Precise component-level PIM fault location in antennas using the novel location capabilities of the PIMPoint Analyser

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The Intensifying PIM Problem

With the explosion of mobile broadband, the need for good PIM performance in radio system components has never been greater. PIM can have a serious impact on mobile networks, significantly reducing coverage and capacity. As a consequence, mobile network operators and system integrators are specifying demanding PIM requirements on components such as remote radio units, filters and all antenna line devices. The need to simultaneously support multiple frequency bands and multiple antenna ports significantly increases antenna complexity. This places an enormous challenge on antenna manufacturers, who need to deliver high quality low PIM products.

Each antenna must be PIM tested on multiple port/ band combinations. This testing can be immensely time consuming. However, if a PIM failure is found the time to identify the fault, implement a repair and then retest adds an even greater burden on the manufacturing process. The PIMPoint PIM Analyser provides a significant step forward in reducing the net cost, time and required skill level associated with the PIM test/ repair cycle.

Current PIM diagnosis

The conventional approach to PIM fault diagnosis relies predominantly on highly skilled operators using mechanical tapping, in an attempt to focus in on the region where a PIM fault may be located. This testing must be conducted in an anechoic PIM test chamber with the full test power (typically 2x 20W) applied to the antenna. Once a suspect area is found a close visual inspection by the skilled operator may sometimes give further insight to the fault location. Rework will follow and then re-test and yet further rework carried out as suspect faults are eliminated one by one until the real problems are finally isolated and repaired. This all takes time and the multiple rework cycles can in themselves introduce new PIM faults and, even more worryingly, have a negative impact on the long-term reliability of the antenna.

The equipment used for the above type of test is the conventional two-tone PIM tester, which has existed in its current form for many years. Some attempts at improved solutions have added DTP (distance to PIM). However, with DTP the distance resolution available is limited and the base station antenna architecture almost always includes multiple parallel feed paths. These parallel feed paths severely limit the usefulness of the DTP method.

Other methods that have been attempted for locating PIM faults include robotic scanning looking for RF products radiated by the non-linear fault, or for thermal heating. The latter can in some cases be associated with PIM generation mechanisms. An ultrasonic vibration method has also been reported that can find application in identifying some PIM faults. However, to date there has been no widely accepted PIM location method shown to provide a significant reduction in fault location/ repair time with low operator skill level requirements.

The PIMPoint™ Approach

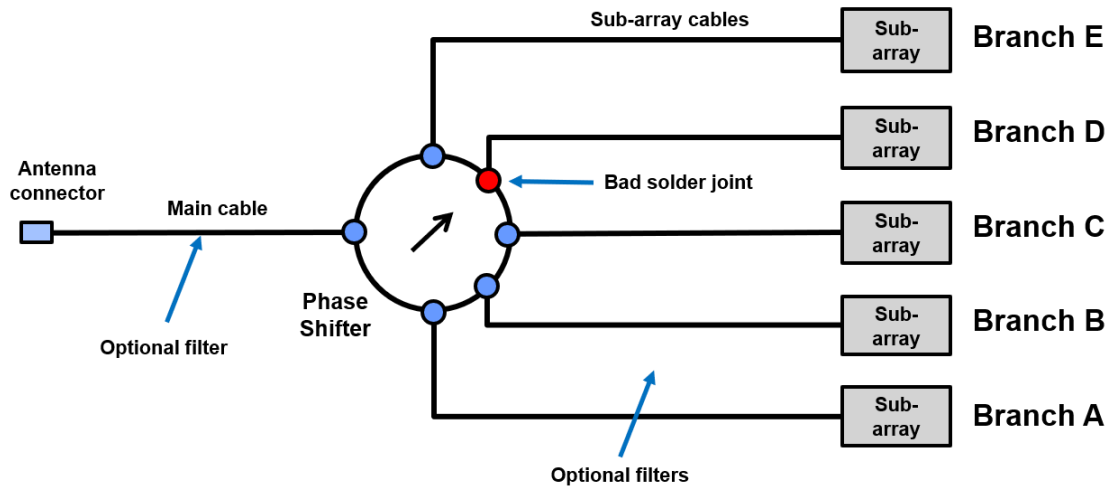
PIMPoint provides the capability to identify PIM fault locations in addition to running industry standard IEC 62037 two tone PIM tests. This fault location capability has been demonstrated to halve the typical rework time for complex multi-band antennas as well as reducing the operator skill level needed for the entire process. PIMPoint provides a streamlined factory PIM testing solution with automated test sequences intelligently driving the test and analysis / PIM fault location functions. PIMPoint flags the need for operator intervention when required. The PIMPoint test is directed by an antenna-specific device under test (DUT) file that contains key information about the antenna under test. Additionally, all measurement and location analysis output can be directed to an FTP server so that long-term Data Analytics can be used to highlight potential production or design aspects contributing to fault instances.

