# Method Of Procedures (MOP) 1-port PIM Finder

# Contents

# 1 General

## 1.1 Purpose

As the complexity of the cellular base station increases with the deployment of new frequency bands, a new type of PIM issue is arising: PIM sources external to the antenna systems can now become problematic, in particular when low order PIM products (IM2, IM3, IM4 and IM5) are susceptible to falling in the receiver frequency bands.
External PIM sources are generally poor metal to metal contacts exacerbated by long exposure times to the weather.
This document describes the Method Of Procedure (MOP) for performing external PIM finding using the 1-port PIM Finder Solution from Kaelus. The MOP focuses on standard equipment setup and process to be followed for a successful mitigation of external PIM.

## 1.2 Scope

This document provides a step by step process to efficiently locate PIM external to an antenna system.

## 1.3 Audience

This document is intended for the installer and technician of cellular sites to guide them through the trouble shooting process of PIM mitigation.

## 1.4 RF Safety

*WARNING! The radio frequency fields near cellular antennas may exceed safe levels for human exposure. Personnel engaged in troubleshooting external PIM sources should be trained for work in radio frequency environments and use a personal RF monitor if working near active antennas.*

The PIM test equipment is capable of producing up to 80 Watts pulsed (10% duty cycle) of radio frequency (RF) power in the 600 MHz to 2600 MHz frequency band. Users are reminded that proper precautions must be taken to minimize exposure to these RF fields to the recommended limits. Please pay particular care to the following areas:

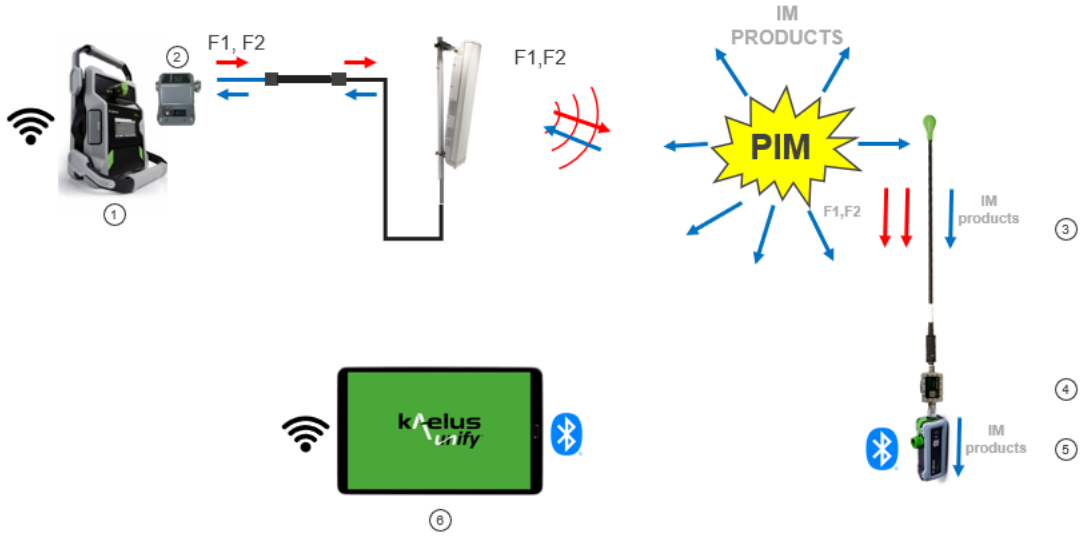
- Always turn off the RF power whenever a test is not being conducted;
- Switch off the RF power from the test equipment before removing or connecting the cables to the test port. Burns to fingers and permanent damage to eyes can result from exposure to connectors carrying high levels of RF power;
- Always terminate the output port of the test equipment into a load, a loaded line or a line that will radiate the energy to free space before turning on the RF power;
- Ensure that any antennas being tested are placed so that no personnel are exposed to RF field levels in excess of the maximum exposure limits

Also, the unit should be operated by a suitably qualified operator in order to ensure interference is not caused to other spectrum users.

Please refer to the ICNIRP (ICNIRP | Base Stations) and the local RF Exposure and Safety instructions for further guidelines.

# 2 Equipment overview

## 2.1 1-Port PIM Finder Solution




| # | Model | DESCRIPTION | Note |
|---|---|---|---|
| 1 | iPA | 1-port Passive Intermodulation Analyser | Multiple frequency variants available, see section 2.4 |
| 2 | RTF | Range to Fault Module | Multiple frequencies available, see section 2.4 |
| 5 | iVA-0627A | IVA Cable and Antenna Analyser | |
| 6 | iVA-SW-FI-A | PIM Finder Software Upgrade for the iVA | Compatible with Android, Microsoft and Apple Devices |
| 3 | R29-4788 | Low PIM probe | |
| 4 | Filter | Filter to protect the iVA receive from the transmit tones generated by the iPA | Multiple frequency variant available, see section 2.5 |

## 2.2 Accessory kit: iAK-0060A

| Model | DESCRIPTION | Note |
|---|---|---|
| **PIL-0005A** | Low PIM Load | Used to verify IPA performance before starting the test |
| **CIS-0001A** | PIM Source | Used to verify IPA performance before stating the test and normalise the RTF |
| **Adaptors** | Various Low PIM adaptors | To connect to various part of the antenna systems |
| **Cables** | Low PIM cable | To connect to various part of the antenna systems |
| **Battery and Battery Charger** | | The IPA has interchangeable batteries so the testing can be performed through the day without interruption. The iVA has an internal battery which, if full at the beginning of the day, should last the whole day under normal use. |
| **Cleaning kits** | Various cleaning material and swabs | To keep RF connectors clean during measurement |

## 2.3 PIM mitigation and tools

To successfully optimise the cell site for PIM interference, material to either eliminate the PIM sources or hide them will be needed.

