Passive Intermodulation Measurement Techniques

White Paper

INTRODUCTION

Through interaction with engineers and technicians in many countries throughout the world, Kaelus has had the opportunity to discuss and evaluate measurement techniques as they apply to a wide variety of items. We have discussed the problem of IM with component manufacturers, infrastructure providers, site managers and service providers. This perspective combined with the knowledge gained through the development and manufacture of our Passive Intermodulation Analyzers, forms the basis of our approach to the measurement of passive intermodulation, and the test capabilities built into our analyzers.

Our findings suggest the following:

- Consistently manufacturing low IM items is extremely difficult to achieve in mass quantities where the emphasis is on cost reduction
- Dynamic measurements should be performed on all PIM critical devices
- Fixed frequency measurements may not be adequate due to the frequency dependent characteristics exhibited by many devices and subsystems

WHY TO WE CARE ABOUT PASSIVE INTERMODULATION (PIM)?

Passive IM is an increasing concern in the wireless community, because of the debilitating affect it can have on the performance of the telecommunications network. Passive IM is generated whenever more than one frequency encounters a non-linear electrical junction or material. The resulting creation of undesired signals, mathematically related to the original frequencies, can result in decreased system capacity and/or degraded call quality.

Reduced capacity and call quality at a cell site leads to reduced income for the wireless service providers. The economic loss is compounded when the affected customer becomes frustrated and switches over to a competing provider.

Q&A

Question: Is Passive IM A Design Issue, A Manufacturing Issue, or A Maintenance Issue?
Answer: "All of the Above".

A good design is a necessary, but not a sufficient condition for success...

At one time, many companies considered IM something that could be controlled simply by following a few well-documented design rules.

- Avoid the use of ferrous metals
- Minimize the number of contact junctions
- Design all contact junctions such that they are precise and under sufficient pressure to maintain good contact
- Solder or cold weld all junctions where possible
- Avoid dissimilar metals in direct contact
- Plate all surfaces to prevent oxidation
- Make certain plating is uniformly applied and of sufficient thickness

The bigger challenge is building it...

Although, the rules seem straightforward, manufacturing excellence is the key to success. Minor deviations from the ideal process can create unacceptable levels of Passive IM.

Some of the real world deficiencies that occur:

- Poor alignment of parts
- Inadequately torqued screws and fasteners
- Bad solder joints
- Insufficient or incomplete cleaning of parts prior to plating
- Contaminated plating tanks
- Plating material build-up
- Using wrong materials
- Poor plating adhesion

Then you have to integrate and install it...

Once you have good designs and well-manufactured components, the next challenge is integration and system installation. Recall that all junctions are potential PIM generators.

Therefore, every interconnect is a potential source of trouble. Joints that test out fine in a benign environment can become problematic when mechanically stressed (bending of cables, torsional loads on connector interfaces, over/under torqued connectors).

In summary, it is not a given that interconnecting components that meet their IM specification assures a subsystem that also meets the IM specification.

... And then Mother Nature takes over.

The natural elements are the enemy of those portions of the network that are exposed to them.

- Wind-induced vibration
- daily temperature variations
- moisture in its various forms
- thermal loading by the sun
- air borne dirt

Each of these works to break down and erode the quality of the components in the network, and ultimately the communication channel. The weakening of joints, separation of junctions, invasion of moisture, oxidation of materials, and contamination by dirt and dust all give rise to passive intermodulation and desensitization of the receiver.

The result is a cell site performing below its design potential

TEST METHODS

Quantifying passive IM performance

Good communication quality requires maintaining an acceptable Carrier-to-Interference (C/I) ratio. Therefore, the goal is to keep 'I' as low as possible. In the ideal case, 'I' would always be below the receiver noise floor. One source of undesired interference is passive intermodulation.

A typical specification requires a passive IM level no greater than —110dBm when two +43dBm carriers are injected into the device under test, i.e., -153dBc. To put this into perspective, this is a ratio of 1:2,000,000,000,000,000, or the equivalent of trying to measure the distance to the sun to an accuracy of one-tenth of a millimeter.

The old way

A commonly used approach to measuring passive IM is to inject two fixed frequency CW tones of 20W per tone into the device under test and measure the IM power levels generated. This test scenario is consistent with that proposed by the international standards committee tasked with defining test methods for the measurement of passive IM (I EC TC46 WG6).