PIMPoint™ 3D Location technology

AceAxis have developed a novel 3D PIM fault location technology that looks for specific PIM fault signatures. These signatures are captured whilst exciting the antenna with a combination of specialised wideband and narrowband test stimuli, at the same time as sweeping the antenna tilt by Remote Electrical Tilt (RET) control. The DUT file contains basic information about the antenna architecture and dimensions that enables the location algorithm to predict the unique PIM signature expected from each candidate fault position.

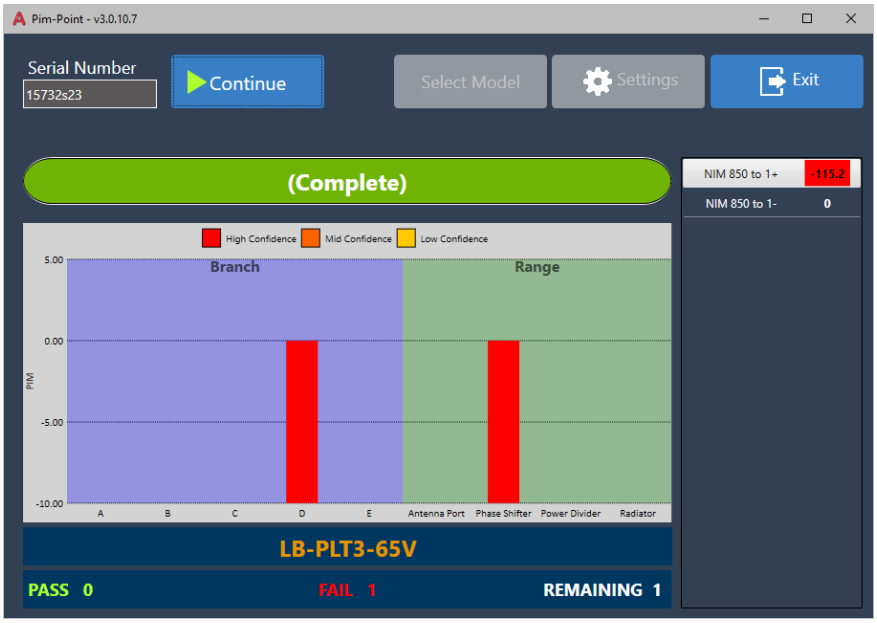
Extensive testing of this technology has been undertaken both in test laboratories and in antenna factory environments. These tests have demonstrated a high location accuracy for a wide range of antenna types and samples. This includes low band, high band and complex multi-band, multi-port antennas.

The location process aims to locate the fault to one of the components or joints illustrated in the generic antenna architecture as shown below.



Location is by branch (A to E) and by component type from left to right (Antenna connector, phase shifter or radiating element or sub-array) giving a totally new dimension to PIM measurement capability. Sometimes antennas may also include filters or diplexers or other functions at the locations indicated and in many cases faults at these components may also be identified.

