White Paper

Cross-Band PIM Generation in Collocated Cellular Base Stations

Brendan Horsfield & Mostafa AbuShaaban

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 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 refarmed 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 always 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 it and all collocated BTSs are transmitting at the same time.

Cross-Band PIM Generation Mechanisms

Collocated RRH Units with External PIM Faults

A common cross-band PIM scenario arises when multiple remote radio head (RRH) units are collocated in close proximity to each other on the same tower or rooftop. In such cases, it is possible for an external source of PIM to be illuminated by transmit signals from two or more RRH units. This causes PIM to be excited in the external PIM source, which is then re-radiated back towards the cell site and into the RRH receivers. This scenario is depicted in Figure 1.

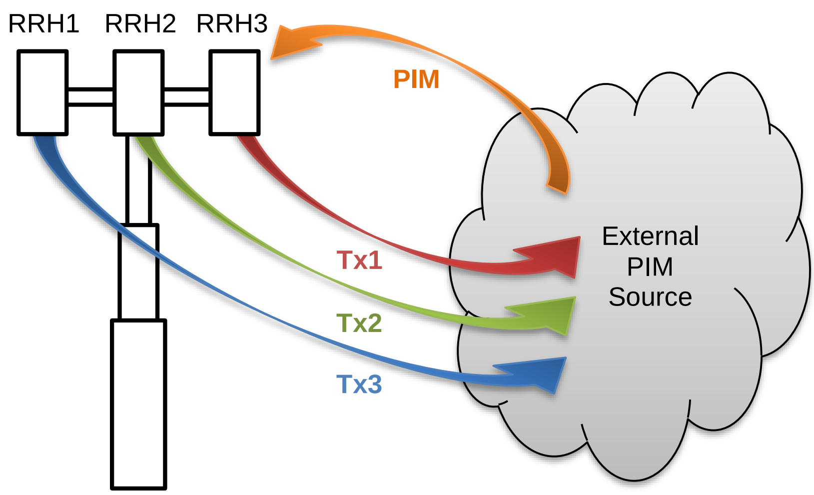

Figure 1. Illustration of cross-band PIM scenario involving 3 collocated RRH units. Downlink carriers Tx1, Tx2 & Tx3 illuminate an external PIM source, which then re-radiates PIM back towards the cell site.

In order for an external PIM source to cause cross-band PIM problems, it must usually be located within a few metres of the sector antennas. Examples of external PIM sources include chain link fences, electrical plant (e.g. air conditioning units), rooftop sheeting & guttering, structural steel beams and metal water tanks.

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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 2. In the event that 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.

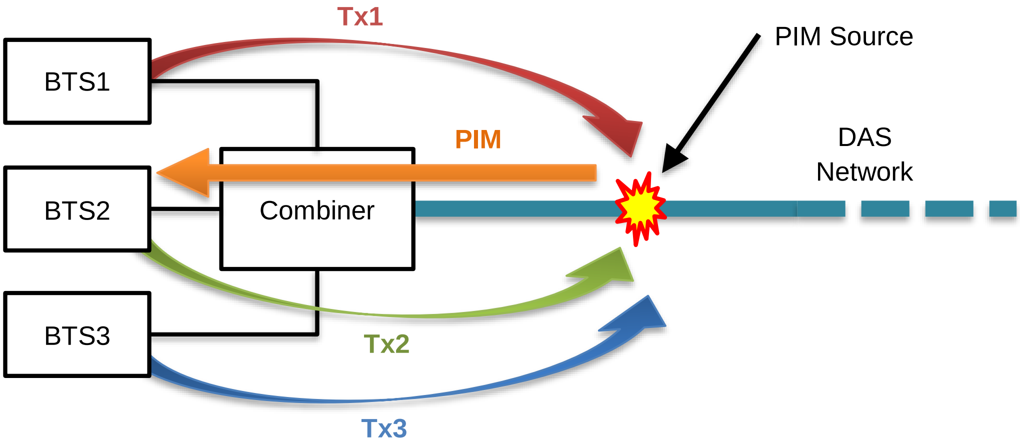

Figure 2. Illustration of cross-band PIM scenario in a passive DAS installation with three BTSs. Downlink carriers Tx1, Tx2 & Tx3 excite a PIM source in the common RF path, which then emits a PIM signal back towards the BTSs.

The root causes of PIM faults in DAS installations are many and varied. They include the usual suspects like loose connectors, damaged cable assemblies and 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 collocated RRHs described previously.

Prediction of Potential Cross-Band PIM Scenarios

Before making the decision to collocate a new BTS beside an existing one, it is prudent to investigate whether cross-band PIM has the potential cause problems. This can be predicted mathematically, although unfortunately this is often a very laborious task, due to the fact that the number of PIM products increases exponentially with the number of downlink bands in use at a cell site.

In order to streamline these calculations, Kaelus has developed a software application that automatically determines which uplink bands are at risk of cross-band PIM interference from a given set of downlink bands. The application considers all possible downlink combinations, from one band transmitting to all bands transmitting, for PIM product orders ranging from IM2 to IM9. The analysis can be extended to even higher-order PIM products if desired, although these are usually of little practical interest due to their low amplitudes.

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Case Study

As an example, consider a cell site that contains two RRH units collocated on the same tower. RRH1 operates in the Lower SMH portion of the 700 MHz band, while RRH2 operates in the Extended PCS band at 1900 MHz. When RRH1 & RRH2 are transmitting simultaneously, no noise floor rise is observed, indicating that the current site configuration is unaffected by any cross-band PIM problems.

Now suppose that a new RRH unit is installed on the same tower in close proximity to RRH1 & RRH2, similar to the arrangement depicted in Figure 1. The new system, RRH3, operates in the 600 MHz band. The proposed site configuration is summarized in Table 1.

