

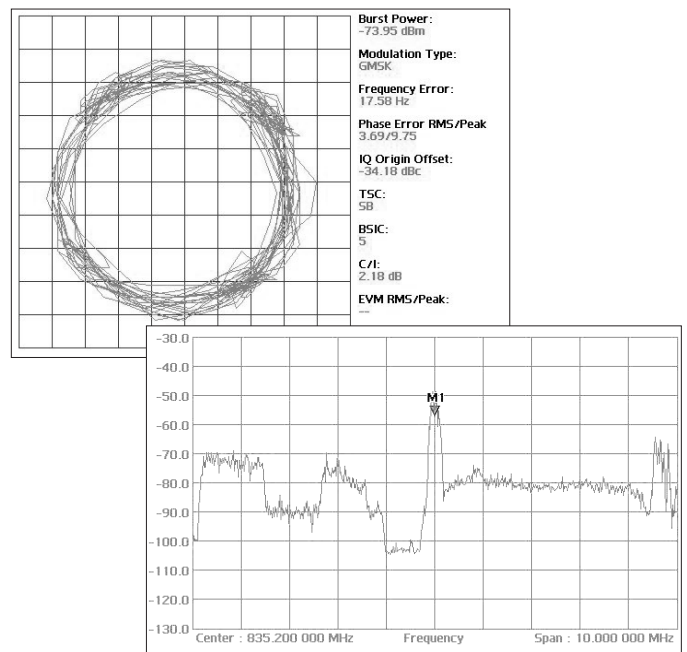
Interference in Cellular Networks

Intermodulation and Frequency Refarming

Interference in cellular networks is one of the most common problems in the radio access network (RAN). Different systems and services such as mobile communications, mobile radios, paging, wireless local area networks, and digital video broadcasting each use an assigned spectrum to avoid transmitting different services at the same frequency—causing signal collisions or interference.

However, even if different wireless services don't generate harmonics, frequency drifts, or RF leakage, cell sites are subject to internal interference caused by the improper conductivity of passive devices such as connectors, cables, or antennas. This internal interference can generate intermodulation signals at the same frequency band as mobile transmitters (uplink).

Another common case of interference internal to the RAN is caused by frequency refarming. Operators evolving their mobile technology to LTE use refarming to deliver higher throughput for mobile devices while maintaining their existing technologies such as GSM and WCDMA. This technique supports a gradual adoption of LTE. The co-existence of multiple technologies in a limited spectrum is forcing mobile operators to increase the number of carriers and to re-use frequencies, creating a RAN subject to internal interference.



Intermodulation

Intermodulation in passive components is created when two signals are transmitted in a cabling system with improper conductivity characteristics such as loose jumpers, bent cables, different metals in jumpers, or corrosion.

This intermodulation generates signals as products or multiples of the two transmitted signals. For example, if signal A is transmitted in a center frequency F_1 and signal B is transmitted in a center frequency F_2 , intermodulation in third order will generate four signals:

- a. $[2 \times F_1 + F_2]$
- b. $[2 \times F_1 - F_2]$
- c. $[2 \times F_2 + F_1]$
- d. $[2 \times F_2 - F_1]$

Similarly, intermodulation in fifth order will generate signals as $[3 \times F_1 + 2 \times F_2]$ and $[2 \times F_1 + 3 \times F_2]$. Subsequently, other products of higher order are generated, each with lower signal strength.

A case of intermodulation in cellular networks is when different carriers are allocated in the same frequency band such as GSM and WCDMA in the 800 MHz band or GSM channel 128 (center frequency FGSM = 869.2 MHz) and WCDMA channel 4458 (FWCDMA = 891.6 MHz). In this case, the third order intermodulation will be:

- a. $2 \times F_{GSM} + F_{WCDMA} = 2,630 \text{ MHz}$
- b. $2 \times F_{GSM} - F_{WCDMA} = 846.8 \text{ MHz}$
- c. $2 \times F_{WCDMA} + F_{GSM} = 2,642.4 \text{ MHz}$
- d. $2 \times F_{WCDMA} - F_{GSM} = 914 \text{ MHz}$

In this example, the third order intermodulation described in (b) of 846.8 MHz is within the transmission band reserved for mobile devices which is 824 to 849 MHz.

