Application Note

Using the IFR 2975 for advanced P25 Phase II and LSM analysis

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Within the P25 standard, the modulation formats for over the air transmission of digital data have been harmonized to allow for different, but compatible modulation formats to be utilized depending on application and bandwidth requirements. This application note will deal with the utilization of CQPSK modulation used in new P25 systems that employ Linear Simulcast Modulation™ technology and in P25 Phase II systems.

Understanding P25 Modulation Formats

P25 systems utilize digital modulation techniques to transmit the digital ones and zero's across the air interface. These formats are defined in the TIA/EIA-102 standards and apply to Phase I P25 systems and Phase II systems. Each of the modulation formats accomplishes the task of transmitting digital information over the air in a bandwidth efficient manner. Two modulation formats are called out in the P25 standard, C4FM modulation in a 12.5 kHz bandwidth which is used for current P25 Phase I systems and CQPSK or Compatible Quadrature Phase-Shift Keying modulation which is intended to be utilized for Phase II P25 systems operating in a 6.25 kHz bandwidth.

Phase 1 P25 systems utilize a form of digital modulation called C4FM. C4FM is a 4-carrier modulation format where the carrier is shifted in frequency at a particular rate (time) to a particular location around a center frequency. This allows for each of the 4 "states" to represent a binary number. Each state is a "DiBit" or "Symbol" which contains two bits of information. Figure 1.0 shows how C4FM is used to impart the digital information over the air.

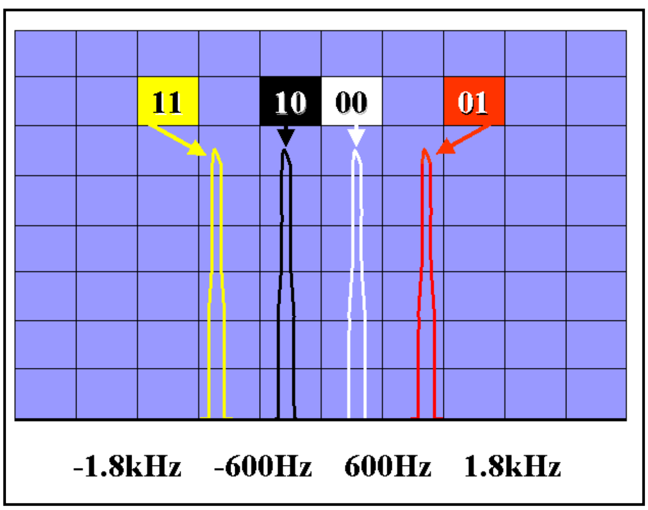

Figure 1.0 - C4FM Modulation

As you can see, each of the carriers depicts a particular symbol. This is a simplified representation of C4FM since, in reality, the carriers would not be seen as individual, stand alone carriers shifted off center from the fundamental frequency. Although each carrier has a fixed offset (-1800 Hz, -600 Hz, +600 Hz, +1800 Hz), the carrier never returns to center frequency. Each transition of the carrier is encoded to start from where it was last positioned. Figure 2.0 shows how a C4FM signal would look on a frequency plane or a vector signal analyzer like the Agilent 89440A/89431A after the decoding process.

Note: P25 Phase II Systems are in development and there are at least two different Phase II approaches that are either specified or in development. They include potentially a TDMA system that provides similar bandwidth efficiency. This application note deals with the Phase II P25 systems utilizing 6.25 kHz bandwidths and CQPSK modulation.

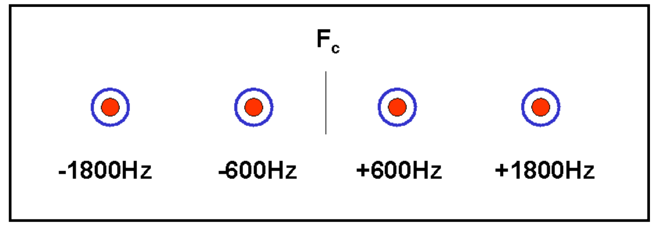

Figure 2.0 C4FM in Frequency Plane with Decision Points

As can be seen, there are 4 decision points (indicated by the red dots) that represent the frequency states of the C4FM signal at a particular time. Each are valid decision points that tell us what the value of the symbol will be (11, 10, 00 or 01). Each of the decision points has to fall within a valid range to be recognized as a symbol. If it falls outside the "window" (shown as the blue circle), it becomes an invalid symbol and the demodulator in the radio will decode it as an erroneous symbol and will therefore see a higher "BER" or Bit Error Rate.

