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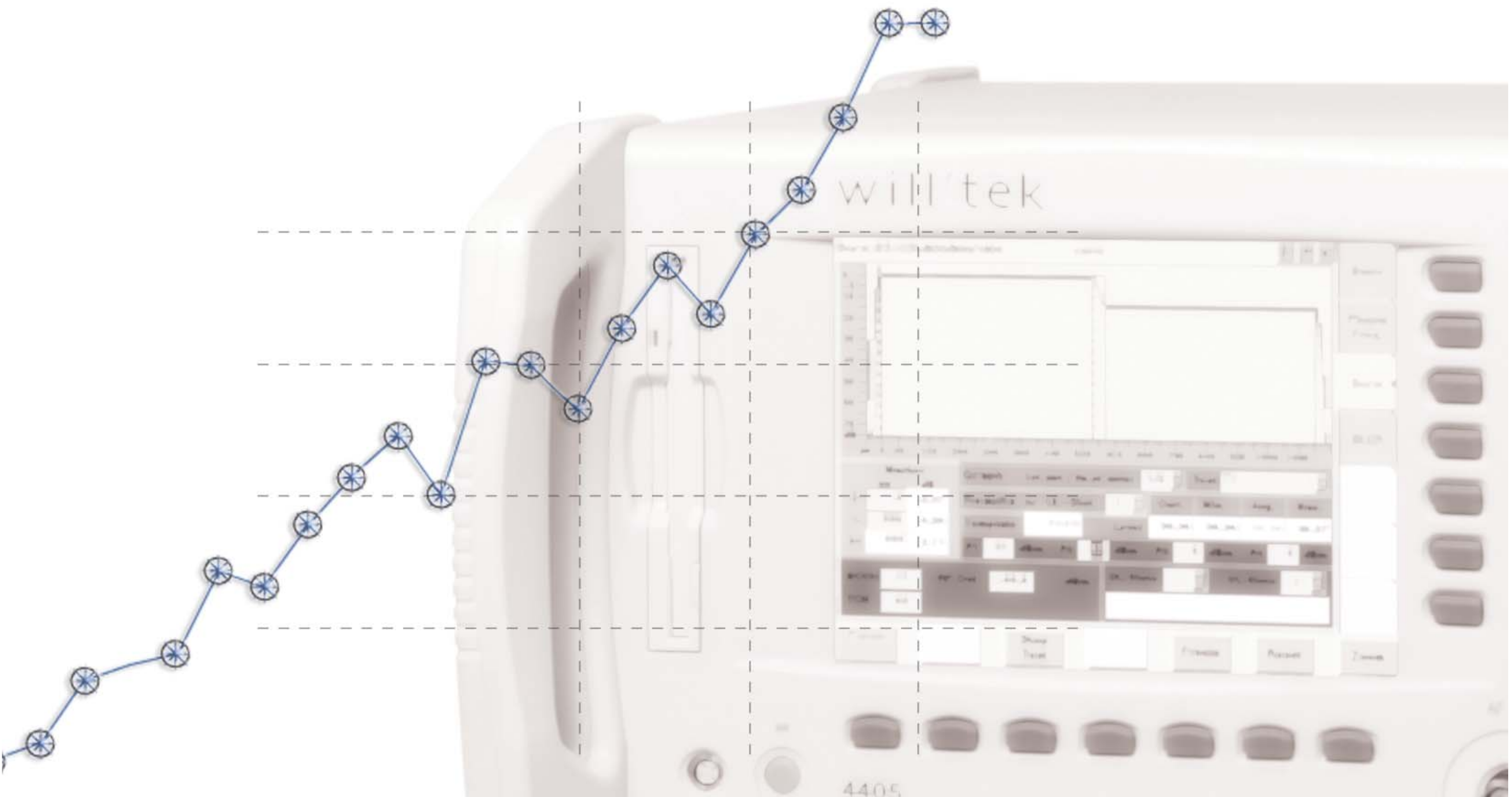
White Paper

EVM measurement design for 3G test equipment



Introduction

With the rapid development in technology and in standardisation for the mobile communications, the test equipment for the new generation mobile becomes more complicated, which results in the measurement accuracy analysis (it is important for any measurement.) being more complicated. Error Vector Magnitude (EVM) is specified as a modulation quality metric by 3GPP [1]. EVM is a statistic variable, its performance is an important issue. The mean and the variance of EVM are related with the data length and the signal-to-noise ratio (SNR) of the measured signal. In practice, EVM is measured with a test equipment. The fact that the test unit itself contains noise makes the EVM performance analysis more complicated. This paper discusses the relationships among the test unit noise, the target EVM and its deviation. Based on this discussion, an EVM measurement design method is proposed. EVM and its statistic properties are presented in section 2. In section 3, the basic relationships among the test unit noise, the target EVM and its deviation are shown by Eq. 4, then an EVM measurement design is presented, which includes a method to choose the data length and the test unit SNR. In section 4, an example is used to show the design result, and a simulation is used to show the measured EVM performance. Finally, section 5 gives a conclusion.