To realize the necessary test setup, the classic approach has been to rack and stack two synthesizers feeding two high power amplifiers that connect to an array of RF components, which combine, filter and duplex the signals, and then route the signal of interest through a low noise amplifier to a spectrum analyzer for detection and display. A power meter is used to set the proper transmit powers and then readjust on a periodic basis to compensate for drift.

The rack-and-stack approach to building a passive IM test bench is clearly a difficult process. Furthermore, because there are so many discrete instruments, components and interconnecting cables, the measurement results are sometimes difficult to repeat, and the setups are often unstable and susceptible to damage. As if that weren't enough to discourage all but the stouthearted, the measurement is time-consuming, and as we are beginning to realize, the results can be inconclusive and misleading.

The Kaelus Way

With an understanding of how passive IM testing was performed (and the associated deficiencies), Kaelus set forth the following design goals:

- Build a test instrument that produces high quality, repeatable measurements
- Make the instrument easy to set up and use
- Advance the state-of-the-art by providing new and useful test tools
- Bring standardization to this difficult measurement in order to establish a clear basis of performance comparison
- Stay current with emerging technology trends and test standards
- Listen to the customer and incorporate their recommendations as appropriate to provide the most comprehensive and easy to use test instrument possible

This led to the three significant design features incorporated into Kaelus' Passive IM Analyzers:

1. A highly integrated design: Minimize the number of external components by packaging all of the RF components in a single enclosure. This results in improved reliability, stability and repeatability.

2. High-speed digital receiver technology. The speed and the frequency agility of the Kaelus analyzers make it possible to:

   - Measure multiple IM products simultaneously
   - Measure and record transient events such as PIM burst and changing IM due to mechanical and environmental stress

   - Measure swept frequency intermodulation characteristics to verify performance over the entire specified frequency range

3. Innovative new test capabilities: The resulting instrument is easy to use, time-efficient and High-speed digital receiver technology. The speed and the frequency agility of the Kaelus analyzers make it possible to:

I REVEALING REALITY

Most measurements are made with a single pair of carrier frequencies, usually set at the transmit band edges for the wireless standard you were testing.

For example, consider the measurement of a device used in a PCS1900 Band network. Typically, this test is performed by setting Carrier 1 to 1930 MHz and Carrier 2 to 1990 MHz. (Note: There are some PIM test setups that, due to their design, must use one carrier set to a frequency in the receive band while the other carrier is set to a frequency in the transmit band. The validity of this approach open to debate.)

After the transmit frequencies and powers are established and the spectrum analyzer configured to measure the IM response, the test is initiated. During the measurement, care is often taken not to disturb the device under test or the test setup in case instabilities might produce a data a spike at the precise moment the spectrum analyzer happens to be sweeping past the IM frequency.

Experience suggests that this approach to measuring PIM is much too limited and leaves too many potential problems hidden.