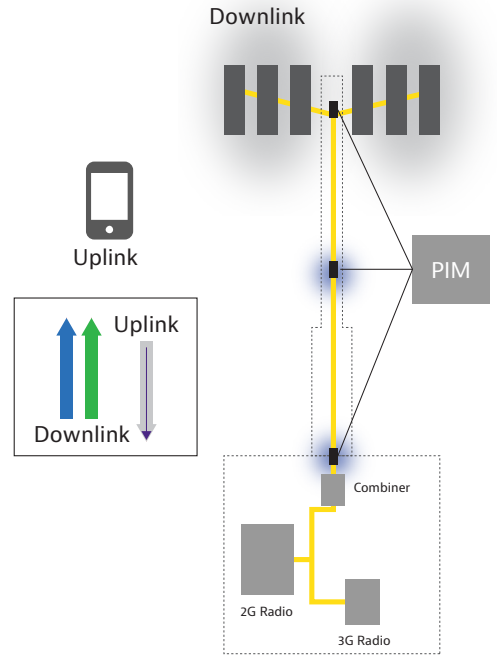
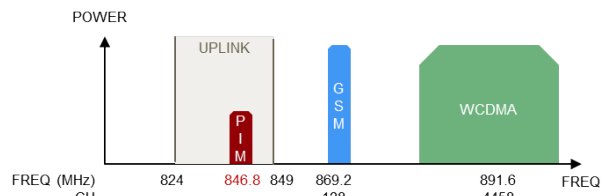


Figure 1. Cell-site intermodulation



$$PIM_{IM3} = 2 \times F1_{GSM} - F2_{WCDMA} = 2 \times 869.2 - 891.6 = 846.8$$

Figure 2. Intermodulation in GSM and WCDMA band 850

Intermodulation can also be present in LTE networks, where the signal transmitted by the radio is composed as an aggregate of subcarriers (15 KHz) which together constitute a wideband signal. For example, a 10 MHz LTE channel is composed of 600 subcarriers.

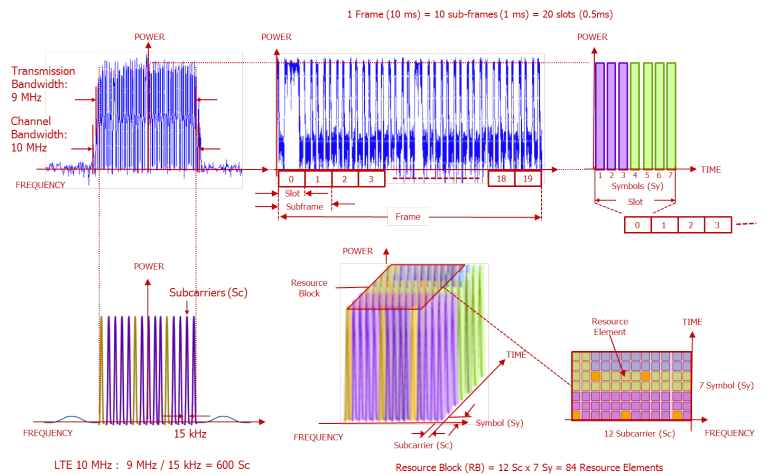


Figure 3. LTE-FDD signal format

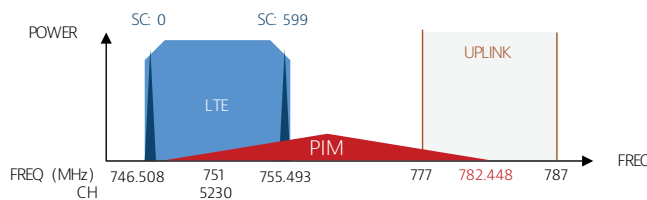
The interaction of LTE subcarriers in transmission lines with improper conductivity characteristics will create intermodulation which can interfere with the transmission of mobile devices.