As an example, there may be a fault identified at the phase shifter and on branch “D”. This narrows the fault down to a specific solder joint on the phase shifter as identified in red on the diagram above. The fault location results from PIMPoint are indicated on a display graph in the GUI software. An example location result for this case is shown below:



The results are shown by branch and by component with the colour of the bars indicating the algorithm’s confidence level in the displayed result. The amplitude of the result becomes important if multiple faults are detected, whereby in that case the relative levels of the faults are indicated. The location algorithm can detect faults in 2 separate branches and in up to 2 different component types. Fault location test time is dependent on the antenna and RET characteristics, but can be completed in just over 2 minutes.

PIMPoint also has the capability to undertake a restricted fault location for antennas that don’t have a RET capability. However, in that case the fault branch cannot be isolated.

PIMPoint can therefore be seen to have added a new dimension to PIM measurement capabilities targeted at significantly enhancing antenna production workflow. Summarising the differentiation in PIM measurement technologies:

- 1D - PIM level measurement, as widely used in the industry for many years.
- 2D - Distance to PIM, mostly used for field diagnosis in the case of long cable runs.
- 3D - PIM fault location in antennas, delivering component/ branch level fault diagnosis.

PIMPoint™ Equipment

The PIMPoint equipment consists of the wideband PIMPoint Analyser and PA combined with separate band specific duplexers. This approach provides enormous flexibility as a pair of low band and high band Analyser/ PAs will cover all sub-3GHz 3GPP bands. The equipment owner can thus re-use the Analyser/ PA for any band with the addition of just the band specific duplexers needed for the bands under test, as dictated by the specific product being tested. This is a real departure from the inventory challenges that apply to legacy PIM testers where a band-specific tester is required for each individual band to be tested.

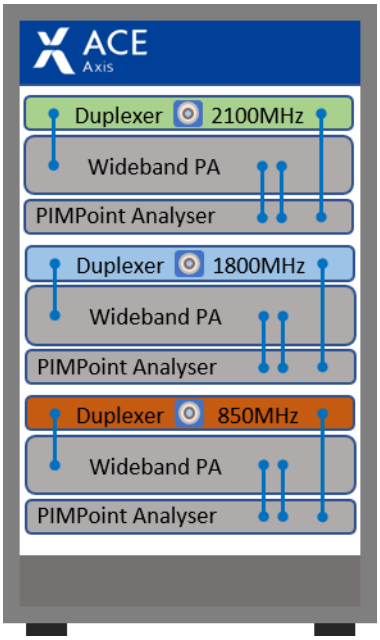
PIMPoint Analyser and Wideband PA

The PIMPoint Analyser is based on a Software Defined Radio design providing a wideband capability combined with the flexibility to generate the specialised test stimulus waveforms needed for the location function. The wideband PA can generate up to 44dBm per tone for standard IEC 62037 tests, or up to 47 dBm per tone when using the higher power PA option.

The PIMPoint Analyser provides a powered AISG port so that the RET function of an AISG 2.0 compatible antenna can be controlled, as required by the fault location process.

The PIMPoint application software is provided in the form of a user-friendly GUI that will run on a PC. This application software is capable of controlling multiple PIM analysers to enable test of multiband antennas. In this case the GUI will automatically sequence tests to ensure that all ports and bands of the DUT are tested.

The image to the right illustrates how a multi-band test station may be configured for a specific band, set simply by equipping it with the necessary duplexers.



