WHITE PAPER

TETRA C/I Measurement with MAC Ltd's CatchAll™ Receiver

Introduction

The CatchAll and CatchAll-SE radio frequency (RF) measurement receivers not only accurately measure the RF signal strength of TETRA carriers, measuring the whole 5 MHz frequency band 125 times per second, but they also ascertain the downlink quality of service (QoS).

The GIS-based application that provides the platform for detailed examination of this QoS information is TRAMPS™ which can be used with the output files from both CatchAll receiver products. Whereas QoS data captured with the CatchAll receiver can be examined only after the drive test has been completed, the CatchAll-SE receiver provides a subset of the QoS data in real time as the walk-test or drive-test progresses. This subset includes the channel number, signal strength, location area code (LAC) and an estimate of the carrier-to-interference ratio (C/I).

This white paper explains the CatchAll receiver C/I estimation methodology so that users can derive the maximum benefit from the CatchAll receiver C/I estimation.

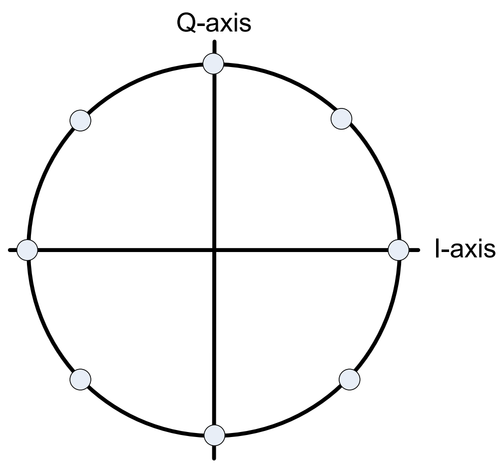
In order to obtain C/I estimates from the CatchAll receiver the sub-channel capture feature needs to be enabled during the drive-test or walk-test. When the 'Enable sub-channel capture' check box on the CatchAll settings tab is checked the receiver decodes information on the main control channel (MCCH) and the slow associated control channel (SACCH)†

The Perfect Digital Signal

In order to understand the CatchAll receiver C/I measurement it is probably best to begin with the diagrammatic representation that is normally used to illustrate the properties of the modulation system in signal space.

Such a signal in its simplest form is represented by the two dimensional constellation diagram shown in Figure 1, where the x-axis represents the component of amplitude that is in phase with the unmodulated carrier and is therefore referred to in the constellation diagram as the I-axis. The y-axis shows the component of amplitude that is 90° out of phase with the unmodulated carrier and is referred to in the constellation diagram as the Q-axis. The radius of the circle is the amplitude of the received signal. In the perfect system illustrated in Figure 1 each received symbol lies exactly on the circle representing the signal amplitude.

Figure 1 Constellation diagram showing the amplitude and phase of the received symbols



The constellation diagram is usually used to describe linear modulation schemes; there are other, nonlinear schemes, such as Gaussian Minimum Shift Keying (GMSK) as used by the Global System for Mobile (GSM) that are best represented in other ways, but such schemes are not addressed in this white paper.

The constellation diagram for a specific modulation scheme is an ideal representation of the modulation scheme symbols and shows their relationship in signal space to each other. The section "TETRA Modulation Scheme" below gives more detailed information regarding the modulation scheme used

† Decoding the SACCH in addition to the MCCH ensures that control information continues to be decoded even though each of the time-slots available within the TETRA TDMA frame may be occupied by traffic.

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by the TETRA system.

The constellation points of a signal sent by a perfect transmitter across a perfect transmission path and received by a perfect receiver would be located precisely at the theoretic allocations for that specific modulation scheme, as shown in Figure 1.