ConcealFab offers a range of PIM mitigation equipment and consumables such as cable ties, cable racks, PIM blankets: Innovating for the 5G Future | ConcealFab

Other tools such as brushes and standard tools are recommended to free the site from debris and tighten loose connections.

## 2.4 Passive Intermodulation analyser and Range to Fault Module

Any of the 1-port Passive Intermodulation Analysers (IPA) can be used for PIM finding, refer to Kaelus iPA Series | Battery Portable Passive Intermodulation Analyzer | Kaelus.

Select a Range to Fault (RTF) module suited to the IPA model.

| Model | DESCRIPTION | TX1 RANGE | TX2 RANGE | RX RANGE (PIM) | RTF MODULE |
|---|---|---|---|---|---|
| **iPA-0600D** | 600MHz, 2x40W | 617-630 MHz | 640-652 MHz | 663-698MHz | RTF-1000 |
| **iPA-0707D** | 700MHz LOW/HIGH, 2x40W | 728-731.5MHz | 741-764MHz | 698-716MHz / 776-802MHz | RTF-1000 |
| **iPA-0703A** | APT700 LTE | 758-768MHz | 778-803MHz | 703-748MHz | RTF-1000 |
| **iPA-0790A** | LTE 800 | 791-796MHz | 808-821MHz | 832-862MHz | RTF-1000 |
| **iPA-0850A** | 850MHz | 869MHz | 879-894MHz | 824-849MHz | RTF-1000 |
| **iPA-0901A** | EGSM900 | 925-935MHz | 945-960MHz | 880-915MHz | RTF-1000 |
| **iPA-1800A** | DCS1800 | 1805-1812MHz | 1825-1880MHz | 1710-1785MHz | RTF-2000 |
| **iPA-1921A** | Dual Band PCS/AWS | 1930-1950MHz | 1970-1990MHz | 1850-1910MHz | RTF-2000 |
| | | 1930-1950MHz | 2110-2155MHz | 1710-1755MHz | |
| **iPA-2100A** | UMTS (3rd & 7th) | 2110-2130MHz | 2150-2170MHz | 1920-1980MHz / 2050-2090MHz | RTF-2000 |
| **iPA-2600A** | LTE 2600 | 2620-2630MHz | 2650-2690MHz | 2500-2570MHz | RTF-2600 |

## 2.5 Uplink Filters

An Uplink filter will be required to protect the iVA from the high transmit carriers generated by the iPA to prevent internal PIM being generated in the iVA. Select a filter suited to the IPA model.

| Part number | Description | Frequency range | IPA Model |
|---|---|---|---|
| **BPA-0707A** | Band Pass Amplifier - 700L/700H UL* | 698-716MHz / 776-802MHz | IPA-0707D |
| **R29-4790** | 600MHz Ulink Filter | 663-698MHz | IPA-0600D |
| **R29-4798** | 700 MHz Uplink Filter | 703-748MHz | iPA-0703A |
| **R29-4794** | 850 MHz Uplink Filter | 824-849MHz | IPA-0850A |
| **BPA-0790A** | Band Pass Amplifier 800MHz* | 832—862MHz | IPA-0790A |
| **R29-4799** | 900 MHz Uplink Filter | 880-915MHz | iPA-0901A |
| **FIL-0900A** | 900 MHz Uplink Filter | 890-915MHz | iPA-0901A in co-location with 850 systems |
| **R29-4795** | 1750 MHz Uplink Filter | 1710-1785MHz | iPA-1800A and iPA-1921A |
| **R29-4796** | 1900 MHz Uplink Filter | 1850-1910MHz | iPA-1921A |
| **R29-4800** | 2100 MHz Uplink Filter | 1920-1980MHz | iPA-2100A in co-location with 1800 systems |

Note: (*), the BPA-0707A and BPA-0790A contain a battery powered LNA to optimize the sensistivity of the iVA and high rejection filters to suppress TX signals.

## 2.6 iPA measurement modes


Fixed Tones mode:

- The two TX tones are fixed in Frequency. This is the mode used when using the PIM Finder, see section 3.3.7

Swept Tones mode:

- The two TX tones are swept across the frequency. This is useful to measure the PIM level across the receive band and to identify the maximum PIM level. See section 3.3.5

Spectrum Monitor mode:

- The transmit tones are switch off and the RX spectrum can now be monitored for external interference (ie generally interferences not caused by PIM). See section 3.3.4

RTF mode:

- The RTF module need to be fitted for this mode to be enabled. The RTF is used to check the distance to PIM sources and to Return Loss faults. See section 3.3.6

