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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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National foreword

This Published Document is the UK implementation of IEC/TR 61282-10:2013, incorporating corrigendum April 2013.

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TECHNICAL REPORT



**Fibre optic communication system design guide –
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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CONTENTS

FOREWORD.....	4
0 Introduction	6
0.1 Introduction to vector modulated signals.....	6
0.2 Digital coding with vector modulation.....	6
0.2.1 General	6
0.2.2 Constellation diagram	7
0.2.3 <i>IQ</i> diagram	7
0.3 Polarization multiplexing.....	8
0.4 Error vector	8
1 Scope.....	9
2 Normative references	9
3 Terms and definitions	9
4 Error vector magnitude calculations and conditions	10
4.1 Reference vector assignment	10
4.2 Normalization of the measured data	10
4.3 Conditions to be specified with EVM_{rms}	11
5 Apparatus for measuring vector modulated signals.....	11
5.1 Coherent detector.....	11
5.2 Local oscillator	12
5.2.1 Detection based on electrical real-time sampling	12
5.2.2 Detection based on optical equivalent-time sampling	13
5.2.3 One-symbol delayed interferometer	16
5.2.4 Constellations of non-differential and differential phase modulation formats	17
5.3 Digital postprocessing	18
5.3.1 Impairment compensation.....	18
5.3.2 Relative timing skew.....	19
5.3.3 <i>IQ</i> phase angle distortion.....	19
5.3.4 Offset and relative gain distortion	20
5.3.5 Polarization alignment	21
5.3.6 Corrected results	21
5.3.7 Phase tracking (intradyne detection).....	21
5.3.8 Demodulation (optional).....	22
6 Additional measurement parameters to characterize special details of the signal.....	23
6.1 Time-resolved EVM	23
6.2 EVM with reference filter	25
6.3 Magnitude error	26
6.4 Phase error	26
6.5 <i>I-Q</i> gain imbalance	27
6.6 <i>I-Q</i> offset	27
6.7 Quadrature error	27
Annex A (informative) Relationship between EVM and <i>Q</i> factor	29
Annex B (informative) Details and implementations of vector signal measurement.....	30
Bibliography.....	31

Figure 1 – Constellation diagram for QPSK coding.....	7
Figure 2 – IQ diagram for the same QPSK coding.....	8
Figure 3 – Relationship of error vector to reference vector and measured signal vector in the constellation diagram	8
Figure 4 – Block diagram of the main functions for vector signal measurement	11
Figure 5 – Configuration based on coherent detection with a local oscillator	12
Figure 6 – Configuration for linear optical sampling.....	14
Figure 7 – Schematic comparison of real-time sampling and equivalent-time sampling to observe a repetitive signal pattern	16
Figure 8 – One-symbol delayed interferometer for detecting differential phase modulation.....	17
Figure 9 – Simulation of an ideal (D)QPSK signal, represented as a constellation diagram displaying the absolute phase and amplitude of the optical field (left).....	18
Figure 10 – Simulation of a (D)QPSK signal distorted with 10° IQ -quadrature error.....	18
Figure 11 – Calculated influence of impairment.....	19
Figure 12 – Error in I and Q determination from phase angle deviation	19
Figure 13 – Calculated influence of impairment.....	20
Figure 14 – Calculated influence of impairment.....	21
Figure 15 – IQ -diagram with indicated reference constellation and exemplary error vectors (left) and time domain plot of the EVM values for each measured sample (right).....	23
Figure 16 – Measured time-resolved EVM plots of a 28 GBd QPSK signal affected by 8 ps skew	24
Figure 17 – Noise-averaged IQ -diagrams and time resolved EVM plots of a 28 GBd QPSK signal with 0 ps skew (top) and 8 ps skew (bottom).....	25
Figure 18 – Eye-diagram of reference with steep transitions; measured signal $I-Q$ diagram with symbols at decision time; EVM at symbol decision time (red) and EVM for all sample points (blue).....	26
Figure 19 – Eye-diagram of reference with raised-cosine filtering; measured signal $I-Q$ diagram with symbols at decision time, EVM at symbol decision time (red) and EVM for all sample points (blue).....	26
Table B.1 – Methods for measuring vector modulated optical signals.....	30

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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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.

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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:

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

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:

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

where for the example of QPSK, a signal corresponds to ϕ 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.

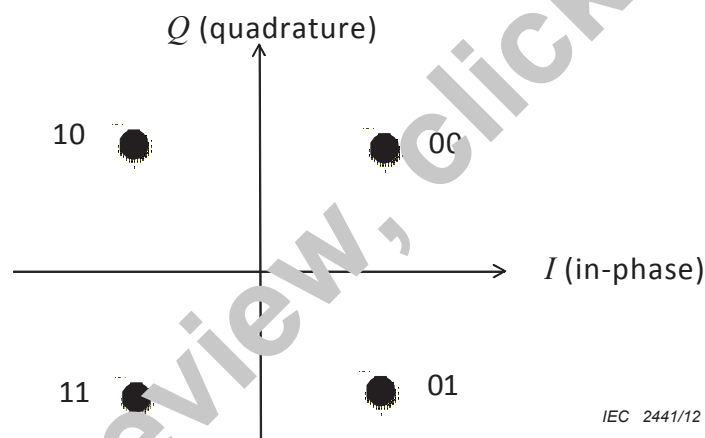


Figure 1 – Constellation diagram for QPSK coding

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.

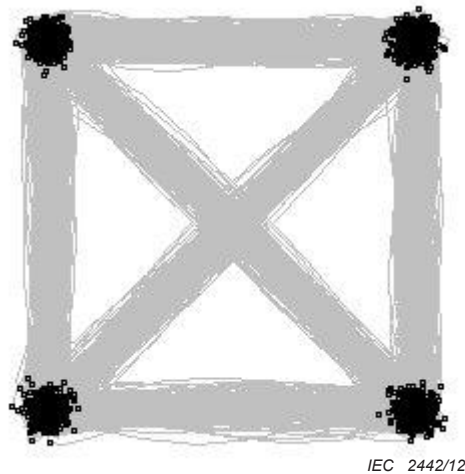


Figure 2 – IQ diagram for the same QPSK coding

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.

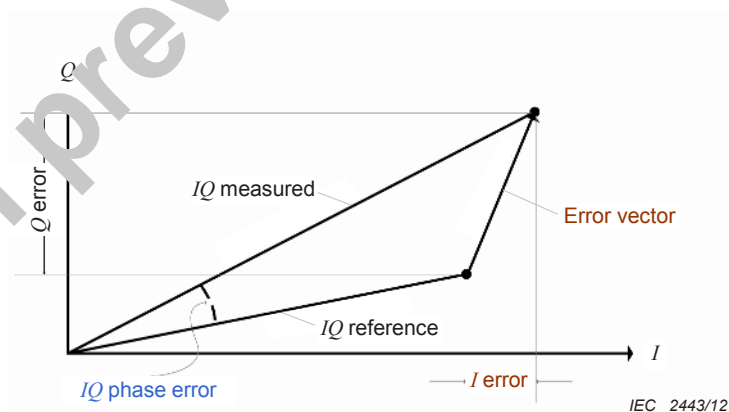


Figure 3 – Relationship of error vector to reference vector and measured signal vector in the constellation diagram

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

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

where

$$\begin{aligned} I_{\text{err}}(kT_s) &= \alpha I_{\text{meas}}(kT_s) - I_{\text{ref}}^{r(k)} \\ Q_{\text{err}}(kT_s) &= \alpha Q_{\text{meas}}(kT_s) - Q_{\text{ref}}^{r(k)} \end{aligned}$$