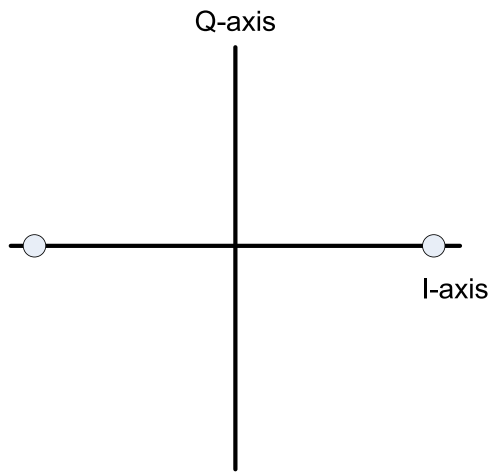
However, in real transmission systems, all of the principal components, power amplifiers, the transmission path and the receiver decoders distort the signal and add phase noise. Co-channel and adjacent channel interference also significantly affect the received signal. The effect of all of these distortions is to introduce errors and to change the relationship between points on the constellation from the ideal positions.

TETRA Modulation Scheme

Any digital modulation scheme uses a number of distinct signals to represent digital data. An early form of such modulation was phase shift keying (PSK), where the phase of the received signal is compared with a reference to recover the original. TETRA uses a form of differential phase-shift keying (DPSK) referred to as π/4 differential quadrature phase shift keying (π/4-DQPSK) which does not require the transmission of the reference signal because the information is encoded in the difference between the phases of successive symbols.

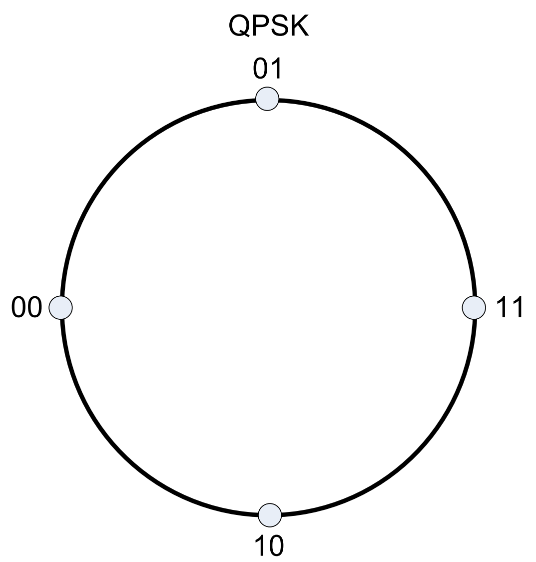
To gain an understanding of characteristics of π/4-DQPSK modulation it is best to first briefly review the simplest implementation of PSK, binary phase shift keying (BPSK), which transmits a phase reversal of 180° for each point on the constellation diagram. This modulation scheme is shown in Figure 2 as the two points that can be used to represent one bit of data per symbol. BPSK is therefore limited in the quantity of data that it can convey.

Figure 2 Constellation diagram for a BPSK signal



Quadrature phase shift keying (QPSK) provides a higher data throughput of two bits per symbol by using four points on the constellation diagram spaced equally around a circle at 90° from each other as shown in Figure 3 below.

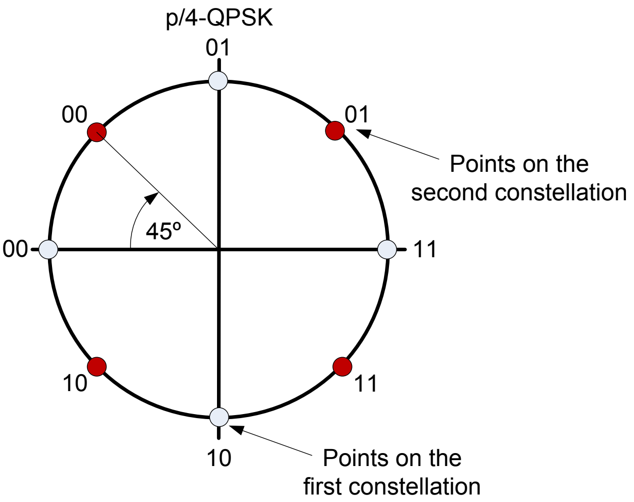
Figure 3 Constellation diagram for a QPSK signal showing each point rotated by 90° (Gray code values shown)