# 3 Process Flow

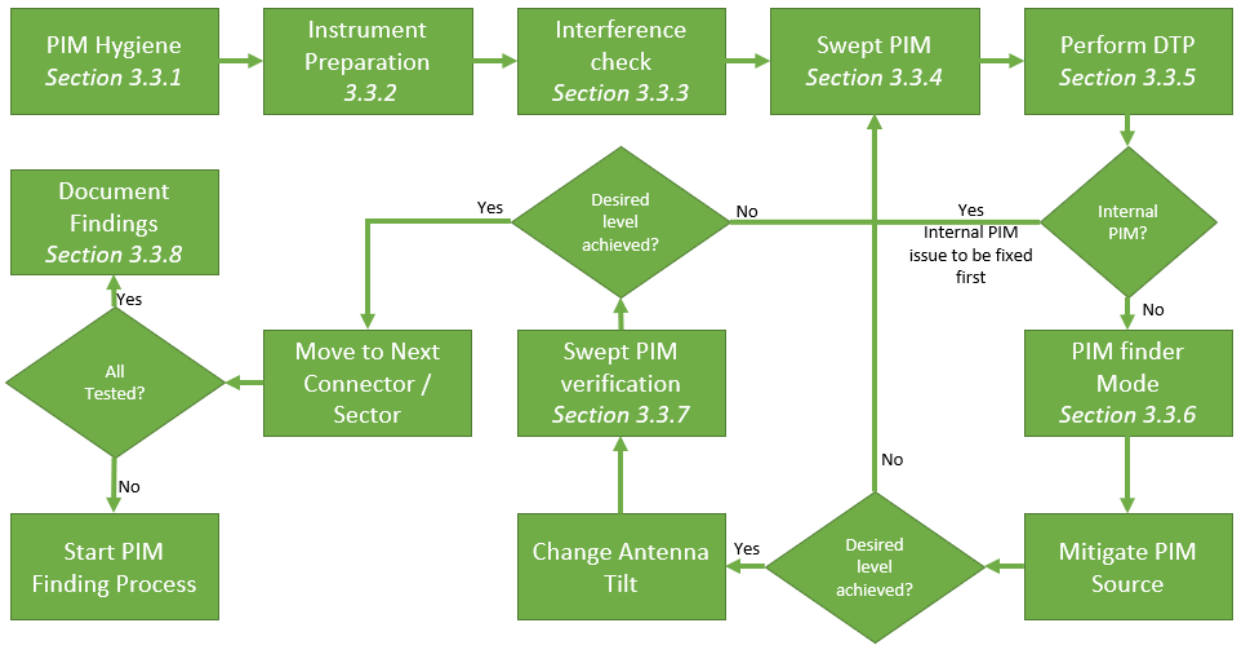
## 3.1 Before going to the site

The first step to a successful PIM mitigation is good preparation prior to the site visit:

- Verify if the issue is related to PIM: you can do so by turning off the radio transmit power. If the receiver noise floor drops, the sector is likely to have PIM issues. If the noise floor remains high, the site is likely to have external interference issues.
- Obtain the frequency allocation for the site and check the potential IM combinations created. There are various tools available on the internet to help with the mathematical calculation (use keyword PIM calculator).
- Obtain a map of the site vicinity and check if other operators have a cellular site close by. This is particularly important in the case where the 850 and 900 or 1800 and 2100 are co-located: the iVA receiver will need to be protected against the signals from the co-located transmitter(s).
- Obtain photos of the site so you can review the site configuration and anticipate the likely PIM mitigation material requirements.
- Plan a testing sequence, based on the KPI results of the radios, i.e., which sector / antenna ports to focus on first.

## 3.2 PIM finding process overview

Once you arrive on site, the following flowchart shows the overall PIM finding process.



## 3.3 Step by Step Instruction

### 3.3.1 PIM Hygiene

When you arrive on site, perform a site inspection and identify potential PIM sources such as:

- Metal Swarf left over from construction: remedy➔ remove

- Loose cable ties: remedy➔remove, cut excess

- Loose screws: remedy➔ tighten

Essentially any metal-to-metal contact should be inspected to ensure no intermittent connection.

### 3.3.2 Instrument Preparation

#### 3.3.2.1 Decide on the frequency setting of the instruments

Depending on the spectrum allocation used on site, select the relevant IPA model. Although the antenna systems are usually comprised of broad band components, it is recommended to match the radio frequency when performing the testing. For example, if the spectrum in use is 1800MHz, the IPA-1800A should be used.

It is also important to understand any co-location of other transmitters so the iVA receiver is adequately protected.

In Fixed tone mode, the frequency setting of the TX1 and TX2 tones on the IPA should be selected so the IM3 falls in the receive band: IM3 is usually stronger than IM5 so easier to detect. Ideally, the frequencies should be selected in such way that to prevent interference in other operators bands and to comply with the local regulator's directive. You may need to obtain approval to perform this activity. Check with the local authority.

The table below provides some guidance on the frequency settings; however, some adjustment might be required depending on the situation:

| Region | Band | Note | IPA model | Filter model | TX1 (MHz) | TX2 (MHz) | IM3 (MHz) |
|---|---|---|---|---|---|---|---|
| **US** | **600** | | IPA-0600D | R29-4790 | 617 | 652 | 687 |
| **EU/APAC** | **700** | | IPA-0703A | R29-4798 | 758 | 778 | 738 |
| **US** | **700** | 700 Low | IPA-0707D | BPA-0707A | 731 | 764 | 698 |
| **US** | **700** | 700 High | IPA-0707D | BPA-0707A | 731 | 764 | 797 |
| **US/APAC** | **850** | Be mindful of 900MHz receiver if in co-located situation | IPA-0850A | R29-4794 | 869 | 890 | 848 |
| **EU** | **800** | | iPA-0790A | BPA-0790A | 791 | 821 | 851 |
| **EU** | **900** | No co-location with 850 | IPA-0901A | R29-4799 | 925 | 960 | 890 |
| **APAC** | **900** | If co-located with 850, ensure that the correct filter is used to protect the iVA receiver | IPA-0901A | OEM122566 | 935 | 960 | 910 |
| **EU/APAC** | **1800** | | IPA-1800A | R29-4795 | 1805 | 1880 | 1730 |
| **US** | **1900** | | IPA-1921A | R29-4796 | 1930 | 1990 | 1870 |
| **US** | **AWS** | | IPA-1921A | R29-4795 | 1930 | 2110 | 1750 |
| **EU/APAC** | **2600** | | IPA-2600A | R29-4800 | 2620 | 2690 | 2550 |

*Note: it is recommend that the transmission frequencies selected fall in the guardband of the current frequency allocation to prevent interference to other cell sites.*

#### 3.3.2.2 Prepare the test configuration and reporting

If no state files are available, configure the instrument for frequencies, power, IM order and more. You can save the settings in a state file as demonstrated in Creating State File for PIM testing video.

