Notice of Violation of IEEE Publication Principles

"New EVM Calculation Method for Broadband Modulated Signals and Simulation"
by Zhang Qijun, Xu Qinghua, Zhu Wei
in the Proceedings of the Eighth International Conference on Electronic Measurement and Instruments, July 2007

After careful and considered review of the content and authorship of this paper by a duly constituted expert committee, this paper has been found to be in violation of IEEE's Publication Principles.

This paper contains significant portions of original text from the paper cited below. The original text was copied without attribution (including appropriate references to the original author(s) and/or paper title) and without permission.

Due to the nature of this violation, reasonable effort should be made to remove all past references to this paper, and future references should be made to the following article:

"EVM Calculation for Broadband Modulated Signals"
by Michael D. McKinley, Kate A. Remley, Maciej Myslinski, J. Stevenson Kenney, Dominique Schreurs, Bart Nauwelaers,
in the Proceedings of the 64th ARFTG Conference, December 2004, pp. 45-52

A New EVM Calculation Method for Broadband Modulated Signals and Simulation

Zhang Qijun Xu Qinghua Zhu Wei
(Harbin Institute of Technology, Harbin 150001 China)

Abstract: To characterize the quality of wireless telecommunications system more efficiently and integrally, it is necessary to use error vector magnitude (EVM) to be the figure of merit. We describe a typical EVM normalization, and deduce its calculation process. We also have simulated EVM of various modulation types specified by the IEEE 802.11aTM-1999 standard from a given average symbol power based on the basic equation, and compared with the corresponding bit error rate (BER).

Keywords: Error Vector Magnitude; Digital Modulation; Wireless Telecommunications.

1 Introduction

Error Vector Magnitude (EVM) is a common figure of merit for assessing the quality of digitally modulated telecommunication signals [1]. It can allow a more complete picture of the channel distortion and is more closely related to the physics [2] [3].

The most common of these schemes at 5 GHz is known as orthogonal frequency-division multiplexing (OFDM), as specified by the *IEEE 802.11aTM-1999* standard [1]. The *IEEE 802.11aTM-1999* standard specifies use the following different modulation types, such as binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), 16-symbol quadrature amplitude modulation (16QAM), 64-symbol quadrature amplitude modulation (64QAM), etc.

We introduce a new normalization to calculate EVM, and also have certain improvement for the deduced expression which makes the calculation more conveniently and efficiently. Such normalization is implicit in the *IEEE 802.11aTM-1999* standard and is the focus of this paper [4] [5]. We also simulate and calculate EVM for these different types of modulation, and receive a conclusion from the comparison with corresponding BER.

2 Calculation of EVM

We introduce a typical normalization to calculate EVM. All the EVM arithmetic is implemented in simulation software.

A. Constellation Diagrams and EVM

To aid in the visualizing of demodulated signals, constellation diagrams are often used to represent digital bits in terms of symbols. Figure 1 shows three constellation diagrams for 16QAM, which has 16 symbols modulating the RF carrier in both magnitude and phase. In each case, *I* and *Q* represent the in-phase (*0°* relative phase) and quadrature (*90°* relative phase) values of each symbol. This gives each symbol a resulting magnitude and phase. Fig. 1(a) represents a measured set of symbols. Figure 1(b) represents the ideal constellation described below.

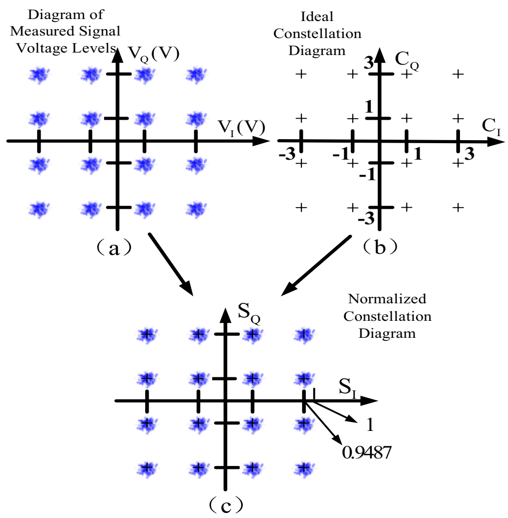

Fig 1. Graphs of (a) measured symbols, (b) the ideal constellation diagram, and (c) a normalized space

To efficiently calculate EVM, the diagrams in

Figs. 1(a) and 1(b) are scaled to form the normalized (dimensionless) constellation diagram in Fig. 1(c). The in-phase (S_I) and quadrature (S_Q) axes are similar to the real and imaginary axes used in complex voltage representations. We derive a scaling for these constellations in this section.