As we begin to look at the modulation format for P25 and Linear Simulcast Modulation™, we need to understand that the CQPSK signal can more easily be depicted in an I/Q plane. I/Q stands for In-Phase and Quadrature-Phase and it is simply a plot of phase and amplitude. Every sinusoid can be expressed as the sum of a sine function (phase zero) and a cosine function (phase p/2). Taking the "sine", or In-phase component and combining it with the "phase-Quadrature" derives an I/Q plot. The "phase-Quadrature" is shifted 90 degrees. The resulting In-phase and Quadrature phase signal can be depicted in an I/Q Plot shown in figure 3.0.

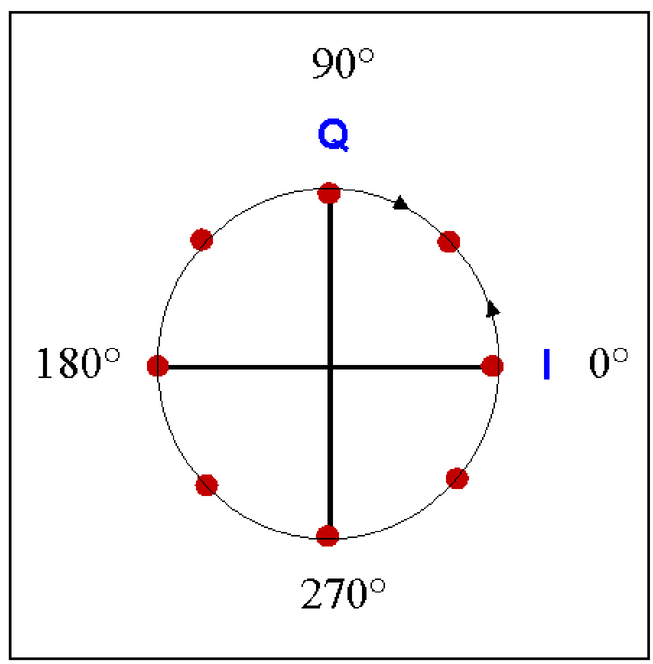

Figure 3.0 An I/Q plot showing phase and amplitude differentials.

Since C4FM is a constant amplitude modulation, the I/Q plot of the modulation looks like a circle, with the 4 decision points referenced by the amount of phase offset from zero. Figure 4.0 shows how C4FM would look on an I/Q plot.

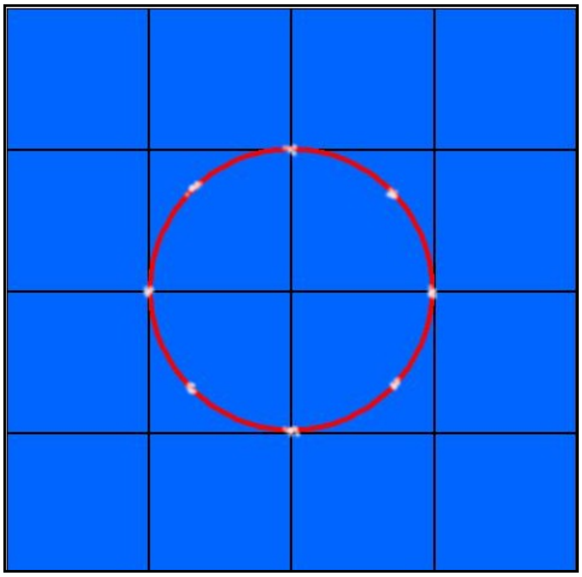

Figure 4.0 C4FM Modulation depicted in an I/Q plot.

Although we do not see an amplitude shift, we do see a phase shift which is attributed to the frequency shift of the carrier. This is the key to compatibility with CQPSK modulation in that the symbols "appear" in the same position in the I/Q plane regardless of modulation formats. (Note: The IFR 2975 does not perform C4FM plot analysis in the I/Q domain.)

Since the data rate, bandwidth and bits per symbol are identical, the main difference between the two modulations is that C4FM, using a frequency shift, provides a fixed amplitude signal. CQPSK, since it requires a phase shift to depict a symbol, imparts an amplitude component to the signal.