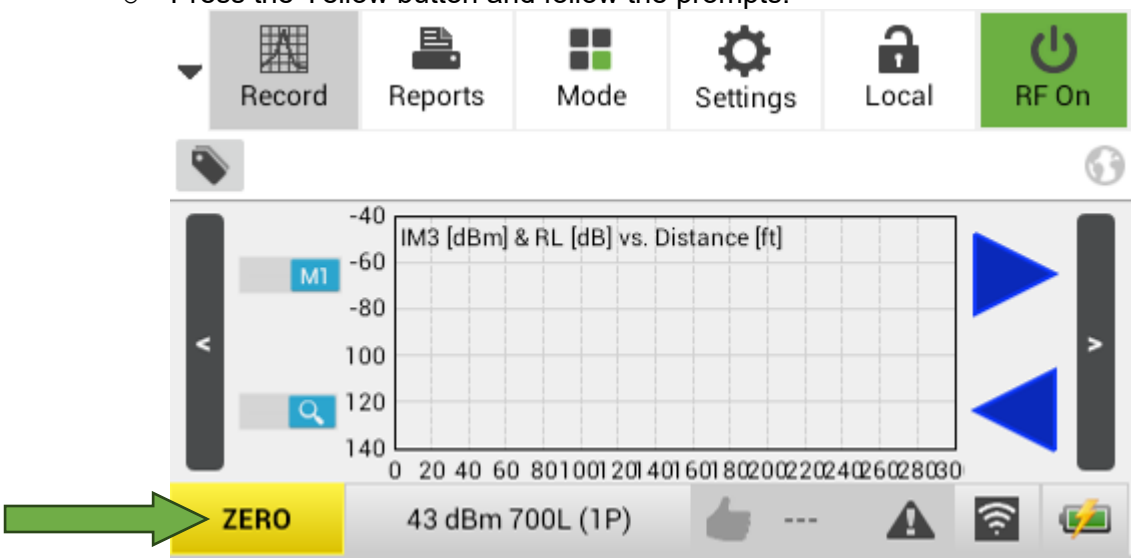
With the iPA, you can document your testing activities as you go. The tags make it easy to indentify the captured plots, results and photos in an orderly manner. Check out Creating Tag Matrix for PIM testing video in the PIM minutes section. You can also prepare the report template in advance. Check out Creating Site Details for PIM test report video.

#### 3.3.2.3 Prepare the instrument

The Videos | PIM Testing | Sweep Testing | Kaelus provide a detailed description of the PIM Finder methodology, in particular the setting of the instruments are well explained.

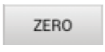
- Clean all RF connectors (iPA, CIS-0001A, PIL-0005A, Low PIM cables and adaptors) as per PIM testing Cleaning Kit Video, to ensure perfect cleanliness and to avoid cross-contamination at all RF junctions.
- Verify the iPA PIM performance by
    - Check the residual PIM level by connecting the PIL-0005A. Set the tones at 43dBm and perform a PIM sweep across frequency. Is the PIM level better than -117dBm?
    - Check the Receiver level by connecting the CIS-0001A. Set the tones at 43dBm and perform a PIM sweep across frequency. Does the PIM level meet the level stated in the datasheet? Kaelus CIS-0001A | Passive Intermodulation (PIM) Source | Kaelus (ie IM3 ~-75dB to -65dBm depending on frequency)

- Perform RTF Zeroing
    - A Yellow Zero Button, indicates that RTF (Port) requires zeroing.
    - The RTF require to be Zero-ed in order to perform DTP and DTF measurements.
    - Press the Yellow button and follow the prompts.




*Zeroing Process*


Important notes:

- Once the Zeroing is complete, the Zero button will turn grey: 

- You can perform the Zeroing even if the Zero button is grey
- Once Zeroing is complete, user is able to make set-up changes, i.e.. frequency, power, range, etc., without having to re-Zero.

- Set up the iVA for the PIM Finder mode, see Videos | PIM Testing | Sweep Testing | Kaelus and PIM Finder Software Quick Start Guide.
- Connect the iVA, Low PIM probe and the filter together. The magnetic holder can be used to secure the phone making one handed operation possible.

In order to effectively utilize the PIM Finder mode with the iPA and iVA, it is imperative to connect to the Kaelus Unify App beforehand, especially when utilizing the iPA as a Wi-Fi hotspot device.

### 3.3.3 Interference check

As per the testing sequence developed prior to arriving on site (refer to section 3.1), select the sector and antenna to be tested and disconnect the RF cable from the radio. Thoroughly clean the connector before connecting to the IPA + RTF.

Switch to Spectrum Monitor mode on the IPA and check there is no interference falling in the receive band. If there is interference, record the frequency and adjust the TX1 and TX2 tones on the IPA to ensure the IM3 frequency is different to the interferer.

Ensure you record the spectrum monitor measurement to add to the comprehensive report.

### 3.3.4 Perform a swept PIM test of the site

Perform a standard PIM test (swept PIM) to establish the base line PIM of the system. This PIM level should be recorded to be able to evaluate the improvement in the PIM mitigation exercise.

Ensure you record the PIM measurement to add it to the comprehensive report.

### 3.3.5 Perform Range to Fault (RTF) measurements.

The RTF is a critical tool used to locate the PIM faults inside and outside the antenna system.

The antenna face is the delimiter between “internal” PIM faults and “external” PIM faults.