A user equipment (UE) is considered as a measurement target in this paper.

EVM and its statistic properties

The error vector magnitude is used to measure a transmitter modulation quality. It is defined in [1] as:

$$EVM = \sqrt{\frac{\sum_{k=1}^{M} \| Z(k) - R(k) \|^2}{\sum_{k=1}^{M} \| R(k) \|^2}} \qquad \text{Eq. 1}$$

Where R is a reference signal (an ideal base band signal) sampled at the chip rate, Z is a measured signal sampled at the chip rate with time offset and frequency offset being removed, M is the data length, and k means the kth sample.

Eq. 1 tells that EVM measures the difference between a measured signal and a reference signal. Considering that the difference is a noise, then the EVM is an estimate of the square root of the noise-to-signal ratio. EVM is a statistic because of the randomness of the noise. If there is no noise, EVM = 0.

Assuming the noise is Gaussian-distributed, it has been proved that the mean and the variance of the EVM can be calculated by the following equations:

$$\mu_{EVM} = \frac{\sigma_n}{\sigma_s} \sqrt{(M - 2 + \pi/2)/M} \qquad \text{Eq. 2}$$

$$\sigma^2_{EVM} = \frac{\sigma^2_n}{\sigma^2_s} (2 - \pi/2)/M \qquad \text{Eq. 3}$$

Where σ_s^2 and σ_n^2 are the signal power and the noise power in the measured data.

Eq. 2 shows that the EVM is an asymptotic consistent estimate of the square-rooted noise power to signal power ratio. Eq. 3 shows that the variance of the EVM depends on the SNR and the length of the data used to calculate the EVM. The SNR of the data may be viewed as the expectation of EVMˆ(–2) of the data, therefore the accuracy of the EVM is related to the EVM value itself.

EVM measurement design

Since EVM is a statistic, its accuracy requirement becomes the measurement design metric. It seems that 3GPP documents specify the minimum requirement for the EVM measurement and its accuracy. Since the EVM accuracy is related to the EVM itself as indicated in the above, the EVM measurement range needs to be specified to meet the standard requirement.

In practice, the EVM is measured by a test equipment. The data used to calculate the EVM not only contains the signal and noise from a test target, but also contains other noise, channel distortions, and error residues from the test unit, which are included in a noise floor. The designer needs to specify the data length M used to calculate the EVM, as well as the test unit noise floor in order to meet the EVM accuracy. Also an EVM measurement range needs to be specified since the EVM accuracy is related to the EVM value itself as mentioned before.

EVM_u and SNR_t

Because of the test unit noise floor, the σ_n^2 in Eq.(3) may be written as $\sigma_n^2 = \sigma_{nu}^2 + \sigma_{nt}^2$

where, σ_{nu}^2 is the noise power of a UE, and σ_{nt}^2 is the noise power of the test unit noise floor. σ_s^2 is the signal power of the measured data. Therefore, the SNR for the test unit can be obtained by the following formula derived from Eq.(3):

$$\text{SNR-t} = \left(\frac{\Delta EVM^2}{16} M(2-\pi/2) - \frac{\sigma^2_{nu}}{\sigma^2_s}\right)^{-1}$$

$$= \left(\frac{\Delta EVM^2}{16} M(2-\pi/2) - EVM-u^2\right)^{-1} \quad \text{Eq. 4}$$

Where

$$\text{SNR-t} = \frac{\sigma^2_s}{\sigma^2_{nt}},$$

$$\text{EVM-u} = \frac{\sigma_{nu}}{\sigma_s}$$

The SNR_t is the signal-to-noise ratio for a test unit. Since the noise floor includes all kinds of noise, channel distortions, and error residues from the test unit before EVM calculation, it may be assumed that the noise floor is approximately Gaussian-distributed; EVM_u is the modulation quality measurement of the UE transmitter, Eq. 3 tells that the EVM accuracy is related to the EVM; ΔEVM is the EVM deviation counting the noise from both the UE and the test unit. It is reasonable to choose the ΔEVM to be four times of the EVM standard deviation, i.e.

$$\Delta EVM = 4\sigma_{EVM} = 4\,\frac{\sigma_n}{\sigma_s}\sqrt{(2+\pi/2)/M} \quad \text{Eq. 5}$$

All the deviations discussed in this paper means four times of the standard deviation.