Dynamic Measurements

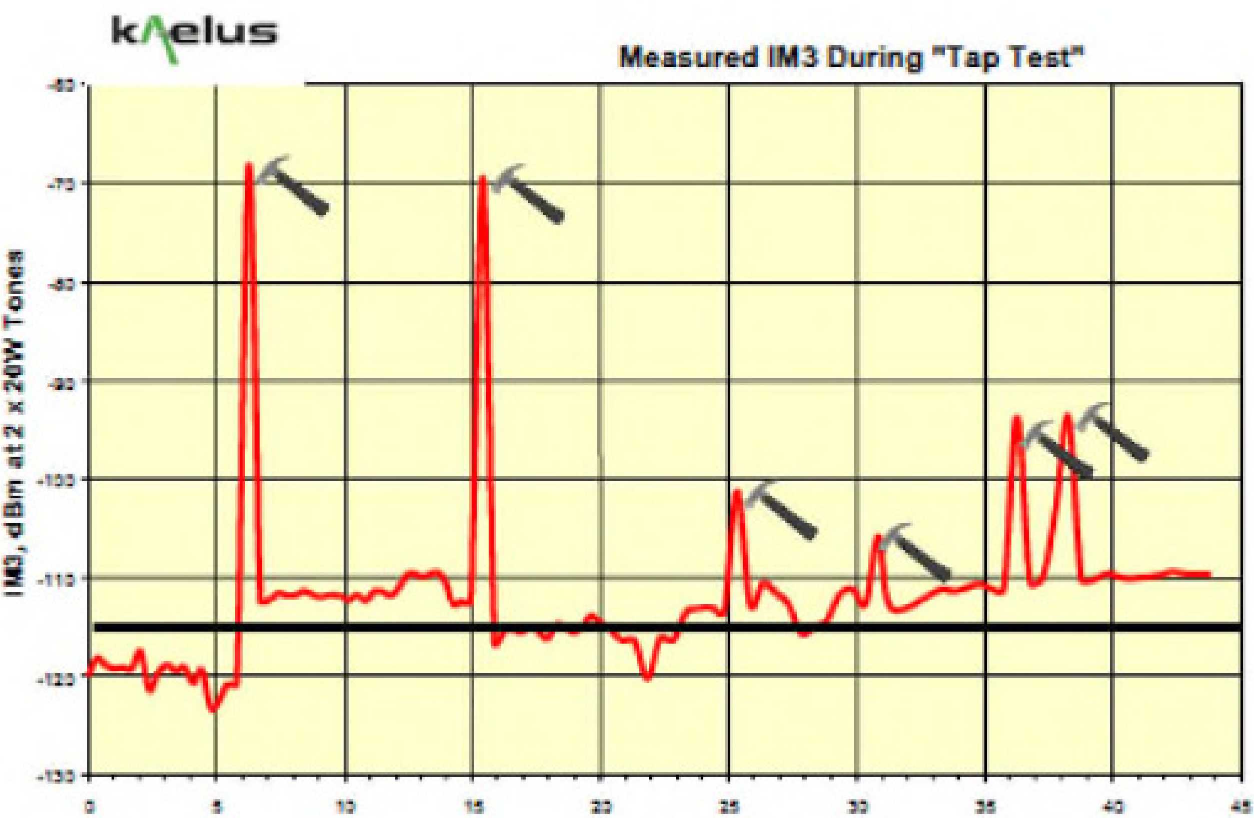
Despite the best efforts to design and manufacture products that are stable regardless of their environment, the passive IM response of components and subsystems can vary dramatically when subjected to stress. In a dynamic measurement, IM performance is monitored during the application of an appropriate stimulus.

The issue of dynamic measurements has been given a great deal of attention with regard to cable assemblies. The concern has to do with the vulnerability of the connector/cable interface as well as IM created in the cable (by micro-cracks in solid conductor cables and discontinuous contact in braided cables). Testing involves measuring the IM as the cable is flexed and/or a bending moment is applied at the connector/cable interface.

In our view, all components on the base station transmit side of the wireless network should be subjected to this scrutiny. Two measurements routinely performed by Kaelus on all PIM critical components used in our analyzers are the "tap" test and the bending moment test. The tap test is simply a matter of tapping the device and watching the IM response. For example, tapping the tuning screws on filters frequently generates high levels of passive IM. After the tapping is stopped, the IM sometimes returns to its low IM condition and sometimes it remains high. The tap test has been demonstrated to be highly useful in screening devices and cables that will fail at some future (and inconvenient) time.

This is illustrated in the following example. In this case, we used the Strip Chart Mode of the Kaelus analyzer to record the IM response over time. The device under test is a PCS1900 band pass filter.

What we are observing is the changing IM due to tapping. Later testing also showed this device to have much-degraded IM performance with temperature changes.