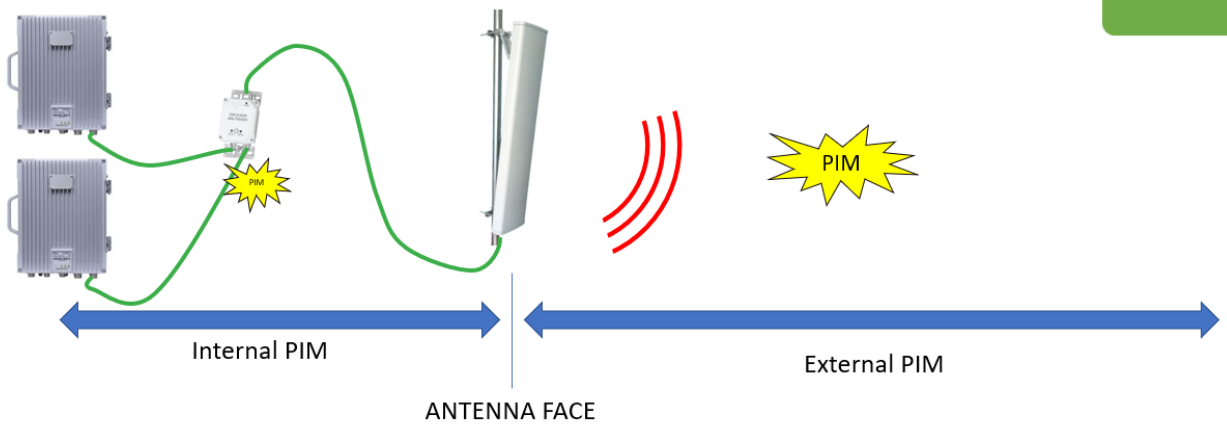
Troubleshooting activities should always begin by identifying and mitigating PIM sources internal to the antenna system.

The first step to this process is to identify the distance to the antenna face.

Step 1:
Identify Antenna face position

Step 2:
Fix Internal PIM

Step 3:
Fix External PIM

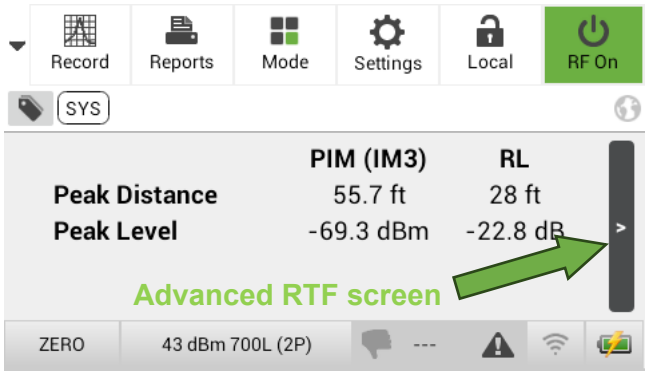



Important notes:

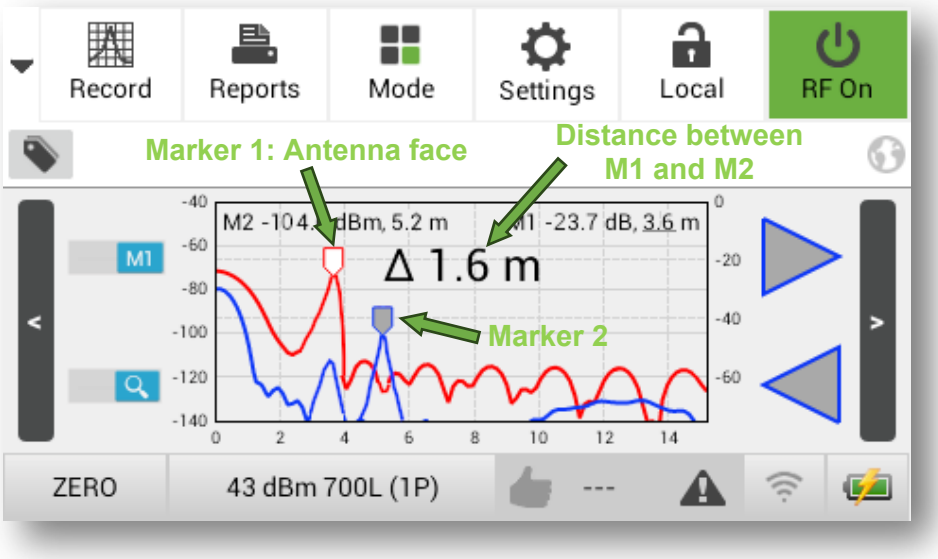
- When troubleshooting for “***internal***” PIM sources, it is recommended to set the Velocity Factor (VF) to 0.8 (signal propagating through cable)
- When troubleshooting for “***external***” PIM sources, it is recommended to set the Velocity Factor (VF) to 1 (signal propagating through air).Once Zeroing is complete, user is able to make set-up changes, i.e.. frequency,

**Step 1: identifying the distance to Antenna Face using the RTF**

***Method: placing a PIM source on the antenna face***




1. Set the Range to 300ft
2. Set the VF to 0.8
3. Create 2 tags:"Internal PIM" and "External PIM"
4. If still in "Basic RTF Screen", Switch to "Advanced RTF screen"
5. Perform a DTP measurement, add tag "Internal PIM" and record the measurement
6. Place a strong PIM source on the Antenna Face
7. Perform a second DTP measurement and compare it with the previous DTP measurement. You should see a strong peak has appeared on the second measurement. This is the location of the Antenna face for Internal PIM measurements.
8. Place marker 1 on the peak, add tag "Internal PIM" and record the measurement.
9. Set the VF to 1
10. Perform a third DTP measurement. You should see the same strong peak but at a different distance. This is still the location of the Antenna face but for External PIM measurements.
11. Place marker 1 on the peak, add tag "External PIM" and record the measurement.



