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Edition 1.0 2013-01

TECHNICAL REPORT

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inside

Fibre optic communication system design guides – Part 10: Characterization of the quality of optical vector-modulated signals with the error vector magnitude

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Fibre optic communication system design guides – Part 10: Characterization of the quality of optical vector-modulated signals with the error vector magnitude

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ELECTROTECHNICAL
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Part 10: Characterization of the quality of optical vector-modulated signals with the error vector magnitude

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IEC 61282-10, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/1071/DTR	86C/1087/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61282 series, published under the general title *Fibre optic system communication system design guides*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

The contents of the corrigendum of April 2013 have been included in this copy.

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0 Introduction

0.1 Introduction to vector modulated signals

Vector or complex modulation is well known since the 1980s in mobile communication and in CATV transmission. In fibre optic telecommunication, coherent transmission was considered during the late 1980s to improve sensitivity and therefore the reach of an optic transmission line. With the introduction of EDFA optical amplification, the need for coherent transmission was then considered less urgent. Recently the foreseeable shortage of transmission capacity and the economic need to optimize transmission capacity without deploying new fibres lead back to the same approach taken for wireless communication in the early 1990s, expanding transmission capacity over a limited number of channels by working with digital complex modulation or vector modulation [1 – 3][1].

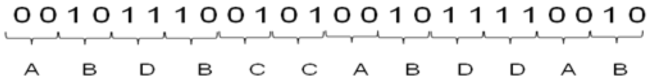
The main difference to on-off keying is that vector modulation, as indicated by the name, is characterized by an additional dimension in modulation space:

Modulation:	**on-off**	**vector**
Amplitude	**X**	**X**
Phase	**-**	**X**

0.2 Digital coding with vector modulation

0.2.1 General

The additional phase dimension offers new possibilities for coding a binary signal and in particular for coding more than 1 bit to each digital symbol. That is, a symbol can be assigned to more than the two states 0 and 1. Consider the following bit stream



This can, for example, be coded to a symbol alphabet consisting of four elements {A,B,C,D}, as shown. As two bits are combined to a new symbol, only half as many symbols need to be transmitted, reducing the transmission clock by a factor of two. This new reduced clock rate is called symbol rate. Consequently, the symbol rate is half the transmission rate for this case.

In practice, of course, it is not possible to transmit letters, but instead a coding scheme onto the transmitted electromagnetic wave can be selected, such as this:

$$\begin{aligned} 00 &\rightarrow a \times \sin(\omega \times t + 45°) \\ 10 &\rightarrow a \times \sin(\omega \times t + 135°) \\ 11 &\rightarrow a \times \sin(\omega \times t + 225°) \\ 01 &\rightarrow a \times \sin(\omega \times t + 315°) \end{aligned} \tag{1}$$

This example uses a pure phase modulation called quadrature phase-shift keying, QPSK, using four vectors defined by the amplitude of the signal and the four relative phases. If in addition the amplitude is also modulated, it is possible to code more bits to one alphabet of vectors. This is especially the case for higher level QAM signals.

---

[1] Numbers in square brackets refer to the bibliography.

To create these kinds of modulation formats, typically two modulators are needed. These two modulators typically operate respectively in-phase and quadrature, denoted I and Q. This is why this kind of modulator is described as an IQ modulator. The vector signal is described by the two parameters:

$$\begin{aligned} I &= a \times \cos(\phi) \\ Q &= a \times \sin(\phi) \end{aligned} \qquad (2)$$

where for the example of QPSK, a signal corresponds to $\varnothing$ values of 45°, 135°, 225° or 315° and the amplitude a is constant.

A common way to display this kind of signal uses IQ or constellation diagrams. In Figure 1, the constellation diagram is shown for the above-described coding scheme.

0.2.2 Constellation diagram

The constellation diagram indicates the amplitude and phase of the signal at the decision point. This is the point in time when the signal must have the correct phase and amplitude value for error-free transmission. This corresponds to the point in on-off modulation where the receiver decides whether the signal is 1 or 0. At each coding location, a cluster of points is displayed, corresponding to a point for each detected symbol in a data pattern.