The modulation format for LSM is the same digital modulation as P25 Phase II, or CQPSK. Figure 5.0 shows CQPSK modulation in the I/Q plane. Here you can clearly see the amplitude component of the CQPSK modulation, and the decision points, which would be the same as C4FM.

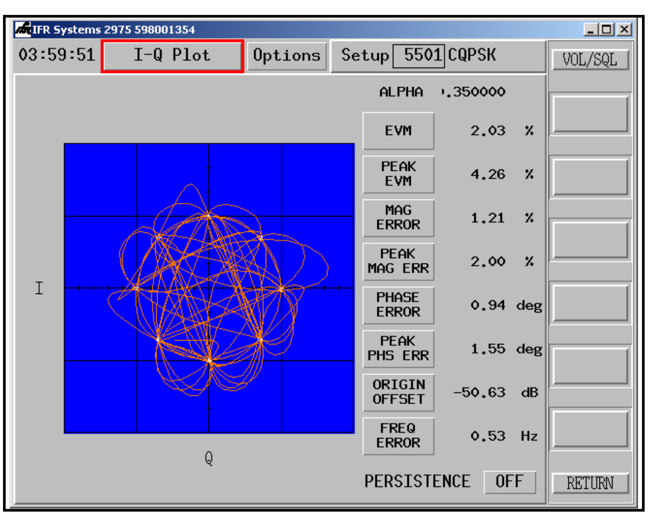

Figure 5.0 CQPSK Modulation

The primary difference between P25 Phase II and LSM is the Alpha, or shaping of the filter. Where the P25 standard calls for a more aggressive Alpha of .2 to keep within the 6.25 kHz channel, LSM uses an Alpha of .35, which provides a more gradual roll-off of the side skirts of the occupied bandwidth, and is used in a 12.5 kHz channel. Figure 6.0 shows the comparison between P25 Phase II and LSM filter shaping.

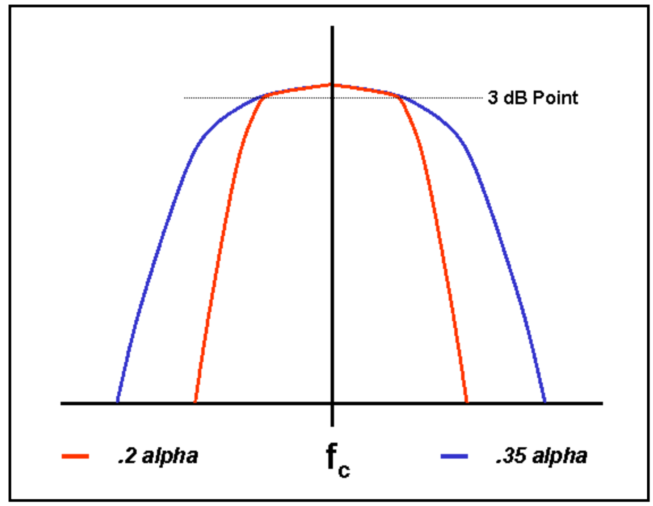

Figure 6.0 Alpha Depiction of .35 and .2

Why LSM is Utilized

Linear Simulcast Modulation™ is utilized mostly in dense metropolitan areas. The amplitude component of the PSK modulation allows for better in-building penetration of the signal. In addition, due to the use of highly linear amplifiers, the range of the signal is significantly extended, sometimes up to twice the distance.

For Control Channels, this equates to better range of the repeater station that controls mobile access to the network. For Voice Channel use, the range of the users' listening capacity is extended.

How do you Measure Frequency Error of a CQPSK Signal?

With digital modulation, seemingly easy measurements like frequency error become difficult. This is due to the fact that with the phase shifts occurring on the RF carrier, a stable frequency measurement is difficult obtain. To determine the actual frequency of the signal, a mathematical rendering of the RF signal must be calculated as a separate computation and then compared against a mathematically derived "ideal" signal. Only then can we determine accurate frequency error measurements. The 2975 with the LSM Advanced Option performs these calculations for fast and accurate frequency error measurements of the LSM CQPSK signal.

What is measured with CQPSK modulation?

In addition to frequency error, there are various parameters that we can derive from the I/Q plot of the phase-shifted symbols. The primary measurements for this digital modulation format include EVM, Phase Error and Magnitude Error. Figure 7.0 shows the various parameters.