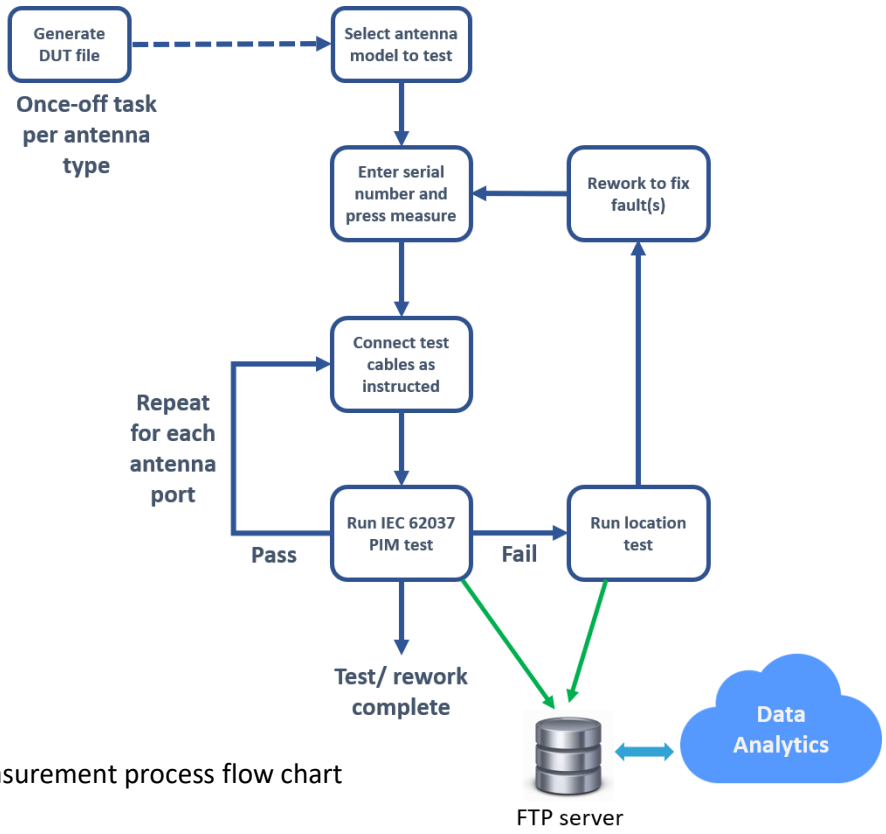
Multi-band test station configured for 850MHz, 1800MHz and 2100MHz bands

Operation

The operational flow of the PIMPoint Analyser test software is illustrated in the flow chart.

A DUT file must be generated off-line for each antenna type to be tested, this is a once-off process. The next section discusses how this can be readily undertaken using the separate "DUT Creator" software GUI.

The antenna model is selected from a drop-down menu, and then testing can commence. The serial number of the antenna is entered, or scanned via bar code, and then an automated test process is initiated, with the operator instructed to connect the respective band PIM Analyser to the correct antenna port. An IEC 62037 test is first run and if passed the operator is directed to connect the next port/ band for the subsequent test in



Measurement process flow chart

the sequence. However, if the test fails, the location test process may be run and the detected fault locations displayed to enable rework to be undertaken. The overall measurement process loops until all desired ports and bands have been covered. All results and measurement and location plots are saved to the local PC disk. The GUI also has the capability to upload all saved results to a specified remote FTP server. As they build up, the stored measurement results can then be analysed by a Data Analytics package to look for result trends and identify production or design issues. This aspect is further discussed in a later section.

