VIAVI Solutions

Application Note

Understanding P25 Modulation Fidelity

The objective of this application note is to clarify how P25 C4FM modulation works, and to explain the critical components of the modulation and how the VIAVI CX300 provides the best means to accurately analyze P25 signals.

With the proliferation of the P25 standard, it is important to understand the meaning of special measurements found in P25. In the P25 standard (TIA/EIA-102) there is a measurement called modulation fidelity. Modulation fidelity is defined as; "the degree of closeness to which the modulation follows the desired ideal theoretical modulation". This is a very important measurement for P25 C4FM modulation as it is an indication of the quality of the signal being transmitted by the radio. Before we can understand the modulation fidelity measurement, we will need to look at the type of modulation that this measurement analyzes and how test equipment must be able to accurately measure this type of modulation.

Most people familiar with VIAVI Radio Test sets will assume that modulation fidelity is one measurement pertaining to the P25 C4FM modulation. In fact, the term "Modulation Fidelity" is really a combination of a number of parameters, including frequency error, symbol deviation, and RMS deviation error. VIAVI utilizes the term "Modulation Fidelity" to be consistent with TIA/EIA-102-CAAB-C, Section 3.2.16 where Table 3-18 is labeled "Modulation Fidelity" limits.

C4FM Modulation

P25 uses a type of modulation called C4FM, which is an acronym for "compatible 4 level frequency modulation". In its simplest term, it is a special type of 4FSK modulation developed for the TIA/EIA-102 standard. P25 uses this type of modulation to transmit digital information in the form of digital "1's" and "0's". 4FSK, as you might imagine, uses four different frequency “states” or “deviation points” to indicate a “symbol”. This symbol then equates to 2 bits of data as one of the four frequency shifts. The frequency shifts that correspond to each 2 bits of data are shown in Chart 1.0:

Information bits	Frequency deviation
00	+600 Hz
01	+1800 Hz
10	-600 Hz
11	-1800 Hz

Chart 1.0 – P25 C4FM Frequency Deviation States

This information is sent at the “symbol rate” which for P25 is transmitted 4800 times per second. The result is a bit rate of 9600 bits per second (4800 symbols times 2 bits per symbol).

As part of modulation fidelity, we want to measure the deviation of each of the symbols that the radio under test generates and compare them with the ideal four deviation points indicated in chart 1.0. This measurement will actually result in producing three important values that together will be indicators of the modulation fidelity of the radio under test.

Frequency Error

The first value that we can calculate from the measured deviation of each of the symbols is the frequency error. Frequency error in this measurement refers to RF carrier frequency error. To understand this, think about the relationship between the four frequency deviations used in C4FM and RF carrier frequency error. A carrier frequency error would tend to shift all four of the deviations by the same amount. A positive frequency error would move all four of the deviation points in the positive direction. Let’s use a real world scenario for our example. In Chart 2.0 below, a 100 Hz frequency error might give the following results:

Information bits	Frequency deviation
00	+716 Hz
01	+1945 Hz
10	-515 Hz
11	-1746 Hz

Chart 2.0 – Example of a Measured P25 Frequency Deviation States

It is important to realize that in an ideal world, the RF carrier error would shift every symbol by the same frequency amount, however this is a real world example and we need to consider that there are other errors that impact the measurement, such as RMS deviation error and symbol deviation that also play a part in the actual symbol deviation points. More on that later.

To find the frequency error, we find the average frequency deviation for each of the four symbols, and then calculate the average of these four deviation points. We perform this average over 144 symbols (288 bits). From the chart above the average would be: (716+1945-515-1746)/4 = 100 Hz.

It is very important to understand that you cannot measure the frequency error of a C4FM modulation signal any other way. An analog frequency error meter would count the average frequency of the signal by counting the number of cycles in a given time period. If a C4FM signal is modulated with a stream of data that includes a lot of zeros, the signal would deviate to the +600 Hz frequency deviation a disproportionate number of times, which would skew the average frequency of the carrier by a positive value.

A zero crossing frequency error meter is accurate when the data is random and the deviations are equally distributed. However, most of the time during a P25 transmission, the deviations are not equally distributed across all symbol points and using a zero crossings frequency error meter would result in an erroneous frequency error measurement.

An example of this would be the P25 standard tone test pattern (1011 Hz pattern). Measuring the frequency error of this pattern with an analog frequency error meter would result in frequency error reading of about 150 Hz, even though no frequency error is present, since the pattern includes a higher number of “00’s” and “01’s”

Deviation

The next value calculated from the measured deviation of each of the symbols is called deviation, and we use the four average values calculated for each symbol that were also used to find frequency error. Before starting this calculation we need to subtract the frequency error from each of the measured deviation values. Next, we find the deviation ratio by dividing them by the expected deviation for that symbol. This translation is illustrated very simply in Chart 3.0.