A further improvement on QPSK referred to as π/4–QPSK uses two identical but separate QPSK constellations, with each constellation point 45° (π/4 radians) from its neighbour. This constellation is illustrated in Figure 4. A key feature of this waveform is that no transition from one constellation point to another passes through the origin of the constellation diagram, which reduces the amplitude variations of the signal and simplifies the design of the power amplifier in the transmitter. However, any one transmitted symbol can still be only one of four constellation points, and therefore like QPSK, π/4–QPSK conveys two bits per transmitted symbol.

TETRA employs differential phase shift keying, which conveys data by purposefully changing the phase of the carrier wave, with the specific phase change being dictated by the actual data being transmitted. When demodulating the π/4–DQPSK signal, instead of ignoring any phase change ambiguity between one point on the constellation and the next, the phase between two successive received symbols is compared and used to determine what the data must have been. The subtle difference here is that the received symbols are not decoded one-by-one to identify the individual constellation points but are instead compared directly to one another, thereby eliminating the need for a phase reference at the receiver and increasing tolerance to frequency error.

Figure 4 Points on two separate constellations each rotated by 45° (Gray code values shown)



The actual phase difference caused by the data can be only one of four values, namely –135°, –45°, +45° and +135°. Interference, distortion and noise will cause these phase differences to change at the receiver, but provided that the distortion and noise are small then measuring these changes will enable the interference to be measured. But how is this done?

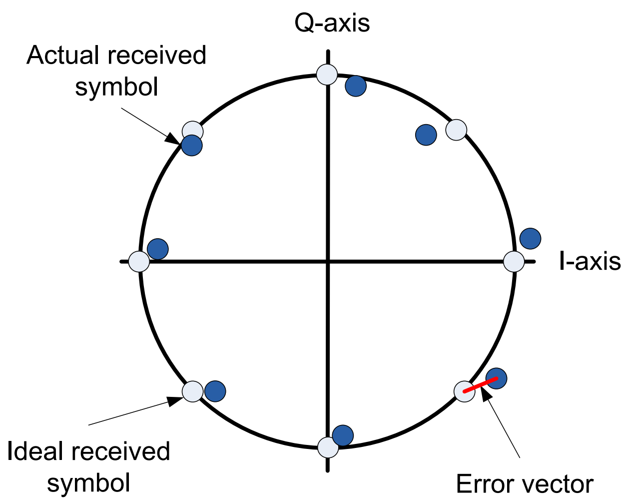
Determining the Impact of Interference

In this section we introduce the concept of error vector magnitude (EVM). EVM is a used as a measure of the error described in the previous section and can therefore be used to quantify the performance of a digital radio transmission path.

We have already seen that the constellation points of a signal sent in a perfect end-to-end transmission system would all be located precisely at the ideal locations shown in Figure 1.

In real transmission systems that ideal positioning is unfortunately not realised and the exact location of each point in the constellation may vary in phase and amplitude. These variations can be introduced by phase noise in the various components of the system and by design compromises such as image rejection, but with careful design such variations can be minimised. External influences such as co-channel and adjacent channel interference are not within the control of the equipment designer and the errors such interference introduces can be much larger than those inherent in the equipment design. The effect of these signal distortions is illustrated diagrammatically in Figure 5. The perfect QPSK constellation that we saw earlier is shown together with the actual constellation produced at the receiver, which is displaced from the perfect signal constellation giving rise to the error vector shown.

Figure 5 Showing a reconstructed perfect constellation and the actual received constellation



EVM provides a measurement of the magnitude of these errors, but does not attribute any proportion of the error to any specific cause. To obtain the magnitude of the error, the error vector is generated in the I-Q plane as shown in Figure 5. This measures how far the actual received points are from the ideal locations.