The following example illustrates the intermodulation products of a 10 MHz LTE-FDD signal in band 13 channel 5230 which has a center frequency of 751 MHz. Its subcarrier 0 is at 746.508 MHz and its subcarrier 599 is at 755.403 MHz, therefore, an example of intermodulation products is as follows:

Table 1. Intermodulation LTE CH 5230

| 3rd IMOD | MHz |
|---|-----------|
| $2 \times F_{SC0} + F_{SC599}$ | 2,248.508 |
| $2 \times F_{SC0} - F_{SC599}$ | 737.523 |
| $2 \times F_{SC599} + F_{SC0}$ | 2,257.493 |
| $2 \times F_{SC599} - F_{SC0}$ | 764.478 |
| 5th IMOD | MHz |
| $3 \times F_{SC0} + 2 \times F_{SC599}$ | 3,750.508 |
| $3 \times F_{SC0} - 2 \times F_{SC599}$ | 728.538 |
| $3 \times F_{SC599} + 2 \times F_{SC0}$ | 3,759.493 |
| $3 \times F_{SC599} - 2 \times F_{SC0}$ | 773.463 |
| 7th IMOD | MHz |
| $4 \times F_{SC0} + 3 \times F_{SC599}$ | 5,252.508 |
| $4 \times F_{SC0} - 3 \times F_{SC599}$ | 719.553 |
| $4 \times F_{SC599} + 3 \times F_{SC0}$ | 5,261.493 |
| $4 \times F_{SC599} - 3 \times F_{SC0}$ | 782.448 |

In this case, the 7th intermodulation product is generated at 782.448 which is within the uplink frequency band of 777 to 787 MHz, possibly causing interference with mobile devices.



$$PIM_{IM7} = 4 \times F_{SC599} - 3 \times F_{SC0} = 4 \times 746.508 - 3 \times 755.493 = 782.448$$

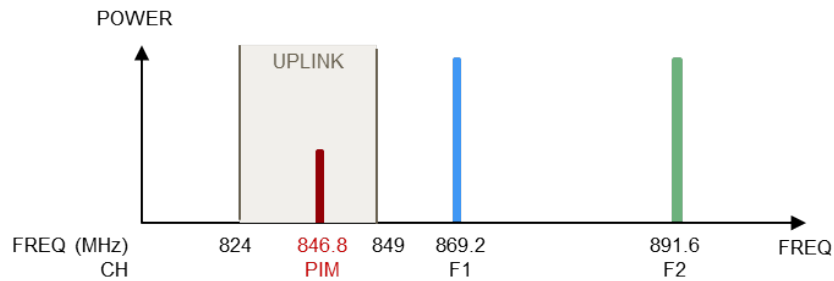
Figure 4. Intermodulation in LTE band 700

The intermodulation product that affects the uplink band is the seventh intermodulation, which has a relative low power, which for a single carrier intermodulation such as GSM won't be significant. However, due to the existence of multiple subcarriers in LTE, this intermodulation product is multiplied in different frequencies. This effectively increases the power level of this seventh intermodulation product. Therefore the interference created will have a ramp shape that will distort the spectral flatness on the uplink band.

Testing Intermodulation

There are two main methods to test intermodulation in cell sites, intrusive and non-intrusive:

- **Intrusive PIM Test** — This test method requires taking the cell site out of service and connecting its feed line to an instrument that generates high-power continuous wave signals (20 W or 43 dBm), emulating the radio's carriers. Testing then shows if any intermodulation product is created with a power level high enough to interfere with the transmission of mobile devices. The following diagram illustrates this method using the previous example of GSM and WCDMA in band 850.