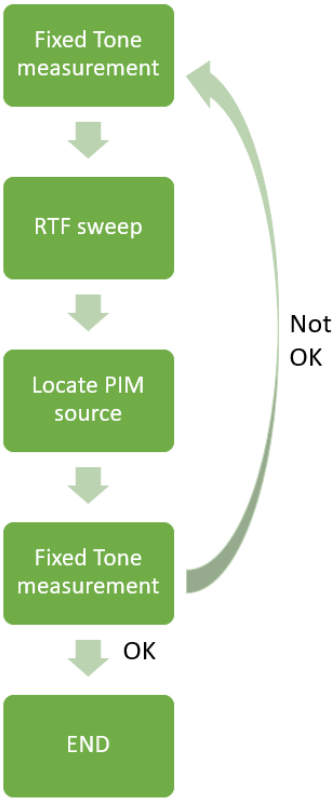
### Step 2: Mitigate PIM internal to an Antenna System

RTF mode set up:

- Select the measurement range: it needs to be larger than the distance from the PIM tester to the antenna face. Typically 200 ft should be sufficient.
- Set the velocity factor to the cable velocity factor, typically 0.8.
- Switch to “Advanced RTF screen”
- Recall the Marker 1 position for “internal PIM” to identify the antenna face location.

Follow the process steps on the right. In RTF mode, identify the PIM sources located before the antenna face. Mitigate those PIM sources and repeat the process until no PIM sources are detected internally to the system (ie before the antenna face).

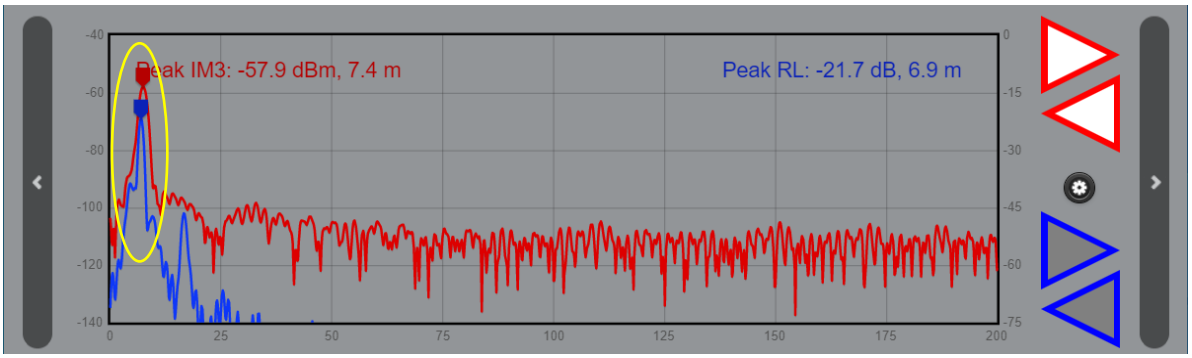
Perform a Fixed tone PIM measurement to verify the PIM level improvement and record the result.




Important note:

The Fixed tone PIM measurement might still provide a poor result if a strong external PIM source is present. If this is the case, then proceed to step 3.

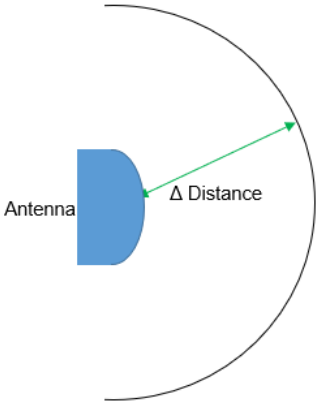
Tip If strong lobes on the Distance to PIM (DTP) trace are observed, PIM sources have been identified at those locations. Overlay the Distance to Fault (DTF) with the DTP plots. If the DTF and DTP lobes coincide, the PIM source is located at an RF junction such as connector joints.



**Step 3: Mitigate PIM external to an Antenna System**

RTF mode set up:

- Select the measurement range: it needs to be larger that the distance from the PIM tester to the antenna face, plus the distance from the antenna to the edge of the site. Generally 300 to 400 ft should be sufficient.
    - Set the velocity factor to 1, you are now only interested to measure the DTP of PIM source which are in ”air”
- Switch to “Advanced RTF screen”
- Recall the Marker 1 position for “external PIM” to identify the antenna face location.
- Run the RTF sweep and locate the strongest PIM source and mark it with marker 2
- You can now read the ”Δ” distance between marker 1 (antenna) and marker 2 (the strongest PIM source).




Using the RTF, we can extract the distance of the strongest PIM source in relation to the Antenna face, however, without the angle information, we can only assume it is located somewhere along the “Δ” distance arc from the antenna. We now need to identify the location of the PIM source using the PIM Finder probe.

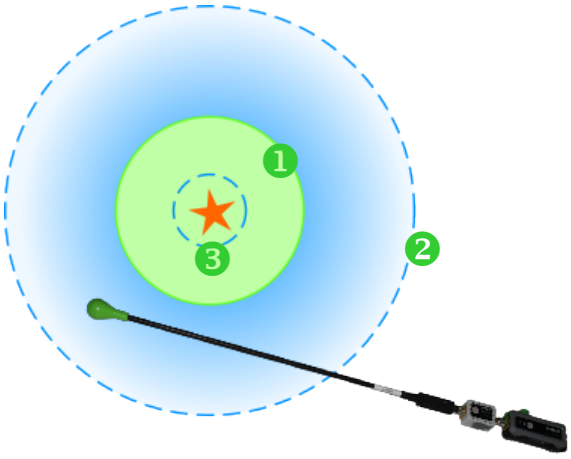
The RTF plot can be zoom-ed in to ignore the area before the Antenna face. Press on the RTF screen to enter the plot settings screen and change the distance to start at the antenna face.