Information bits	Frequency deviation	Average deviation after subtracting out the frequency error	Deviation ratio
00	+600 Hz	+616 Hz	616/600 = 1.0267
01	+1800 Hz	+1845 Hz	1845/1800 = 1.0250
10	-600 Hz	-615 Hz	-615/-600 = 1.0250
11	-1800 Hz	-1846 Hz	-1846/-1800 = 1.0256

Chart 3.0 – P25 C4FM Frequency Deviation Ratio

We next find the average of the deviation ratio values, which gives us the average symbol deviation ratio for all of the symbols.
Average deviation ratio =
(1.0267+1.0250+1.0250+1.0256)/4 = 1.0256

Before displaying this value, we multiply the ratio by 1800, so the result displayed for Symbol Deviation would be 1846. As you can see from this calculation, the final value is not just an indication of the 1800 Hz deviation symbol, but an aggregate of all the symbols.

RMS Deviation Error

The last value calculated from the measured deviation of each of the symbols is called RMS deviation error. Again, the first step of this calculation is to subtract out the frequency error from each of the measured deviations. Next, divide each one of these modified deviations by the deviation ratio. The deviation error is the difference between these modified deviations and the expected deviation for that symbol. The formula for this calculation is as follows:

$$\text{Deviation Error} = \left\{ \frac{\text{Measured Deviation-FreqErr}}{\text{Deviation Ration}} \right\} - \text{Expected Deviation}$$

The RMS value of the deviation error is calculated next, by squaring each of the deviation error values, averaging them, and then finding the square root. This calculation is performed over 144 symbols. The final result is shown as a percentage of 1800 Hz.

Different instruments label this result differently. For the VIAVI CX300, this is labeled as modulation fidelity, in accordance to TIA/EIA-CAAB-C, Section 3.2.16 where Table 3-18 is labeled modulation fidelity limits.

Although this is the value which is displayed as modulation fidelity, it can be seen from this application note that modulation fidelity is really a combination of frequency error, symbol deviation, and RMS deviation error.

CX300 Graphical Displays

The VIAVI CX300 has several different methods of displaying the modulation fidelity results. The first one is in the UUT (Unit Under Test) measurements tile in the P25 test engine. This tile is used to display the actual results for modulation fidelity including RMS deviation error (displayed as Mod Fidelity), symbol deviation, and frequency error, as shown in Figure 1.0.

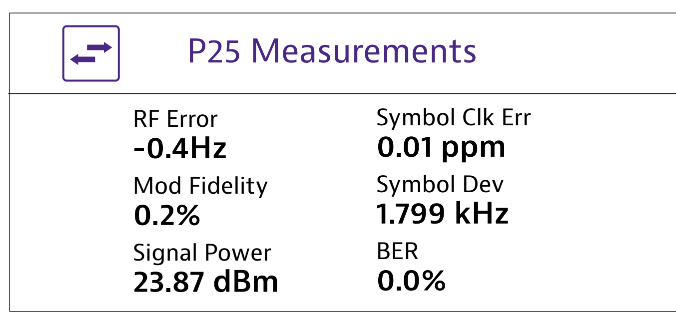

Figure 1.0 - Modulation Fidelity Measurements

In addition to displaying the numerical results, the CX300 offers three graphical displays that provide a visual dimension to these measurements. Figure 2.0 shows the constellation display.

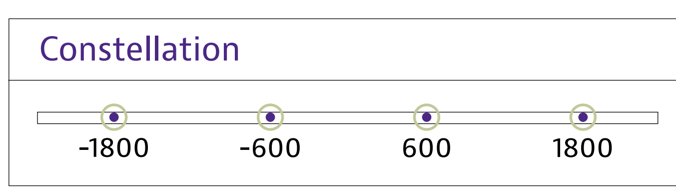

Figure 2.0 – The P25 Constellation Display

The constellation display shows a graph of the measured deviation for each of the symbols. This display provides four circular areas identifying the ideal location for each of the measured deviations. From left to right, these four circles identify the location for -1800 Hz, -600 Hz, +600 Hz and +1800 Hz deviation. A perfect signal would show a single dot in the center of each of the circles. In reality, there is usually a line in each of the circles that shows the spread of deviation for each symbol. A wider line will translate into a larger mod fidelity reading. The line may even extend outside of the circle if the mod fidelity is bad, or if the symbol deviation is too large or too small. The circle should be interpreted as the "bull's eye" though, and not a pass fail indication of the mod fidelity.