$$PIM_{IM3} = 2 \times F1 - F2 = 2 \times 869.2 - 891.6 = 846.8$$

Figure 5. Two continuous-wave generations to induce PIM in band 850

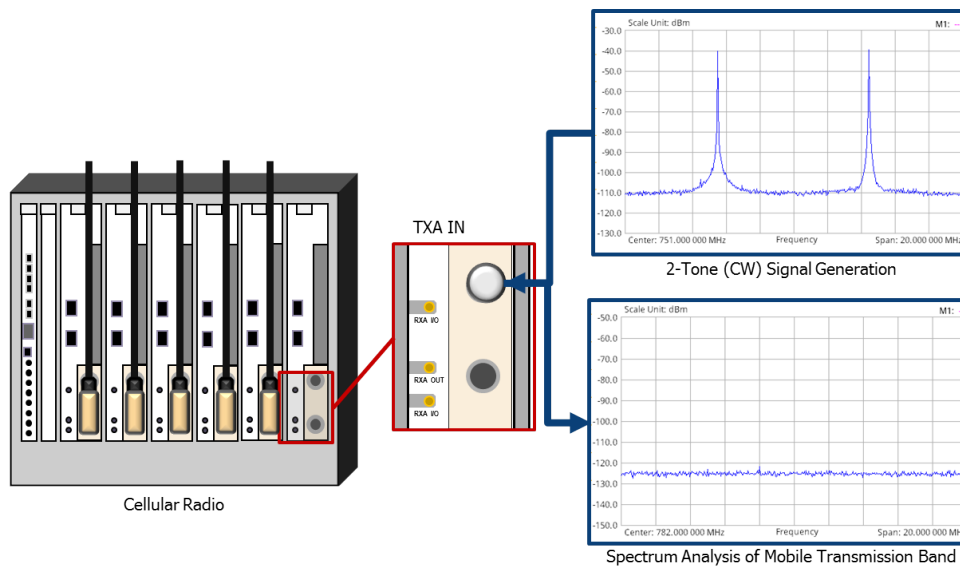


Figure 6. Intrusive PIM test

- **Non-Intrusive PIM Test** — This test method maintains the cell site in service and connects a spectrum analyzer-based instrument into the cell site's receiver monitoring port. The instrument then will test for the presence of low-level signals in the uplink band that can be sufficiently strong to interfere with mobile devices. In case of cell sites with multiple carriers such as WCDMA and GSM, it is practical to make comparisons with and without the presence of PIM by momentarily deactivating and reactivating the transmission of one of the carriers such as GSM. In the case of LTE, one carrier is transmitting multiple subcarriers and is always generating PIM that will modify the flatness of the uplink noise floor. In practice, the power difference across the uplink noise floor is measured. The following diagram describes the setup of non-intrusive PIM testing.

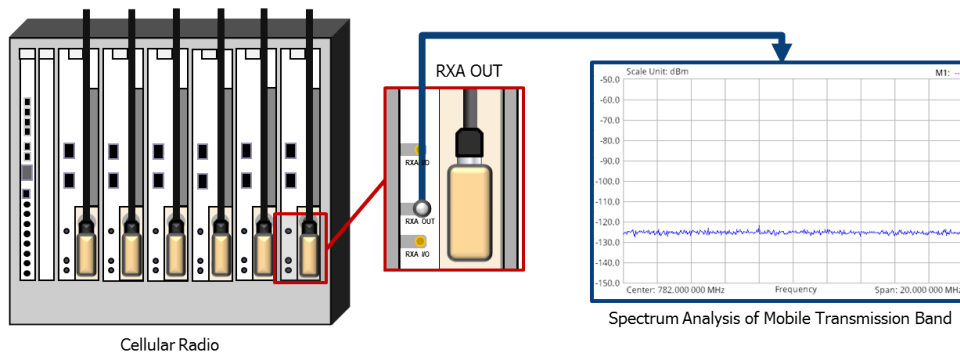


Figure 7. Non-intrusive PIM test

The main differences between these two test methods is that, in addition to its intrusive nature, the generation of high-power tones requires dedicated amplification and filtering on a narrow frequency band. This requires dedicated instruments per band of operation.

For this reason, non-intrusive PIM testing has become the method of choice for cell technicians, since the test is not limited to any particular band and it is generally done to differentiate if the source of interference is external to the cell site or is internal due to PIM.