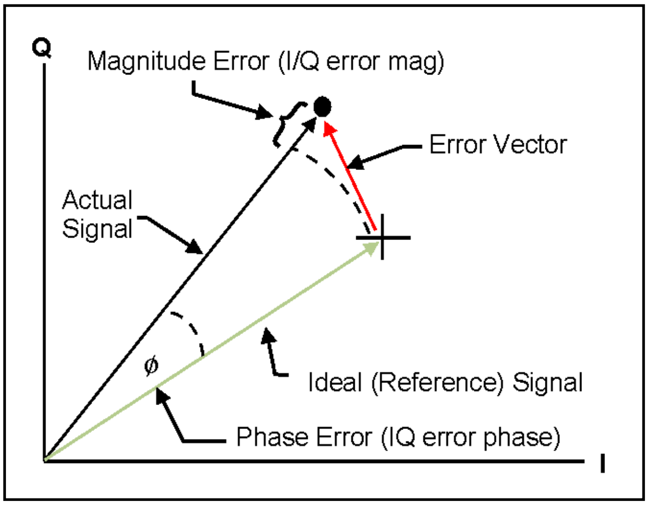

Figure 7.0 EVM, Phase Error and Magnitude Error

Understanding the impact of this is important in testing digital modulation. The ability of the modulator to produce as close as possible to an ideal waveform is critical to the receiving radio's ability to decode the digital data being sent over the air.

As you can see, we start with the ideal symbol point indicated by the (+). This is the point where the symbol "should" be. With digital modulation, these symbol points come close, but rarely land where they should. Here, the actual landing point is depicted by the black dot. The resulting error vector - the red arrow - shows how far the actual landing point is from the ideal point.

Error Vector Magnitude is the ratio of the length of the error vector over the normalized ideal or "reference" signal and is expressed as a percentage. For example, if the magnitude of the error vector is .03 compared to a normalized (to 1.0) ideal signal, the Error Vector Magnitude (EVM) would be 3%.

In addition, more information about the nature of the error is derived by looking at the magnitude error of the actual signal compared to the magnitude of the desired signal. The Magnitude Error is the excess (or shortfall) amplitude of the signal compared to what the magnitude should be. This is also called I/Q magnitude error.

Phase error is another test to verify the accuracy of the modulator. If the "symbol" is shifted in phase from the ideal signal, we have a phase (f) shift between the ideal signal and the actual signal. This is expressed as a phase error, in degrees, from the ideal signal path.

Understanding Origin Offset

Origin Offset, also known as carrier bleed-through or DC offset of the I/Q base-band, shows where the digital signal is offset at the beginning of the I/Q plot. It is defined as an imbalance in the I/Q modulator.

Using the IFR 2975 to analyze CQPSK signals

With Option 11, the 2975 is set up to generate and receive P25 Phase II and LSM signals. With Option 13, the 2975 can further analyze CQPSK signals with a high degree of accuracy. This option allows users of Linear Simulcast Modulation systems to quickly ascertain the modulation accuracy of LSM systems.

Setting Up The IFR 2975 for Analysis of CQPSK Signals

To enable CQPSK analysis on the 2975, we first need to be in either the duplex or receiver mode. Aeroflex's CQPSK analysis has two primary modes of operation: the actual constellation display of the signal received, and the corresponding analysis of the PSK parameters. To observe the constellation display from the Duplex Mode <Mode 3>, we select the "I-Q Plot" option.

(Note: Options are numbered based on how many options are activated on the unit at the time and may vary between differently configured units.)

To enable the CQPSK data tile, we select the "EVM Data" option. This option displays the actual parametric parameters of the CQPSK signal including EVM, Peak EVM, magnitude error, peak magnitude error, phase error, peak phase error, origin offset and frequency error.

See figure 8.0 on how to select the I-Q Plot and EVM Data display.