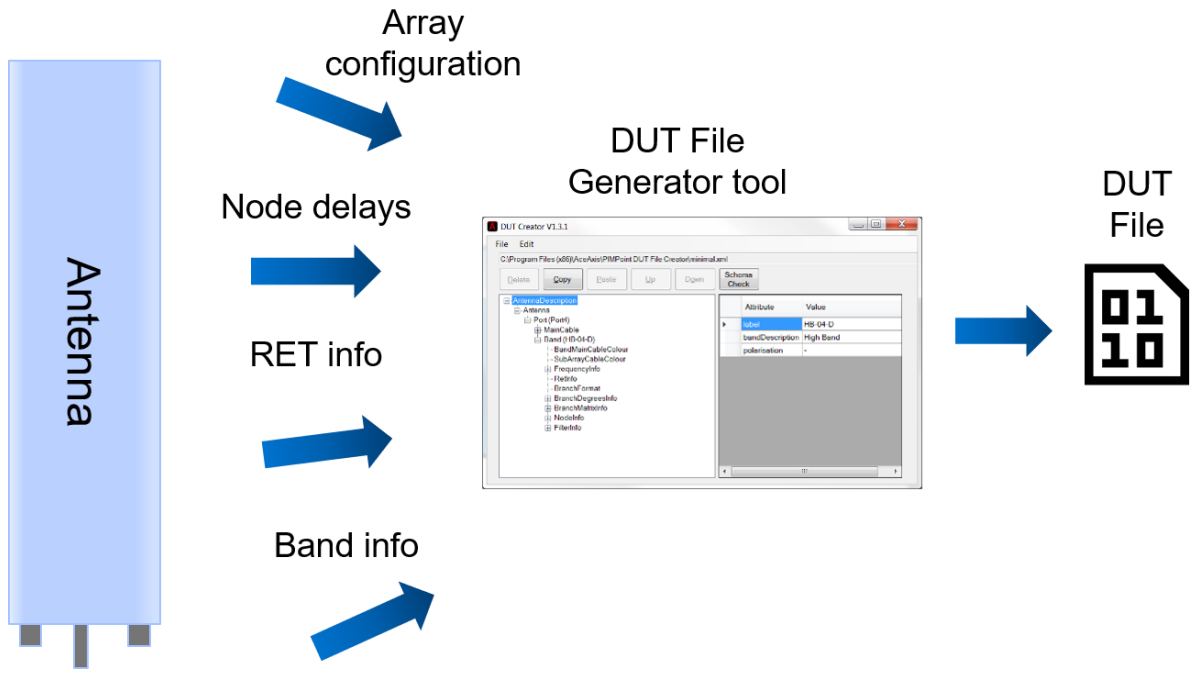
The DUT file

The DUT file provides the PIMPoint Analyser with key information about each antenna port. A GUI tool is provided to simplify DUT file generation and typically a production engineer would generate this file from basic antenna information. Alternatively, the DUT file could be generated in parallel with the antenna design process.

The basic information required to generate the DUT file is:

- The array geometry, which is the relative spacing of the radiating elements or sub-arrays used within the vertical antenna array
- The cable BOM for calculating the cable delays
- Approximate delays for components such as phase shifters and filters
- The RET type and range, e.g. Single, Dual or Multi-RET and any port specific submodule data
- The PIM test frequency

The DUT Creator GUI facilitates rapid generation of the DUT file from the above data. Often there may be near identical antenna characteristics for multiple ports, and so once the first port information has been generated it may simply be copied and pasted to other ports.