The intrusive PIM test, however, provides additional information of intermodulation such as the location of the passive device that is generating the intermodulation. For example, with conventional macro sites, where the coaxial feed lines can be several feet long, it is more practical to locate the passive device causing intermodulation and conduct the corresponding repairs. However, for macro sites with distributed radios where the coaxial feed line is just a few feet long from the remote radio unit to the antenna, the location of the passive device generating intermodulation is not needed, since in practice the coaxial cable is replaced.

Analyzing Intermodulation

Intermodulation analysis of both methods is also similar. The main difference is that intrusive PIM testing is typically reported in relative units (dBc) since the intermodulation is created from a known continuous wave and power level; whereas the non-intrusive PIM testing is reported in absolute units (dBm).

The following diagram illustrates the relationship between both test methods. In this example, the intrusive PIM test has a maximum permissible PIM power level of -153 dBc which corresponds to a non-intrusive PIM test maximum permissible PIM power level of -110 dBm.

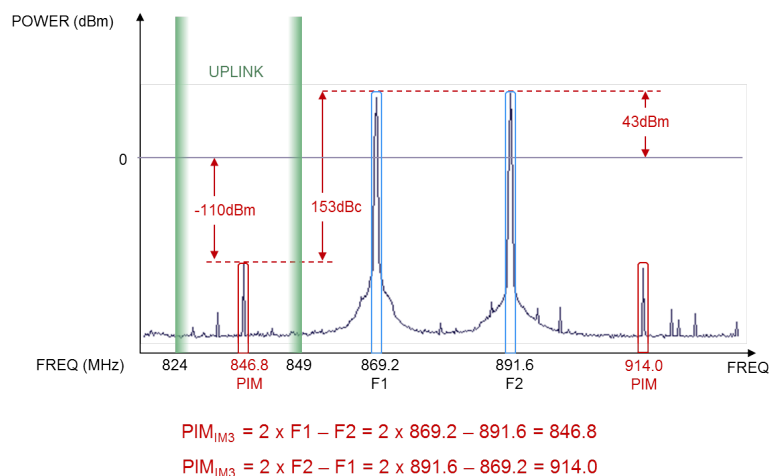


Figure 8. Intermodulation analysis

Ultimately the analysis of intermodulation should be based on spectrum analysis in order to test the amount of interference created on the uplink band due to intermodulation. The severity of this interference has a direct relationship with the level of sensitivity of the cell site.

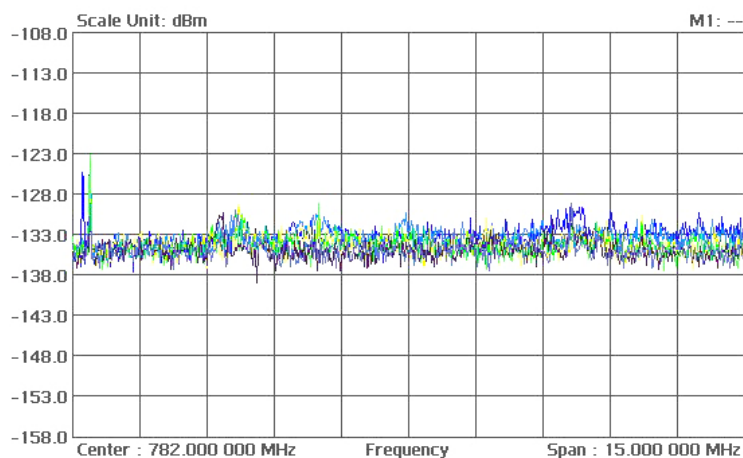


Figure 9. Uplink spectrum without PIM (LTE: 3 sectors, MIMO 2x)