To enable the normalization, we assume a uniform distribution of the transmitted symbols into the constellation. This means that the transmitted symbols have an equal probability of visiting each location on the constellation and the number of symbols transmitted is a multiple of the number of unique symbols in a constellation.

Ideal constellation diagrams show the ideal placement of symbols for a given modulation type which are often represented by symbols at integer levels. We see this in Fig. 1(b). Furthermore, the number of levels along either an in-phase or quadrature axis for an ideal constellation is

$$n = \sqrt{N}.$$

(1)

The integer coordinates of the ideal constellation points for each symbol are

$$C_{ideal,\ pq} = C_{I,ideal,pq} + jC_{Q,ideal,pq} = (2p-1-n) + j(2q-1-n).$$

(2)

Where the integers p and q satisfy $1 \le p \le n, 1 \le q \le n$, and the integer n is defined in (1). From (2), we can obtain what we refer to here as the "ideal constellation diagram," Fig. 1(b), for any of the common digital modulation types.

B. Normalizations of the measured and ideal representations

To find EVM, we must compare the ideal symbol values from the ideal constellation diagram to the arbitrary voltage values that we measure. One way to enable this comparison is to normalize both the measured and ideal symbols, as illustrated in Fig. 1. We describe this procedure below [6][7].

1) Measured Case. For the measured case, one method for accomplishing this normalization is to divide the power in each symbol, $P_{V,symbol}$, by the average symbol power calculated over all symbols in the constellation, to obtain $P_{S,symbol}$:

$$P_{S,symbol} = \frac{P_{V,symbol}}{P_V / T}.$$

(3)

where P_V , the total power of a measured constellation having T symbols, is

$$P_V = \sum_{r=1}^{T} \left[\left(V_{I,meas,r} \right)^2 + \left(V_{Q,meas,r} \right)^2 \right] (W).$$

(4)

where $V_{I\ or\ Q,mear,r}$ is the RMS voltage level of the in-phase and quadrature components of the measured symbols and T is typically >> N.

From (3), we see that $P_{S,symbol}$, is dimensionless. The average of all $P_{S,symbol}$'s in the normalized constellation will be equal to one. To calculate EVM, we must represent this normalization in terms of voltage. We identify a normalization factor $|A_{meas}|$ from (3) as

$$|A_{meas}| = \sqrt{\frac{1}{P_V / T}}.$$

(5)

2) Ideal Case. For the ideal case, a similar procedure can be used for the integer space if we use N instead of T where N is the number of unique symbols in a constellation (e.g., 4 for QPSK or 16 for 16QAM). In this case, P_C does not represent the total power in a constellation as P_V does, but it's rather the sum of the squares of the amplitudes of all symbols:

$$P_C = \sum_{p=1}^{n} \left[\sum_{q=1}^{n} \left(C_{I,ideal,pq}{}^2 + C_{Q,ideal,pq}{}^2 \right) \right].$$

(6)

Here, $C_{I,ideal,pq}$ and $C_{Q,ideal,pq}$, are, respectively, the real (in-phase) and imaginary (quadrature) integer values corresponding to each symbol, and n is defined in (1). Note that for the ideal, integer-based constellation diagram (Fig. 1(b)), P_C can also be found by substituting the values in (2) for C_I and C_Q :

$$P_C = \sum_{p=1}^{n} \left[\sum_{q=1}^{n} \left((2p-1-n)^2 + (2q-1-n)^2 \right) \right].$$

(7)

Similar to (5), the normalization scaling factor for ideal symbols, $\left|A_{ideal}\right|$, is written as

$$\left|A_{ideal}\right| = \sqrt{\frac{1}{P_C/N}}.$$

(8)