Table 1. Operating bands of three collocated RRH units.

System	Band Name	Uplink Frequencies (MHz)		Downlink Frequencies (MHz)	
RRH1	700 Lower SMH	698	716	728	746
RRH2	Extended PCS	1850	1915	1930	1995
RRH3 (NEW)	600	663	698	617	652

The question is, will the installation of RRH3 create a risk of cross-band PIM problems at this site?

Using Kaelus's cross-band PIM analysis software, we obtain the list of at-risk uplink bands shown in Table 2, along with the associated "aggressor" downlink bands. The reported results have been restricted to IM3 only, due to the fact that 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.

Table 2. Potential cross-band IM3 scenarios arising from collocation of 600 MHz, 700 MHz and PCS-band RRH units.

		Aggressor Downlink Bands			PIM Freq Range (MHz)		At-Risk Uplink Bands		
Test Case	**PIM Order**	**RRH1 (700)**	**RRH2 (PCS)**	**RRH3 (600)**	**Min Freq**	**Max Freq**	**RRH1 (700)**	**RRH2 (PCS)**	**RRH3 (600)**
1	3		X	X	626	761	X		X
2	3	X	X	X	1801	1919		X	
3	3			X	1851	1956		X	

From Table 2 it is evident that all three RRH systems are at risk of cross-band PIM interference when RRH3 is installed. There are 4 cross-band PIM scenarios in total, generated by 3 downlink frequency combinations. Collectively, these carrier combinations can generate IM3 anywhere in the RRH1, RRH2 & RRH3 uplink bands.

It is important to remember that this problem could not necessarily be anticipated by performing noise floor rise tests on the individual RRH units. That is, even if RRH1, RRH2 & RRH3 each had perfect noise floors when monitored separately (by virtue of their individual traffic configurations), it is still possible for all 3 systems to experience a PIM-induced noise floor rise when they are transmitting simultaneously.

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Mitigation of Cross-Band PIM Issues

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

Step 1: Identify those combinations of downlink bands that have the potential to generate cross-band PIM products in the respective uplink bands. This can be predicted mathematically using Kaelus's cross-band PIM analysis software.

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, in order to reduce the risk of cross-band PIM problems occurring with future BTS deployments at the site.

Step 2: Test each BTS individually with a PIM analyser and confirm that no intra-band PIM problems exist. Note that any narrowband filters in the BTS 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 BTSs 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 BTS with a PIM analyser, as shown in Figure 3, 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.

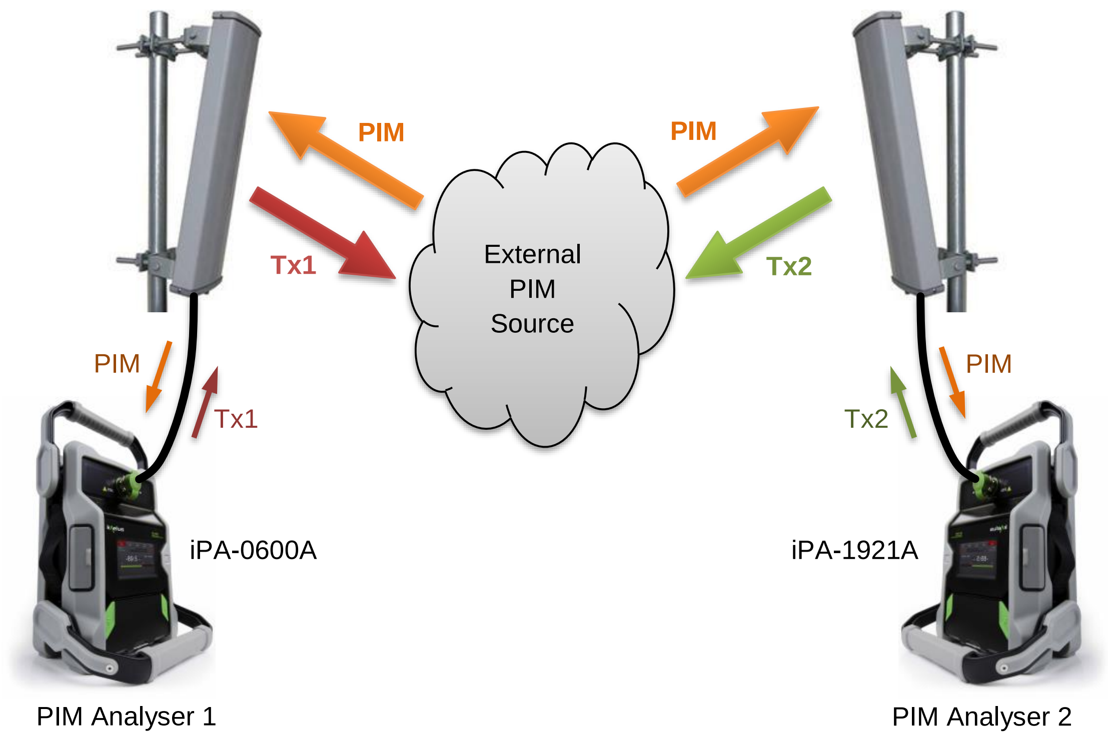

Figure 3. Typical equipment setup used to perform cross-band PIM testing on a cell site with two co-sited RRH systems.

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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 4. 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 BTSs to be collocated on the same tower or to share common RF infrastructure.

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

Compounding this problem is the fact that base stations may return perfect PIM results when monitored individually, but still exhibit large PIM-induced noise floor rises when all collocated 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 BTSs to rule out intra-band PIM problems; testing the entire cell site for each cross-band PIM scenario that has been identified; and pinpointing the location of any PIM sources using one of the many troubleshooting tools & techniques available.

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