Another display that the CX300 provides for illustrating the C4FM modulation fidelity is the distribution plot. Shown in Figure 3.0, this type of graph shows not only the deviation of each of the symbols, but also the relative number of occurrences of each of the deviations.

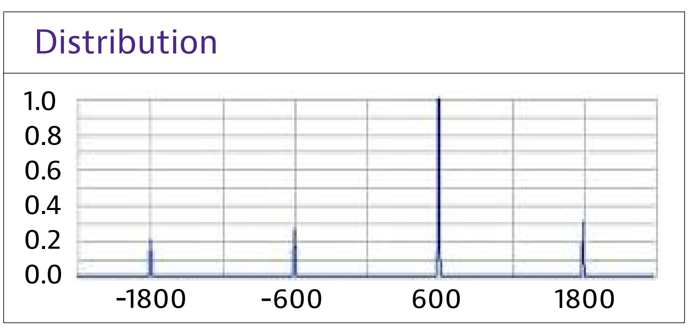

Figure 3.0 – The P25 Distribution Plot

An extremely valuable display, this graph shows a wide range of parameters associated with modulation fidelity. In this graph, the horizontal axis is the frequency deviation of the signal at symbol time and the vertical axis shows the number of times the deviation occurred. From left to right the vertical dotted lines indicate the ideal deviation points of -1800, -600, +600 and +1800. In this particular graph, the signal deviates to +600 more often than the other three deviations. This is due to a larger number of "00" symbols associated with the +600 Hz deviation.

Notice that the shape of the distribution plot forms an upside down V shape at the four deviations. A perfect signal would have a single line superimposed on top of each of the dashed lines. If the distribution plot is shifted wider than the location of the dashed lines, then that indicates a symbol deviation greater than 1800 Hz. Conversely, a plot that is narrower than the dashed lines would indicate a symbol deviation less than 1800 Hz.

The final display of the P25 modulation is the Eye Diagram (shown in Figure 4.0). While the constellation and distribution displays show the demodulated signal at the symbol point, this diagram shows a graph of the demodulated signal at all points. This is a graph of the symbol deviation versus time. To understand this graph you need to know that the horizontal scale is time and the vertical scale is the deviation. The four horizontal dashed lines represent the deviations at the symbol points and are deviations of (from bottom to top) -1800 Hz, -600 Hz, +600 Hz and +1800 Hz.

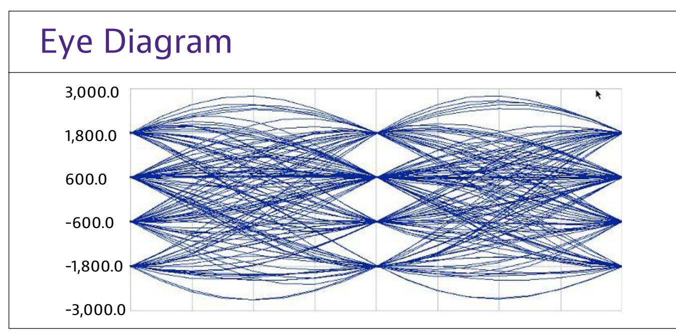

Figure 4.0 – The P25 Eye Diagram

The vertical dashed line and the start and stop of the graph are the locations at which the graph goes through a symbol point. With a good P25 signal the lines should cross precisely through the point at which the vertical and horizontal dashed lines meet. As the modulation fidelity becomes larger or symbol deviation becomes wider or narrower, the graph will show this with the plot of the symbol deviation passing below and/or above the dashed lines.

Conclusion

This measurement, along with the symbol clock error measurement and power, give a complete picture of the P25 C4FM Modulation accuracy. You can be confident in the fidelity of the transmitter, if it passes these tests. The TIA-102.CAAB standard specifies that the RMS deviation error should be less than 5% for class A mobiles, portables and base stations and less than 10% for class B. The deviation should be between 1620 Hz and 1980 Hz. The frequency error accuracy depends on the frequency band of the radio and is shown in Table 1.

Frequency Departure (PPM)		
Assigned Frequency (MHz)	**Mobile & Portable**	**Base Station**
Below 100	5.0	2.5
From 138 to 174	2.5	1.5
From 406 to 512	2.0	0.5
From 764 to 806	1.5	0.1
From 806 to 869	1.5	0.15
From 896 to 941	1.5	0.1

Table 1.0 - Operating Frequency Accuracy Limits

VIAVI Solutions

Contact Us **+1 844 GO VIAVI**
(+1 844 468 4284)

To reach the VIAVI office nearest you,
visit viavisolutions.com/contact

P25modulation-an-rts-nse-ae
30193754 900 0823