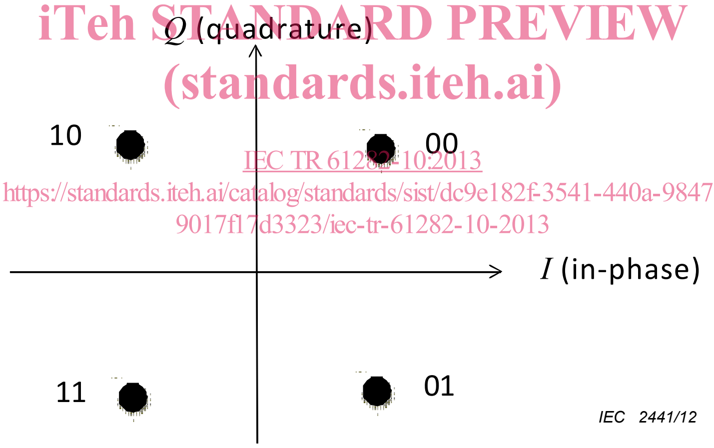
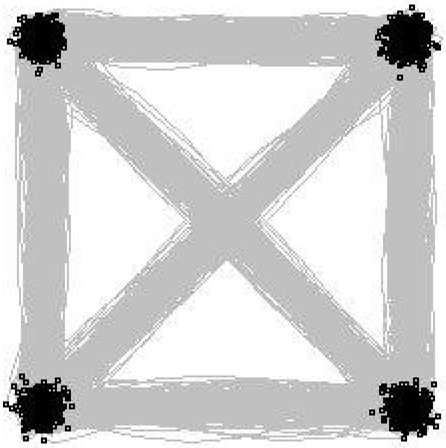


Figure 1 – Constellation diagram for QPSK coding

0.2.3 *IQ* diagram

The *IQ* diagram displays the complete phase and amplitude transitions between transmitted vectors as the signal is sampled. It reflects directly the combined I and Q components of the signal at any sample time of the data acquisition. The traces on the diagram show the path of the signal vector over the data pattern.



IEC 2442/12

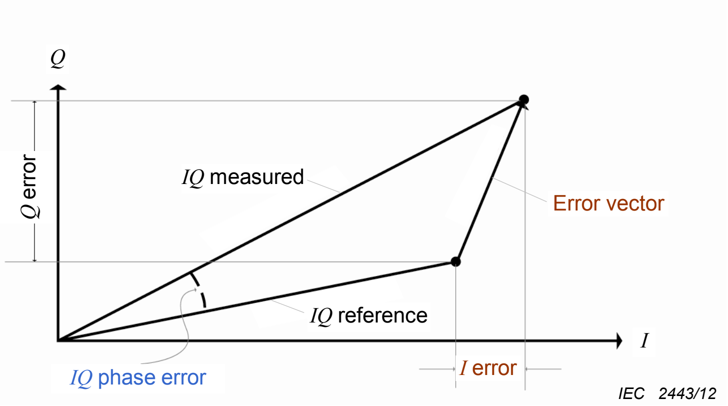
Figure 2 – IQ diagram for the same QPSK coding

0.3 Polarization multiplexing

The phase modulation of a signal is demodulated by optical mixing, as described below. The mixing depends on the relative polarization of the two optical carriers. Since the incoming signal generally has an unknown and nonconstant polarization, demodulation then needs to produce demodulated signals for two orthogonal polarization axes. With this doubling of the demodulation information, it is then also possible to detect signals based on two carriers with orthogonal polarization, each carrying independent bit streams, to double the transmission rate for a given wavelength channel. For such polarization multiplexed signals, two independent pairs of I and Q traces exist and two separate constellation or IQ diagrams are used.

0.4 Error vector

Each transmitted symbol is described by a vector with amplitude and phase, which codes a number of bits. Deviations from ideal modulation and impairments during transmission impact the received vector with noise and distortions resulting in a different vector location in the IQ diagram, compared to the reference vector for that symbol, as illustrated in Figure 3.



IEC 2443/12

Figure 3 – Relationship of error vector to reference vector and measured signal vector in the constellation diagram

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 10: Characterization of the quality of optical vector-modulated signals with the error vector magnitude

1 Scope

The purpose of this part of IEC 61282 is to define the error vector magnitude (EVM) as a metric for quantifying the quality of an optical vector-modulated (modulation of phase and possibly magnitude) signal from a transmitter or optical transmission link. The considerations required for reproducible measurement results are detailed. The relationships with other related parameters from constellation diagram analysis like error vector, phase error, magnitude error, I-Q offset and time-resolved EVM are described, as well as the relationship between EVM and Q-factor.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61280-2-8, *Fibre optic communication subsystem test procedures – Digital systems – Part 2-8: Determination of low BER using Q-factor measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
error vector
difference between a measured IQ vector and the reference vector for the closest symbol D or alternatively for the correct symbol when a known symbol sequence is measured

Note 1 to entry: If the closest symbol and correct symbol differ at the decision point, then the signal is impaired sufficiently to produce a bit error.