EVM is commonly expressed in two ways. First, the EVM may be expressed as a percentage, in this case, the EVM is the ratio of the root mean square of the error vector amplitude to the magnitude of the highest energy constellation point. Second, the EVM may be expressed in decibels, in which case it is the ratio of the average power of this error vector to the highest power constellation point. Using the second form the expression is

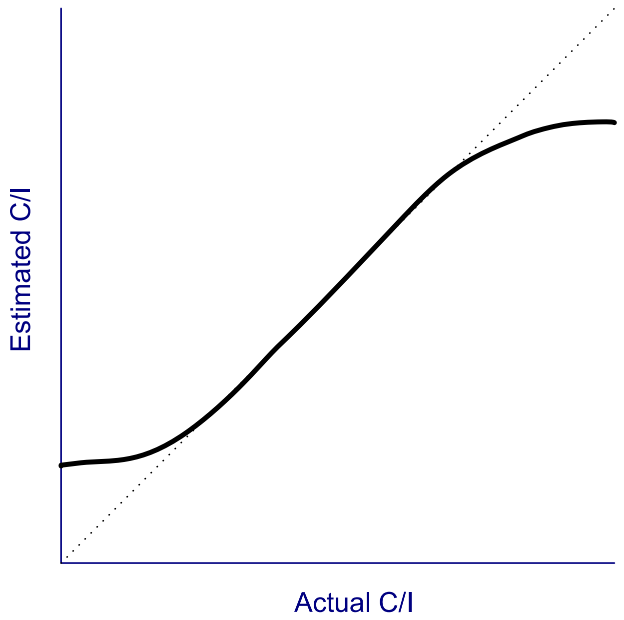
$$EVM\,(\text{dB}) = 10\log_{10}(\overline{P_{error}} / P_{ref})$$

where P_{error} is the power of the error vector and P_{ref} is the power of the highest power point in the reference signal constellation.

EVM is therefore a ratio of a mean error power to a peak signal power. However, the relationship between the peak and mean signal power is dependent upon the constellation geometry and consequently the modulation type. Different transmission systems may report different EVM values for the same mean level of interference, although in the case of QPSK and in particular, the $\pi/4$–DQPSK scheme used for TETRA, the peak constellation power and the mean power are the same.

Using EVM to estimate the level of interference is not perfect. Distortions in the transmitter and receiver, and errors in receiver frequency, timing, and channel estimation contribute to the EVM, and limit the maximum C/I that may be estimated. Similarly, severe interference causes bit errors and limits the minimum C/I that may be estimated. These effects are shown in Figure 6. Furthermore, the mechanism does not allow co-channel, adjacent channel or noise to be distinguished, and the reported measurements of C/I need to be interpreted carefully.

Figure 6 Relationship between estimated and actual C/I, where the dotted line represents the ideal one-to-one relationship



Conclusions

The EVM calculated for the received signal gives a measure of the performance of the TETRA transmission system.

Taking the inverse of the EVM by using the perfect constellation as the ideally received signal and referring the error power to this produces a consistent and repeatable estimate of the carrier-to-interference ratio, the C/I.

Where all carriers from the same base station are subjected to identical levels of phase noise, image rejection and system-derived phase changes, any significant difference in the C/I of one of those carriers is most likely to be due to interference affecting that channel only. When all adjacent channel interferers are eliminated then the predominant cause will be co-channel interference, provided the signal is well above the noise floor.

The CatchAll receiver products calculate the EVM value for received carriers continuously and display the C/I value through the use of TRAMPS or in the case of the CatchAll-SE receiver (part of the CRIBS™ package) this display is provided in real time.

Familiarity with the values obtained from the CatchAll receivers for C/I of a particular TETRA system will allow the user to quickly identify the severity of specific channel interference. A process of elimination of some of the probable causes can then be used to confirm the existence and severity of co-channel interference.

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