Data length M

Eq. 4 indicates that the following relationship must be satisfied to make the left side of the equation being positive:

$$M > \frac{EVM\_u^2}{\Delta EVM^2}\,16\,(2-\pi/2) \quad \text{Eq. 6}$$

There are two variables on the right side of Eq. 6: the measurement target EVM_u and the ΔEVM. The data length M vs. EVM_u for different ΔEVM are plotted in Fig. 1, where EVM = devm = 0.005, 0.013, 0.015 are plotted.

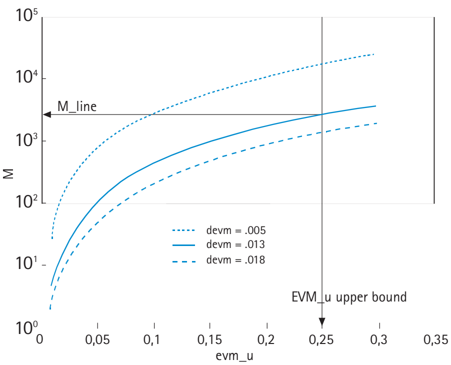


Fig. 1

Fig.(1) shows that:

1) For a specified accuracy ΔEVM, the higher the EVM_u to be measured, the larger the data length will be needed.

2) For a specified data length M, the accuracy ΔEVM is not a constant for different EVM_u. The greater the ΔEVM_u value is, the lower the accuracy will be.

Therefore the data length M may be determined according to the upper bound of the EVM_u measurement range and the required EVM_u accuracy ΔEVM_u as shown in the following example.

Note that it is the ΔEVM and not the ΔEVM_u is used in Eq. 6, but it is the ΔEVM_u which is the accuracy requirement. This problem may be solved by setting ΔEVM = ΔEVM_u, and is explained in the following example.

For example, choose the upper bound of the EVM_u range being 0.25 as shown in Fig. 1. M may be chosen according to the accuracy specification. Let ΔEVM(devm) = ΔEVM_u = 0.013, in Fig. 1 the M vs. evm_u curve with devm = 0.013 is intersected with the EVM upper bound line, this intersection of gives M = 2540. It is shown that, on the left side of the EVM_u upper bound, only the curves with ΔEVM ≤ 0.013 have intersections with the M-line, it means ΔEVM ≤ 0.013 for EVM_u ≤ 0.25. Therefore ΔEVM_u ≤ 0.013 for EVM_u < 0.25 since ΔEVM_u ≤ ΔEVM.

SNR_t

It is hard to use Eq. 4 to obtain the test unit SNR_t since the EVM_u is not a fixed value in practice and the ΔEVM_u varies with the EVM_u. A conventional way is to choose the test unit noise power being 1/r of the target noise power with r ≥ 10, i.e. SNR_t = EVM_û(-2) x r. Fig. 2 plots SNR_t vs. EVM_u for r = 1000, 100, 10.

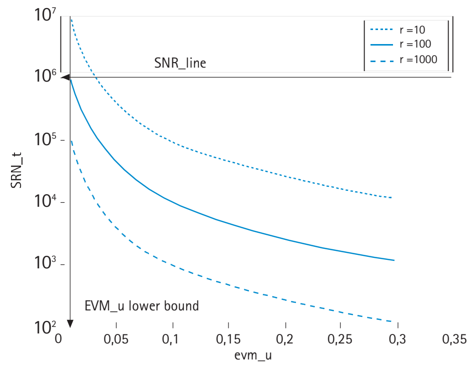


Fig. 2

Fig. 2 shows that:

1) For a specified ratio r, the smaller the EVM_u is to be measured, the higher the SNR_t will be needed.

2) For a chosen SNR_t, the ratio between the SNR_t and the EVM_u is not a constant. The greater the EVM_u is to be measured, the higher the ratio will be.