3) Normalized EVM. From (5) and (8), EVM can be represented as

$$EVM_{RMS} = \left[\frac{\frac{1}{T}\sum_{r=1}^{T}\left(\left|\left(V_{I,mear,r}\right)\bullet\left|A_{mear}\right|-\left(C_{I,ideal,r}\right)\bullet\left|A_{ideal}\right|\right|^{2}\right)}{P_{S,avg}} + \frac{\frac{1}{T}\sum_{r=1}^{T}\left(\left|\left(V_{Q,mear,r}\right)\bullet\left|A_{mear}\right|-\left(C_{Q,ideal,r}\right)\bullet\left|A_{ideal}\right|\right|^{2}\right)}{P_{S,avg}}\right]^{\frac{1}{2}}.$$

(9)

Where,

$$P_{S,avg} = \frac{1}{N}\sum_{p=1}^{n}\left[\sum_{q=1}^{n}\left(\left(2p-1-n\right)^{2}\left|A_{ideal}\right|^{2}+\left(2q-1-n\right)^{2}\left|A_{ideal}\right|^{2}\right)\right].$$

(10)

3 Simulation and Comparison of EVM and BER

In order to test the influence of EVM and BER caused by simple channel distortion of different modulation type, as specified by the *IEEE 802.11aTM-1999* standard, we have made some simulation (see Fig. 2). Random bits are produced by a Random Sequencer, then, become modulated signal with the frequency of 5GHz after passing through a Modulator Baseband. This Modulator Baseband is made up of Modulator Baseband and Frequency Up-Converter. The signal from the Modulator Baseband is complex signal *b* which is also the important ideal input signal for EVM calculation. Then, the modulated signal will pass through wireless channels with different distortion. Finally, we will receive the baseband signal at the receiving terminal from a Demodulator Baseband which is also consisted of Demodulator Baseband and Frequency Down-Converter.

The complex signal *c* is also the important measured input signal for EVM calculation, and obviously has some error compare with signal *b*. The module of EVM calculation is based on the expression (9), *b* and *c* are inputs, and output is from the EVM of wireless system. Signal *d* which is from the demodulator is measured baseband signal, and some error is existed to compare with ideal signal *a*. We could receive BER from the module of BER calculation with the two inputs *a* and *d*. Here, detail description of BER is ignored, for the simple principle.

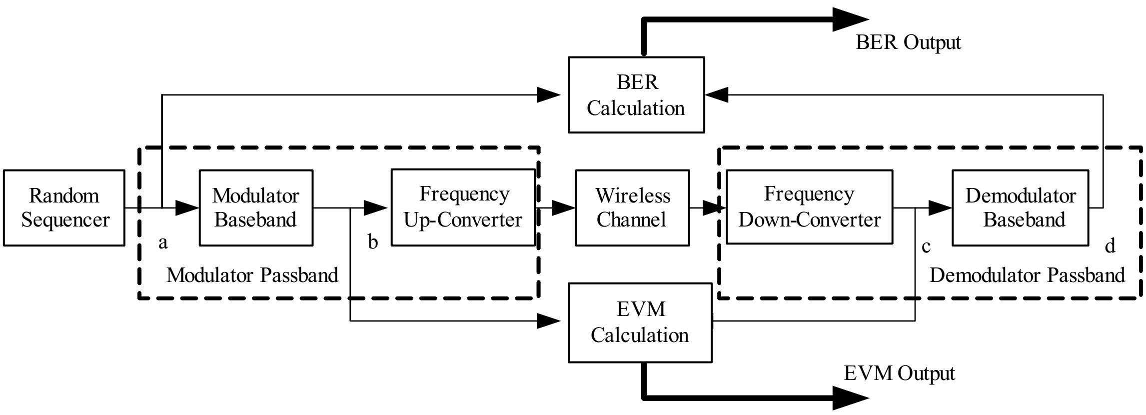

Fig 2. Diagram of System Simulation

For these types of modulation, we have simulated and received the corresponding conclusions from the program of EVM and BER, see Fig. 3. The measurement is carried in a channel with different distortion which has different SNR (Signal-to-Noise Ratio). EVM is required to be 15.8% less than *IEEE 802.11aTM-1999* standard [1][8]. From Fig. 3(a), we could see that it is completely according with the standard in the case of high SNR. However, BPSK and QPSK have exceeded the standard in the case of low SNR.