Time, Seconds

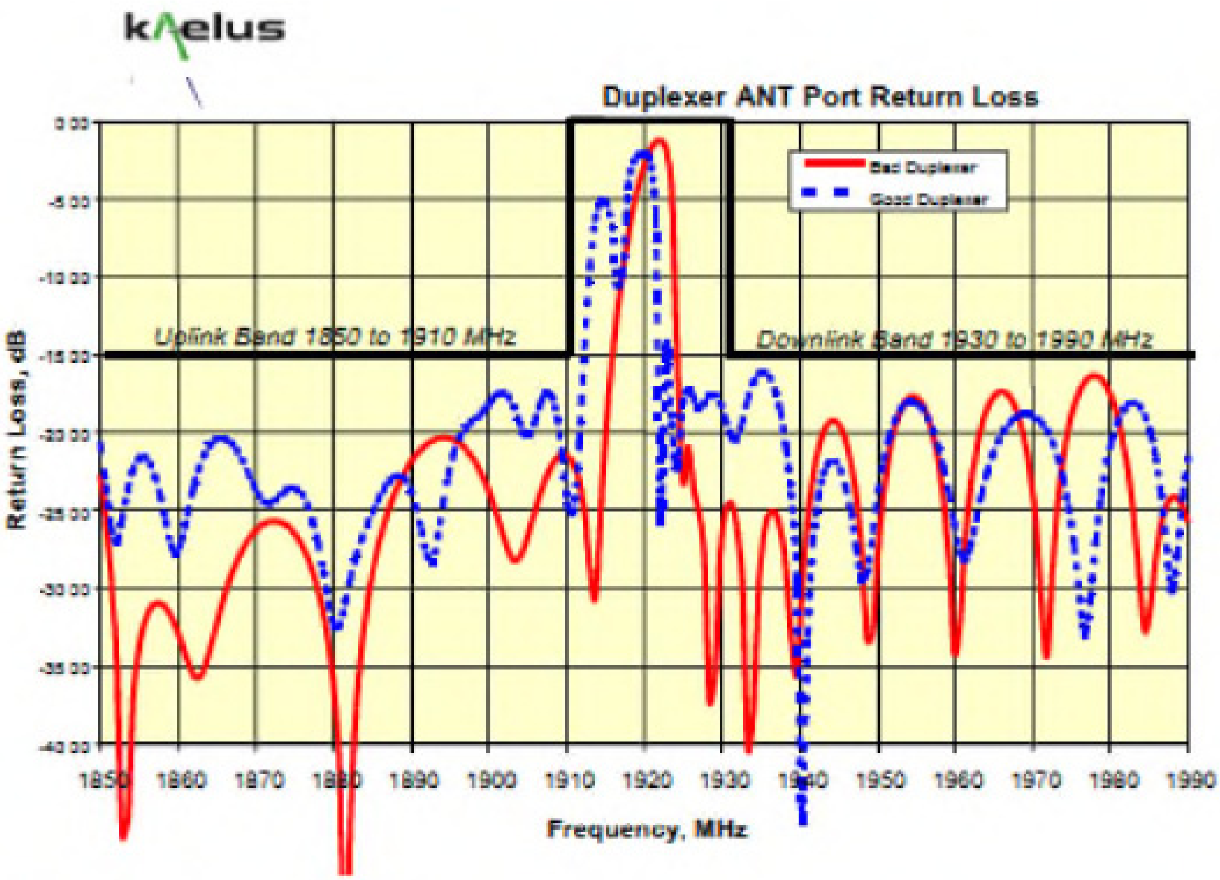
Figure 1: Dynamic IM Measurement

The bending moment test is performed by applying a modest side force to the connector on the device under test. If the connector is not adequately attached to the body of the component, or if the launching mechanism within the device is not solid, IM will be generated.

Swept Frequency Measurements

Until now, the accepted method for measuring passive IM was to set the carrier to two fixed frequencies, usually, but not always in the transmit band, and measure the IM generated. What has been discovered is that on many devices, this is not adequate, because these devices exhibit IM characteristics that vary as a function of frequency. Kaelus Passive IM Analyzers make this measurement at multiple frequencies practical and easy.

An example clearly demonstrates the virtue of the swept frequency IM measurement. In this case, a PCS1900 band duplexer with a bad connector is measured. It should be noted that the connector damage was caused by over-torquing the connector and is undetected by visual inspection and swept return loss measurements. The comparison between the "good" and the "bad" duplexer return loss is shown in the following figure.



The "good" duplexer meets the —115dBm specification at all frequencies, but the "bad" duplexer has a severely degraded IM as the tranmsit carriers are moved from the band edges. Both duplexers would pass QA screening if only band-edge carriers were used for the testing.

To fully characterize the device under test, the swept —frequency capability of the Kaelus Passive IM Analyzer records the IM performance as each of the two carriers is swept in frequency across the transmit (down-link) band. Only one carrier at a time is swept, while the remaining carrier is held fixed at the band edge. In the plot below, Carrier 1 is fixed at 1930MHz while Carrier 2 is swept from 1950 to 1990MHz producing third order intermodulation products (IM3) that occur at frequencies from 1870 to 1910MHz.

The measured data can be logged to a file, copied to the computer clipboard where it can be pasted into another application, or it can be directly hard-copied to a printer.

SUMMARY

With the wireless service providers working hard to win and maintain customers, controlling the generation of passive intermodulation distortion can impact the financial success of the providers. The presence of passive IM at a cell site impacts base station capacity and service quality. Therefore, it must be considered, measured and controlled from design through manufacturing, and at the base station in order to realize optimum performance.