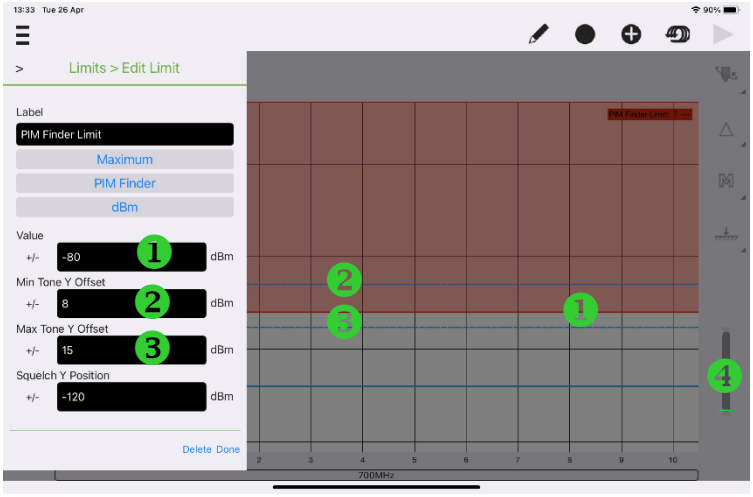
Since Marker 1 represents the location of the antenna face, it is a critical marker position. It can be locked to prevent accidental change.

### 3.3.6 PIM Finder Mode

Using the iVA in PIM Finder Mode, create your "Circle of Concern" (figure below):

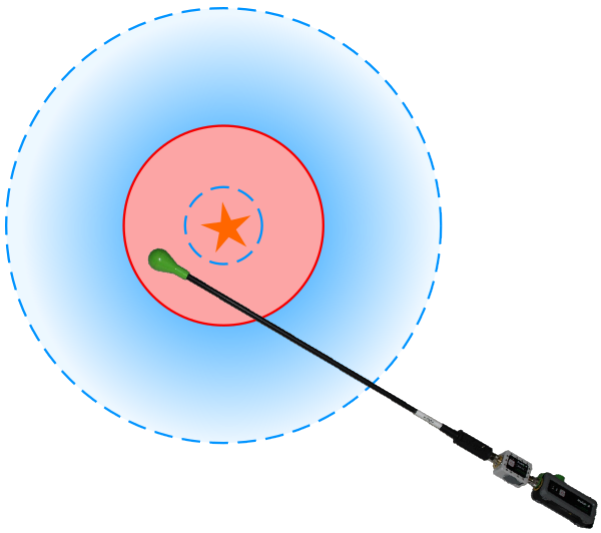
Set target value ❶, a good starting point would be ~10dB lower than the IM Swept result performed with the PIM tester. The *Min* ❷ and *Max* ❸ *Tone Y Offset* values are represented by blue dashed lines relative to your target value ❶. These offsets control the lowest and highest discernable audio tone values. Any signal received between these will provide a smooth Theremin-like audio feedback, and anything below the Min ❷ Tone Offset value will be silent, anything above the Max ❸ Tone Offset value with have a continuous and high pitch tone. By being defined as offsets, these values move with your target value, meaning no adjustments are required as you scroll your threshold ❹ to target a differently sized PIM source. Your circle-of-concern will always be ready for your next challenge.

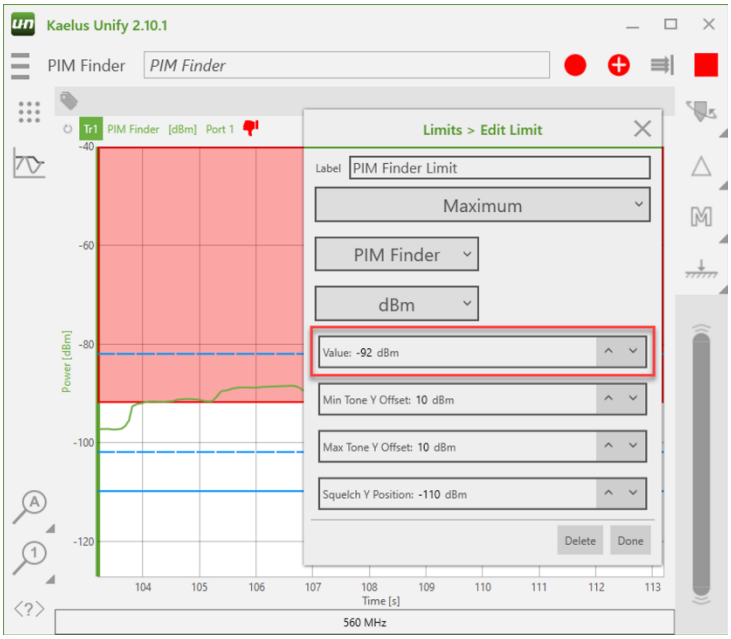



Finding the center

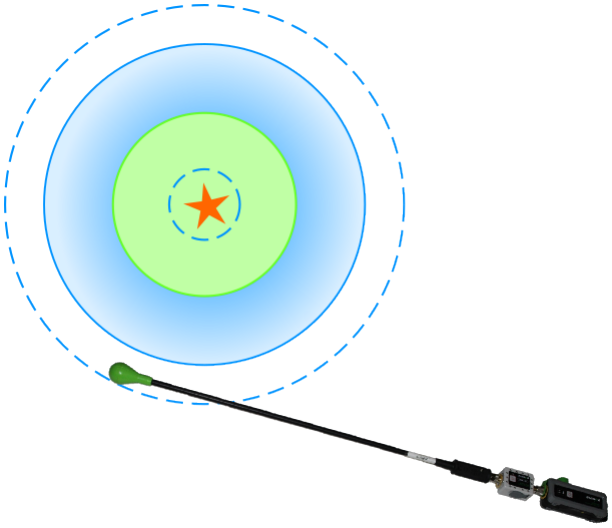
Your screen turns red and stays red, *only* when the trace crosses the threshold set by your PIM Finder Limit. A short beep gets your attention without distracting from the continuous audio.