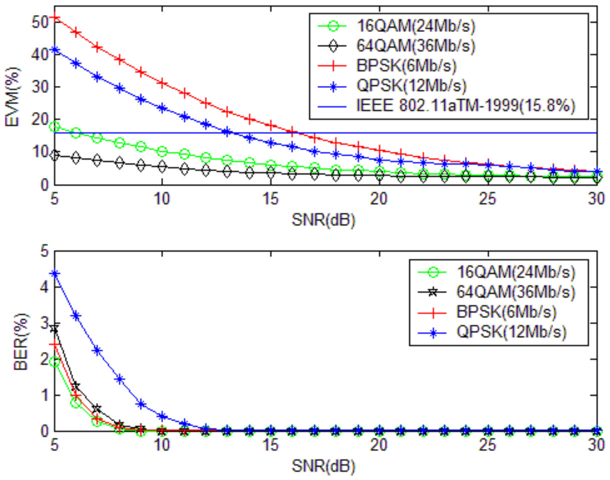

Fig 3. (a) EVM-SNR of different types of modulation
(b) BER-SNR of different types of modulation

It has been proved that the normalization, defined by expression (9), could calculate EVM of different types of modulation in different conditions by the given average symbol power, and compared with correspond BER. From Fig. 3, we can see that EVM is far greater than BER. In the case of high SNR, BER is nearly equal to zero which could not fully characterize signal distortion of system. Obviously, it is incapable to pursuit perfect system, while EVM still has high enough value which contains more information and could characterize the imperfection of system. Thus, the developers of communication system could find the flaw of system with the measured EVM, and have repeating improvement for the perfect design.

From the simulation conclusion, we could also find that the increase of EVM is far greater than that of BER along with decrease of SNR.

4 Discussion and Conclusion

We describe a constellation normalization for EVM calculation, viz. to multiply mean-square amplitude normalization scaling factor by in-phase and quadrature components of each symbol, thereby reached the normalization of vector magnitude. Finally, we have deduced the equivalent expression we want for the direct EVM calculation and received EVM of different types of modulation specified by the *IEEE 802.11aTM-1999* standard. It has proved that EVM of different types of modulation could be calculated with a simple mathematical expression.

From the comparison of EVM to BER for different types of modulation in different conditions, we have drawn the conclusions:

1) According to *IEEE 802.11aTM-1999* standard, which is for EVM 15.8% less than the case of high SNR. However, BPSK and QPSK have exceeded the standard in the case of low SNR.

2) Increase of EVM is far greater than that of BER along with decrease of SNR.

References

[1] IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-Speed Physical Layer in the 5 GHz Band, IEEE Standard 802.11aTM-1999.

[2] Roland Hassun, Michael Flaherty, Robert Matreci, Mitch Taylor, Efffective Evaluation of Link Quality Using Error Vector Magnitude Techniques, Wireless Communications Conference, 1997

[3] Apostolos Georgiadis, Gain, Phase Imbalance, and Phase Noise Effects on Error Vector Magnitude, IEEE Transactions on Vehicular Technology, Vol. 53, No. 2, Mar 2004

[4] Hewlett-Packard Co. , Notes on Error Vector Measurements with the HP894000 Vector Signal Analyzer. Jan 1996

[5] Roland Hassun, Hewlett-Packard Co, Comparing Analog and Digital Techniques for measuring Noise Power Ratio, Microwave Journal, March 1997

[6] B. Zarlhgo, Bewlett-Packard, Adaptive Equalization and its

Effect on Error Models for Digitally-Modulated Signals, World Wireless Conference, 1997.

[7] S. Forestier, P. Bouysse, R. Quere, A. Mallet, J.-M. Nebus, and L. Lapierre, Joint optimization of the power-added efficiency and the error-vector measurement of 20-GHz pHEMT amplifier through a new dynamic bias-control method, IEEE Trans. Microwave Theory and Tech, vol. 52, no.4, pp. 1132-1140, Apr. 2004

[8] M. S. Heutmaker, The Error Vector and Power Amplifier Distortion, Proc. Wireless Comm. Conf., 1997, pp. 100-104.

Author Biographies

Zhang Qijun, born in Ningbo, China, in 1983. Received his B.S. and M.S. degrees from Jilin University and Harbin Institute of Technology, respectively. His research interests include nonlinearity measure technology of wireless communication system.