring each analyser to transmit a single tone into the antenna feed network of each system, while monitoring the at-risk uplink band(s) for cross-band PIM products.

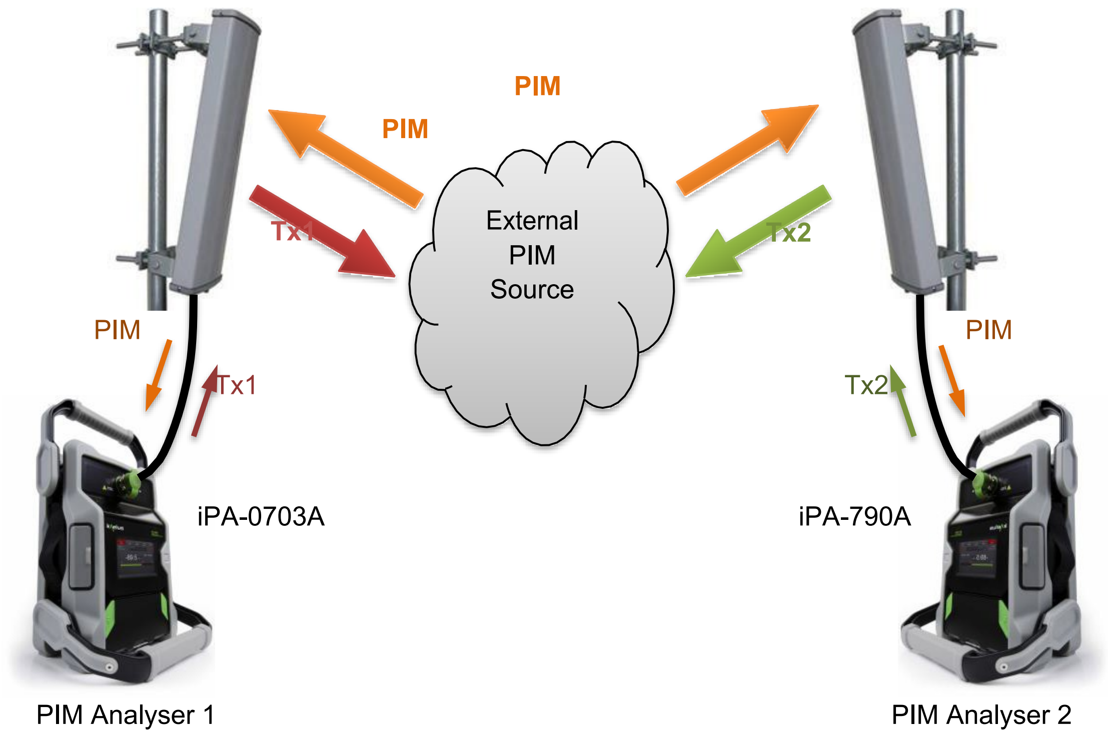


Figure 7. Typical equipment setup used to perform cross-band PIM testing on a cell site with two co-sited RRU systems.

- **Step 4:** Once it has been established that a cross-band PIM problem exists, the location of the PIM fault must be pinpointed. For external PIM sources, a spectrum analyser with an over- the-air (OTA) probe can help speed up this process. The Kaelus *PIM Finder* is an example of such a system, as shown in Figure 4.

Figure 8. Troubleshooting an external PIM source on a rooftop site using the Kaelus PIM Finder.

Another fault-finding strategy – or in some cases, even a permanent solution – is to use low- PIM RF absorbing blankets to shield suspected PIM-generating objects from the energy in the downlink signals.

In the case of internal cross-band PIM sources (e.g., in DAS installations) that do not show up on any intra-band tests, there is unfortunately no alternative but to work through the network one component at a time until the PIM fault is found. Bear in mind that DAS installations can also be vulnerable to external PIM faults, so this possibility may need to be investigated as part of the troubleshooting process.

Conclusion

Cross-band PIM generation is an increasingly common phenomenon in cellular base stations due to the growing trend for multiple RRUs to be co-located on the same tower or to share common RF infrastructure.

The problem is being exacerbated by the re-farming of RF spectrum to create new cellular bands, as it creates opportunities for mixing between new combinations of downlink signals.

Compounding this problem is that radios may return perfect PIM results when monitored individually, but still exhibit large PIM-induced noise floor rises when all co-located base stations are transmitting simultaneously.

The steps involved in remedying cross-band PIM problems are:

- Identification of potential cross-band PIM scenarios using a software-based analysis tool
- PIM testing individual RRUs to rule out intra-band PIM problems
- Testing the entire cell site for each cross-band PIM scenario that has been identified
- Pinpointing the location of any PIM sources using one of the many troubleshooting tools & techniques available:
    - For Internal PIM: the iPA with RTF or iXA used in conjunction with the standard PIM troubleshoot procedure will help locate the internal PIM sources
    - For External PIM: the Kaelus PIM Finder Solution will help locate the external PIM sources