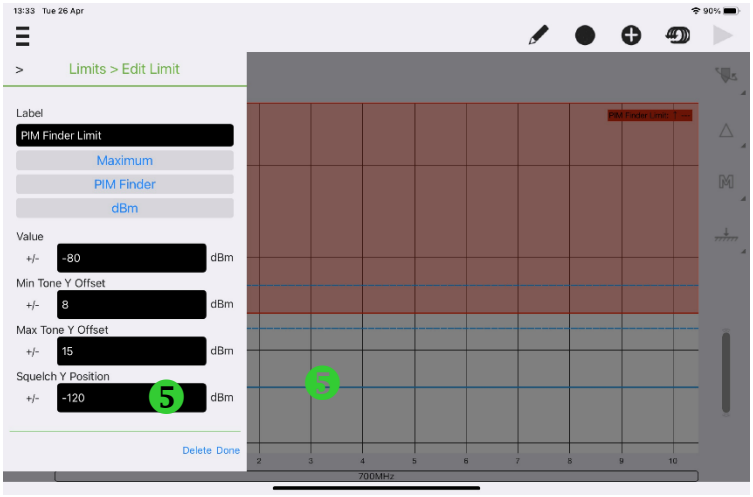




## Avoid the noise floor

Often you must search for PIM right down to the noise floor of your spectrum monitor. If the lower audio threshold happens to go below the noise floor, you will hear a tone and you lose your circle-of-concern. Set the *Squelch Y Position* 5 just above your noise floor to automatically trim your circle-of-concern when getting down this low. It will save having to adjust your audio offset settings.





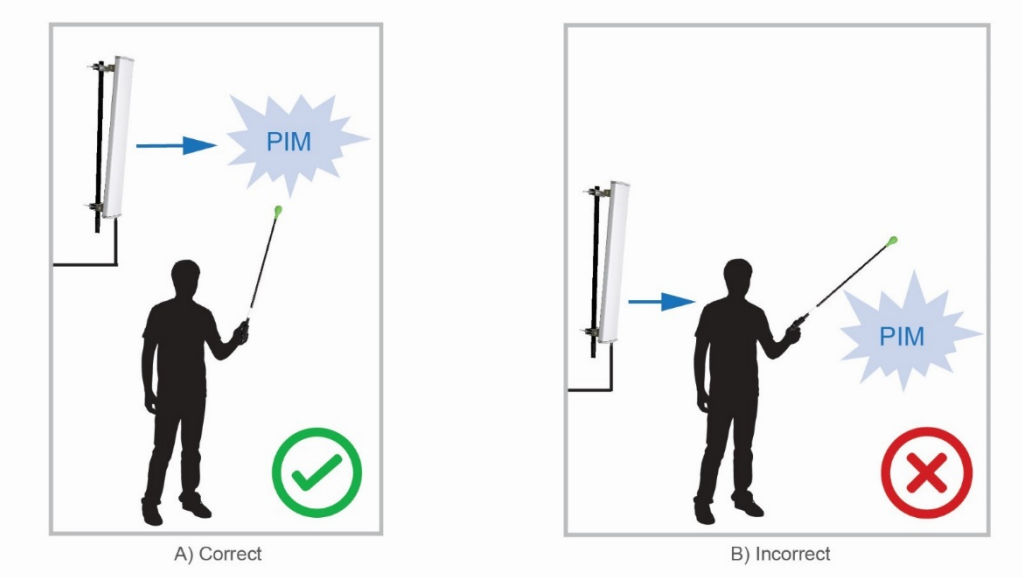

Now that the iVA is correctly set up, turn on the iPA transmitter and start sweeping the PIM probe on the arc distance measured by the RTF. Listen to the Theremin sound and mark the position(s) where the PIM centers were identified. Focussing on each of the PIM centers, orient the probe at different angles to confirm its location.

Once the PIM source has been identified, it is time to implement a mitigation plan. Turn off the IPA and mitigate the PIM source. In an ideal situation, the PIM source should removed: consider Low PIM attachments, for example, clamps and cable ties from ConcealFab. The second- best alternative is to conceal the PIM source: ConcealFab offers PIM blankets, absorber, PIM foil, PIM roofing materials and more.

Turn the IPA transmitter on and using the probe, confirm that the PIM level has been reduced.

Take a picture of the mitigation implemented so it can be added to the report.

Note: during the search process, be conscious of where you are standing. The body is a good RF attenuator when standing between the antenna and the external PIM source. The PIM level may drop dramatically.




Note: items such as keys and RFID can be a very good source of PIM. Ensure that personnel performing the trouble shooting does not carry these items during the exercise.

### 3.3.7 Verify the PIM level

Once the PIM source has been removed, perform a PIM test (Swept PIM using the IPA) and compare it to the base line. The PIM level should have improved and must be verified at different antenna tilt positions. If the improvement is sufficient, document your findings and move to the next antenna port or next sector and start the process again at step 0 (interference check).

If the PIM improvement is not sufficient, go back to step 3.3.4 and find the next strongest PIM source.

Ensure you record the PIM level not only for documentation purpose but also to establish the new base line.

Note: It is advisable to verify the PIM level at various antenna tilts. Depending on the angle of signal in relation to the PIM source, the PIM level generated could vary greatly.

### 3.3.8 Document your findings

Once all antenna ports and sectors have been tested as per the test plan, document your findings.

As you have been recording the results at each step of the process, ensure that you compile the results in a single comprehensive report.

There may be PIM sources identified which are part of the infrastructure around the site which may need future work. Ensure the relevant pictures and sketches are collected so that further site improvements can be effectively performed.