Table 2. Cell-site sensitivity levels by technology as defined by 3GPP

| Technology | Cell-Site Type | Sensitivity (dBm) |
|------------------------------|-----------------------------------|-------------------|
| GSM/EDGE (3GPP TS 45.005) | Normal BTS | -104.0 |
| | Micro BTS M1 | -97.0 |
| | Micro BTS M2 | -92.0 |
| | Micro BTS M3 | -87.0 |
| | Pico BTS P1 | -88.0 |
| CDMA (3GPP2 C.S0010-D) | Macrocell — bands 450 and 800 | -117.0 |
| | Macrocell — band 1900 | -119.0 |
| | Picocell | -117.0 |
| | Femtocell | -110.0 |
| WCDMA (3GPP TS 25.104) | Wide area BS | -121.0 |
| | Medium range BS | -111.0 |
| | Local area/home BS | -107.0 |
| LTE (3GPP TS 36.104) | Wide area BS — 1.4 MHz | -106.8 |
| | Wide area BS — 3 MHz | -103.0 |
| | Wide area BS — 5, 10, 15, 20 MHz | -101.5 |
| | Local area BS — 1.4 MHz | -98.8 |
| | Local area BS — 3 MHz | -95.0 |
| | Local area BS — 5, 10, 15, 20 MHz | -93.5 |
| | Home BS — 1.4 MHz | -98.8 |
| | Home BS — 3 MHz | -95.0 |
| | Home BS — 5, 10, 15, 20 MHz | -93.5 |

Frequency Refarming

Mobile operators are constantly looking to provide superior services in the most efficient manner; however, properly managing the mobile network is a complex job with significant challenges, such as:

- Mobile subscriptions should be sufficient to cover all potential customers
- Mobile services should be high quality, from clear voice communication to high data throughput
- Networks need to evolve to new wireless technologies from GSM to WCDMA and LTE with limited spectrum
- Customers are migrating from voice-only service (GSM) to high data throughput applications (WCDMA/HSDPA and LTE).

The combination of network evolution and the migration of customers to additional services challenges the coexistence of the old and conventional and the new and different. From a network perspective, older wireless technologies such as GSM should coexist with newer radio generations such as WCDMA/HSPDA and even LTE at the same cell site. From a mobile user’s perspective, in the same service area of a cell site there will be users only interested in voice services and users using data or video applications who demand high data throughput.

This coexistence in a scarce spectrum has driven mobile operators to reuse spectrum. For example, they refarm frequencies assigned to GSM carriers into WCDMA/HSDPA or LTE; therefore, multiple wireless technologies are transmitting on the same frequency band.

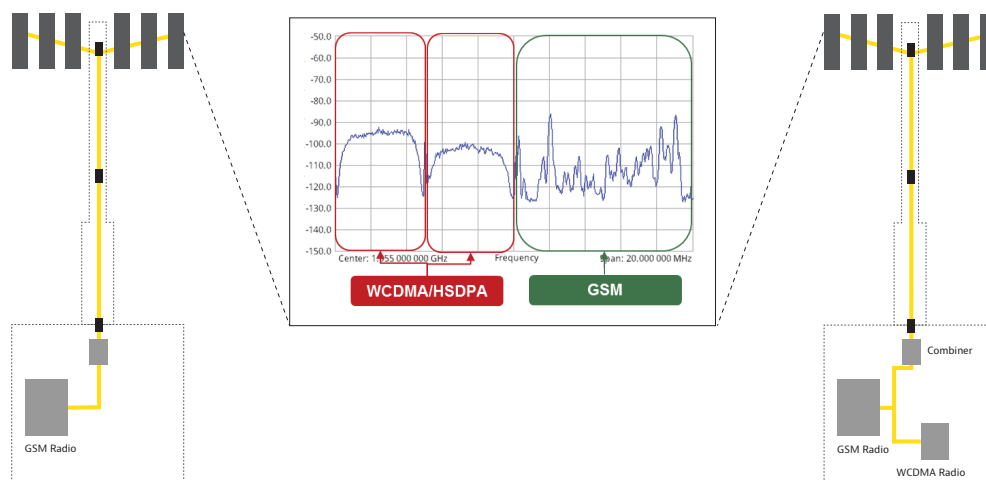


Figure 10. WCDMA/HSDPA and GSM carriers in band 1900

This frequency refarming should be carefully planned and managed in order to avoid interference. For example, the commissioning of carriers with no guard bands might cause carrier overlaps and interference between channels. Similarly, any frequency shift of any of the radios will also cause channel overlap and interference.

The following diagram shows two WCDMA channels with interference in their lower and higher frequencies.