3.2
error vector magnitude
EVM
length of a given error vector

Note 1 to entry: For a vector modulated signal that has been measured to give the time-dependent I and Q traces with sampling interval, T_s, as outlined in Clause 5, the EVM of a particular measurement sample with index k is given by

$$\mathrm{EVM}(kT_s) = \sqrt{I_{\mathrm{err}}(kT_s)^2 + Q_{\mathrm{err}}(kT_s)^2} \tag{3}$$

where

$$I_{\mathrm{err}}(kT_s) = \alpha I_{\mathrm{meas}}(kT_s) - I_{\mathrm{ref}}^{\mathrm{r(k)}}$$
$$Q_{\mathrm{err}}(kT_s) = \alpha Q_{\mathrm{meas}}(kT_s) - Q_{\mathrm{ref}}^{\mathrm{r(k)}}$$

and I_{ref} and Q_{ref} correspond to the reference symbol $r(k)$ for the sample k, that is $r(k)$ is an index pointing to the symbol with the reference vector for sample k.

In practical measurements the measured vector has arbitrary magnitude scaling within the receiver sensitivity, so normalization with a factor α of the measured vectors is required to make the error vector independent of the scaling, as described in 4.2.

3.3
RMS error vector magnitude
EVM$_{\text{rms}}$

root-mean-square of the error vector magnitudes for the N symbol decision times of a burst of N symbols, either determined from directly measured samples or interpolated from the neighbouring samples

$$\text{EVM}_{\text{rms}} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\text{EVM}(n)^2} \tag{4}$$

Note 1 to entry: The r.m.s. EVM is usually expressed in per cent of the magnitude of the longest reference vector. In Equation (4), it is assumed that the reference vector and the measured vector are equally scaled with the factor α, as detailed below.

Note 2 to entry: The r.m.s. error vector magnitude of a burst of N measured symbols can be used as a figure of merit for complex signals, specifying the quality of the signal in one number [4].

4 Error vector magnitude calculations and conditions

4.1 Reference vector assignment

The reference vectors are defined as a normalized set of vectors representing the ideal constellation points. Assigning the reference vector for a sample corresponds to determining $r(k)$ in Equation (3). The reference vectors are scaled so that the longest vector has a magnitude of 1. For QPSK or DQPSK the reference vectors are defined as follows:

$$\mathbf{S}_{\text{ref}}^{r} = \begin{pmatrix} I_{\text{ref}}^{r} \\ Q_{\text{ref}}^{r} \end{pmatrix} = \begin{pmatrix} \pm 1/\sqrt{2} \\ \pm 1/\sqrt{2} \end{pmatrix}, \qquad r = 1 \ldots 4 \tag{5}$$

In this case, the magnitude of all four symbols is 1. For higher level QAM signals, the values need to be calculated accordingly, such that the outermost symbol has a magnitude of 1.

4.2 Normalization of the measured data

Typically, the measured data have arbitrary scaling; depending on signal strength, link attenuation and receiver responsivity, so it is necessary to normalize the measured data to the reference vectors.

The normalization factor α is chosen to match the measured vectors to the reference by first finding the value of a scaling factor β for the reference vectors that minimizes the corresponding unnormalized EVM$_{\text{rms}}$ without changing the distribution of the measured vectors. Then the inverse of β is used as α to scale the measured vectors to the normalized reference. For this purpose, the unnormalized EVM$_{\text{rms}}$ is expressed as

$$U = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left|\beta \times \mathbf{S}_{\text{ref}}^{r(n)} - \mathbf{S}_{\text{meas}}(n)\right|^2}$$
$$\text{where} \quad \mathbf{S}_{\text{meas}}(n) = \begin{pmatrix} I_{\text{meas}}(n) \\ Q_{\text{meas}}(n) \end{pmatrix} \tag{6}$$

The value of β that gives minimum U is determined by solving

$$\frac{\partial U}{\partial \beta} = 0 \tag{7}$$