   Therefore, the test unit SNR_t may be determined according to the lower bound of the EVM_u measurement range and the r as shown in the following example.

Let the lower bound be 0.01, and r be 100, then the intersection of the second curve (r = 100) and the EVM_u lower bound line gives SNR_t = 60 dB as shown by the SNR line in Fig. 2. Also it is shown that, on the right side of the EVM_u range lower bound, only the curves with r ≥ 100 have intersections with SNR line, this means r ≥ 100 for EVM_u ≥ 0.01.

Design example and simulation

[1] specifies that EVM_u ≤ 0.17 for a UE. It is reasonable for test equipment to specify EVM_u measurement requirements as the following:

EVM_u measurement range: 0.01 to 0.25,
EVM_u accuracy EVM_u: ≤ 0.013.

According to the analysis in the previous sections, the data length M = 2560, the test unit signal to noise ratio SNR_t = 60 dB are chosen in this example.

With this design, the EVM_u and the EVM are calculated for a WCDMA UE transmitter signal as shown in Fig. 3, where noise_u is the noise from the UE, noise_t is the noise from the test unit, evm_u is the EVM of the UE, and the evm is the EVM measured by the test unit.

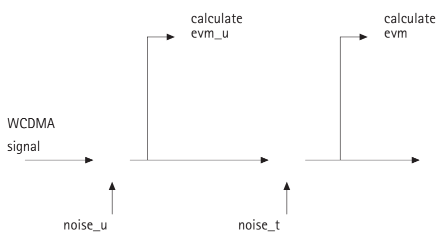


Fig. 3

Note that the evm is what a test unit can obtain, and the evm_u is what an EVM test want to measure. Only when the difference between them is ignorable, the reading of the evm from the test unit can be viewed as evm_u.

In Fig. 4, devm vs. evm is plotted with the line with '*', where evm is the EVM calculated with the measured data which includes noise from both the target and the test unit, devm is its deviation; devm_u vs. evm_u is plotted with the line with 'o', where the evm_u is the target EVM_u calculated with the data which includes noise from the target only, devm_u is its deviation.

Fig.(4) shows that, devm_u vs. evm_u curve is almost an overlay of the devm vs. evm curve. In other words, not only the EVM value evm≅evm_u, but also the EVM deviation devm≅devm_u. Therefore the measured EVM can be considered as the EVM_u of the UE for the specified EVM_u range. Also the plot shows that the EVM deviation is less than 0.013 which is the EVM measurement accuracy requirement.

The difference between the evm_u and the evm is plotted in Fig. 5 as a deviation of the (evm – evm_u). It is shown that this difference can be ignored.

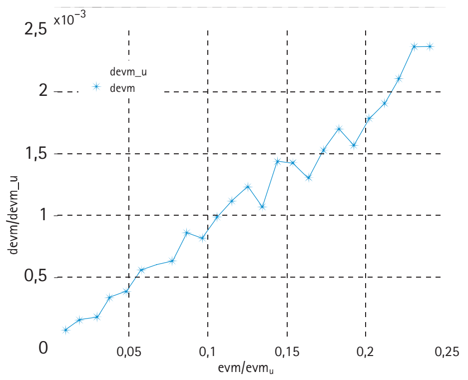


Fig. 4

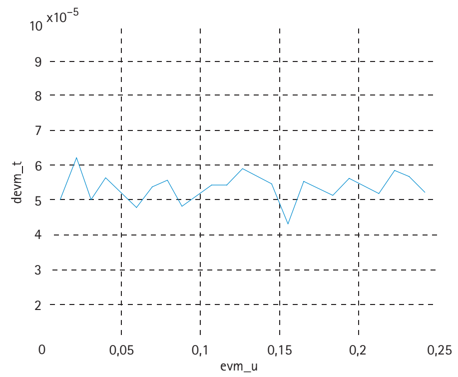


Fig. 5

Conclusions

In this paper, the EVM measurement accuracy issues are studied. A formula is proposed to determine the data length for EVM measurement. The relationships among the test unit noise, the target EVM and its accuracy are discussed. EVM measurement design method is shown with an example, and the resulted EVM performance is shown in a simulation. It is shown that this design meets the accuracy requirement.

Reference:

[1] 3GPP TS34.121: "Terminal conformance specification; Radio transmission and reception (FDD)".

[2] 3GPP TS 25.101: "UE Radio transmission and Reception (FDD)".

Note: Specifications, terms and conditions are subject to change without prior notice.

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