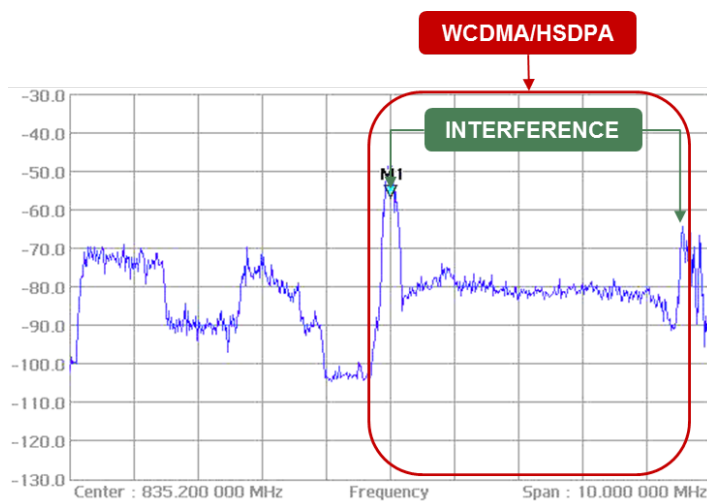


Figure 11. WCDMA/HSDPA interference

Traditionally, once an interference signal is detected, the immediate troubleshooting action is to locate the source of the interferer. This involves making multiple measurements at different geographical locations with directional antennas in order to find areas where the interference signal is stronger. Triangulation then indicates the intersection area where the interferer is located.

This interference finding process can take several hours or days, and if the interference is intermittent, it can extend to weeks. The ability to perform signal identification through signal analysis prior to interference finding can save a significant amount of troubleshooting time.

Signal analysis is the ability to demodulate the signal under test in order to obtain in-depth information about the signal including its modulation format and the cell identifier that is transmitting such signal. In the above example, the interference signal with WCDMA channels were analyzed and identified as a signal modulated with GMSK (GSM). Furthermore analysis obtained the cell identifier of the site transmitting this signal.

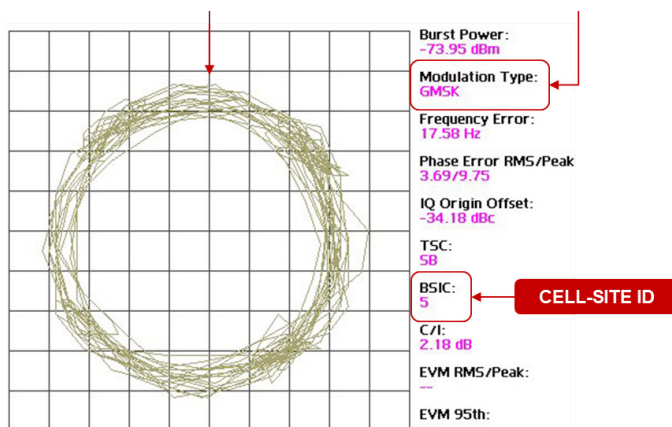


Figure 12. GSM modulation analysis

This is a common interference symptom of frequency refarming that many mobile operators are facing. Now, they can take advantage of signal analysis procedures to promptly identify and solve these interference cases.

Conclusions

Interference analysis in wireless networks is a fundamental testing procedure to monitor the spectrum’s environment—an environment heavily used by different sources and organizations. An accurate and comprehensive analysis of the spectrum should be made in order to ensure service coverage of wireless services. This analysis also identifies any interfering signals which may degrade the intended service.

Interference can be created from the transmission line of the cell site due to intermodulation of its passive elements, and it is becoming a standard maintenance practice to perform non-intrusive PIM testing due to its properties of multiband scope and prompt identification of interference without affecting service.

Interference can also be created by refarming frequencies, caused by neighbor cell sites or co-located radios transmitting different carriers on the same frequency band. The ability to effectively characterize overlapping carriers will significantly reduce network downtime and service disruption.

VIAMI Solutions RF test solutions perform all the necessary measurements that characterize the condition of radio access networks including the proper identification of impairments, transmission conformance, and modulation quality.