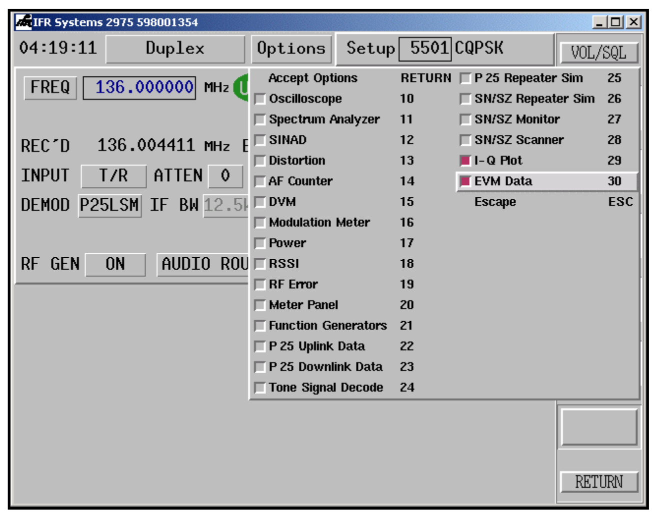

Figure 8.0   Selecting the IFR 2975's CQPSK Constellation Display

After both tiles are enabled, we can see both the constellation and the corresponding data fields for analysis of the CQPSK signal. Figure 9.0 shows how the two tiles together are displayed.

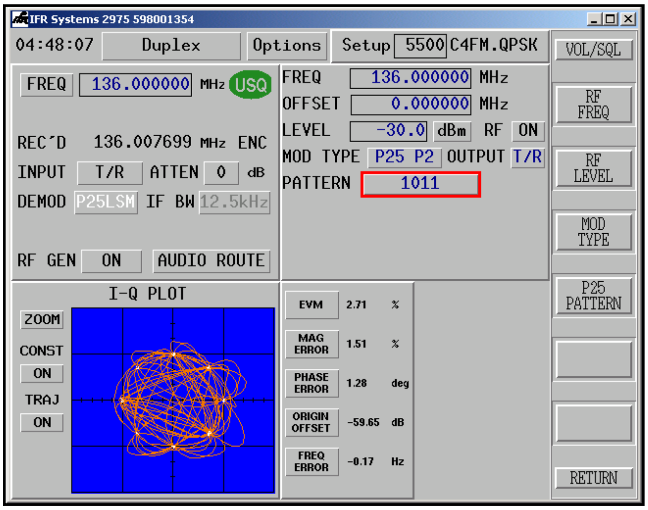

Figure 9.0 Display of both the I-Q Plot and EVM Data tiles

Once the constellation and data tiles are enabled, the user can further analyze the CQPSK signal. By turning off the Trajectory (signal path) of the constellation display, the user can clearly view how closely the actual decision points are landing compared to the ideal landing points. To turn off the trajectory, simply toggle the trajectory button. This analysis provides a very clear display of how accurately the modulator is performing.

The persistence mode of the 2975 CQPSK constellation allows for long-term analysis of how accurately the decision points are landing in the desired "zone" over a long period of time. By simply enabling the persistence mode, the 2975 shuts off the trajectory and then shows the actual symbol points as they accumulate over time. See figure 10.0 which displays how the 2975 accumulates data points.

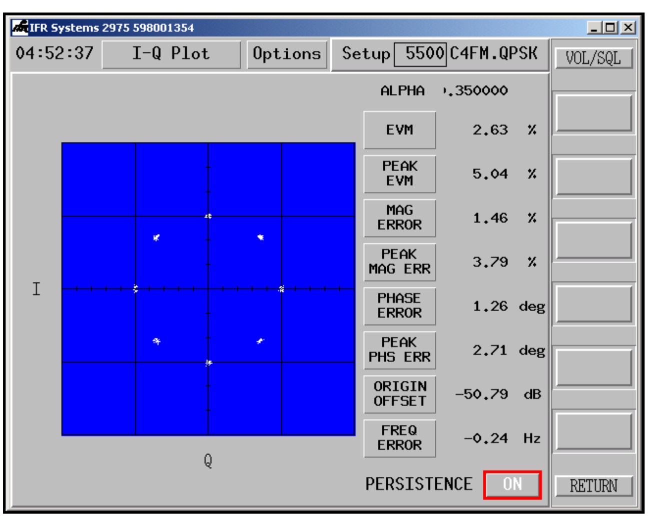

Figure 10.0 Persistence Mode enabled

To further analyze the signal received, we can turn off the constellation display. This allows the user to see the envelope of the modulation and determine problems within the modulator.

Conclusion

Using the IFR 2975 to perform analysis of the CQPSK signals used in Linear Simulcast Modulation™ systems provides a cost effective alternative to expensive stand alone spectrum analyzers or vector network analyzers for determining modulation accuracy. The accuracy of the 2975 for P25 CQPSK signals comes very close to more expensive solutions and provides the added benefit of not having to carry an additional piece of equipment.

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