DUT file generation process

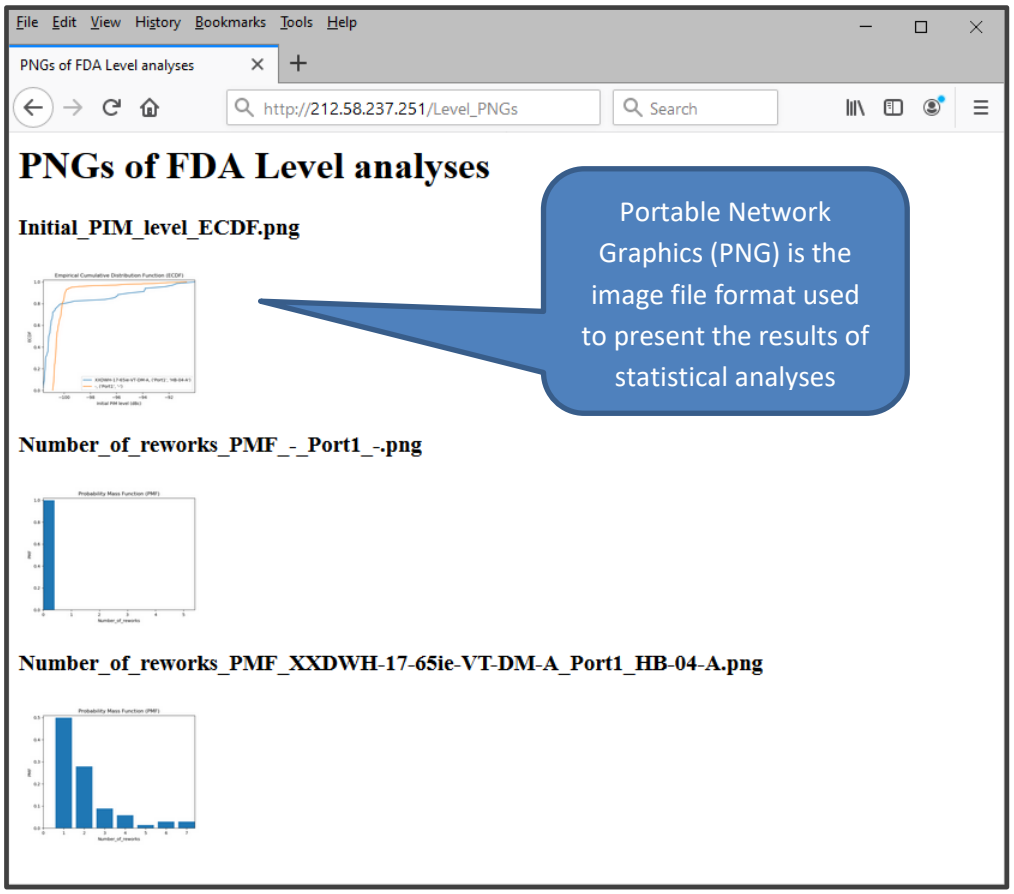
Data Analytics

As mentioned above, all PIM measurements and location analysis output can be directed to an FTP server so that long-term Data Analytics can be used to highlight potential production or design aspects contributing to fault instances.

To achieve this, the location analysis raw test output is first saved to files and folders within the local filesystem of the PC which is running the GUI application that is controlling the PIMPoint apparatus. This GUI application then periodically uploads these local files to a single central remote server, using the FTP protocol within a background process. This central results file repository is then made available for analysis by the separate in-house PIMPoint Data Analytics (DA) software.

The in-house DA software (provided) accesses the central repository of historical measurement data, and carries out various analyses, including the following:

- Numbers of antenna ports showing first-time pass/fail
- Cumulative Distribution Functions (CDFs) of PIM level
- Probability Mass Functions (PMFs) of numbers of reworks
- PMFs of fault frequency per candidate fault location for Branch or Range



The results of these analyses are then served up to the user via a web-based API, such that any user can easy access them using a simple web browser. Through this means the user is also able to access the raw PIM results in JSON format. This JSON data can be accessed either 'in full' or 'pre-filtered' (e.g. by Product code,

Serial number, date and time etc.). The data in this JSON format could then potentially be routed to any pre-existing DA tool, such as off-the-shelf Business Intelligence (BI) software. Alternatively, the user might write their own application to access either this filtered JSON data or even the raw text files from the central repository.

Yet another Data Analytics option open to the customer is to purchase licenses for the 'Production Automation System Software' (PASS) tool by Verifide. This tool is capable of importing the PIMPoint raw results from the central repository into its own 'Dynamic Database' using a custom import library (provided). The PASS tool is then able to carry out a wide range of standard statistical analytics functions and rich data visualisations. It is even possible to create additional PIM-specific *custom* analytics tools as PASS plugins. These plugins are written in a programming language targeted to the .NET runtime (e.g. C#), which is able to access data within PASS using a .NET library provided within the PASS tool.

Conclusions

The production of low PIM antennas continues to present an ever-increasing time and cost burden for manufacturers. The PIMPoint Analyser, with its 3D location technology, provides a very significant step forward towards mitigating these issues. The combination of the automated PIM measure/ locate capability reduces the costs associated with PIM test and rework. Additionally, when location is combined with Data Analytics, even further improvements can be secured in design/ production using the enhanced production fault monitoring and problem identification it offers.

The flexibility of the wide band PIMPoint Analyser equipment reduces the total cost of ownership, providing a solution that is no longer band specific. The equipment can be rapidly reconfigured to address different bands as the production requirements shift, in order to address new product or new market demands.

In summary PIM Point™ enables:

- Reduced test/ rework time
- Use of lower skilled staff
- Band flexibility by simple reconfiguration
- Further benefits from Data Analytics