Discrimination between Noise and Distortion in EVM Measurements

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***Abstract* — EVM (Error Vector Measurement) is used to measure the end-to-end quality of digital communication links. It comes from noise, linear and non-linear distortion, and interference if any. I propose a method to discriminate between random noise that is independent of the signal and distortion that depends on the signal. Interference is more complex to discriminate as it is not random but can be either synchronous with the signal or not. Echoes such as multipath cause linear distortion if they are static. However, variable echoes, such as those created in a reverberation chamber must be treated specifically.**

***Index Terms* — EVM, Error Vector Measurement, Linear distortion, Non-linear Distortion, Echoes, multipath, reverberation chamber.**

I. Introduction

EVM (Error Vector Measurement) is an overall quality measurement of digital communication links [1, 2]. It is generally measured on an end-to-end system and a maximum value is defined for each modulation to guarantee correct demodulation of symbol and low enough BER (Bit Error Rate).

EVM is degraded by many types of effects.

Some effects are deterministic and are the same each time the same sequence of signal is sent through the link. They are mainly:

- Linear distortion such as filter frequency responses.
- Non-linear distortion such as AM/AM and AM/PM curves in amplifiers [3, 4].
- IQ imbalance in modulators and demodulators.
- Quantization errors in DAC and ADC.
- Echoes and multipath that can be stationary (and have the effect of the frequency response of a filter on the signal) or time varying.

Some other effects are independent of the signal, such as:

- Random additive noise.
- Random phase noise.
- Interference (not random but not synchronized with the signal).

Effects that are either random or dependent on the signal but not time varying can be discriminated easily by measurement. The procedure is shown in sections II and III.

Constellations with either the random noise or the distortion are shown in section IV.

Measurement results are shown in section V.

Time varying echoes and interference must be treated separately. An approach to such a procedure is proposed in sections VI and VII.

EVM is computed on IQ sequences by using the opensource IEEE P1765-2022 standard baseline EVM algorithms [5].

II. Measurement of an Averaged Sequence

Deterministic distortion is the same each time the same sequence of symbols is used in the signal. So, and evident way of removing, or at least decreasing the effect of noise on the EVM measurement is to average many received IQ signals obtained from the same ideal signal and the same symbols sequence.

If we average N identical signal sequences, the noise power is divided by N and the effect on EVM is divided by $\sqrt{N}$.

Using 100 sequences allows us to determine if the effect of distortion is lower than one tenth of the overall EVM or not.

Using 10 000 sequences is generally sufficient to measure the effect of a significant distortion even if it is around one percent of the overall EVM.

This measurement can be done in a short time (seconds) with a sequence of around 1 000 to 10 000 symbols and a modulation rate of 10 to 100 MBauds.

III. Measurement of Distortion and Random Noise

A more rigorous computation will consider the fact that a small part of the random noise is present in the averaged IQ signal sequence.

In addition to computing the EVM on the average of N sequences of received signal (EVM_N), we also compute an RMS average of the EVM computed on each of the N signals.

If the EVM on each sequence is composed of a deterministic distortion part D and an independent random noise part R, they are orthogonal, so we have:

$$EVM^2 = D^2 + R^2 \quad (1)$$

After averaging N sequences, the computed EVM is:

$$EVM_N^2 = D^2 + R^2/N \quad (2)$$

The exact resolution of this system gives:

$$R^2 = \frac{EVM^2 - EVM_N^2}{1-1/N} = \frac{N\left(EVM^2 - EVM_N^2\right)}{N-1} \quad (3)$$

And

$$D^2 = \frac{N \times EVM_N^2 - EVM^2}{N-1} \quad (4)$$

Remark that real R and D results are obtained if and only if:

$$EVM^2 \geq EVM_N^2 \quad (5)$$

And

$$N \times EVM_N^2 \geq EVM^2 \quad (6)$$

This has been the case for all simulations and measurements.

Using these more rigorous equations, simulations have shown that very good results are obtained with values of N as low as 4 or 16 instead of 100 or 10 000.

Simulated non-linearity EVM = 4.89 %
Simulated noise EVM = 5.83 %

Simulated noise and distortion EVM = 7.721 %
Average on 16 sequences EVM = 5.102 %
Result distortion EVM = 4.878 %, error = 0.012 %
Result noise EVM = 5.986 %, error = 0.156 %

Simulated noise and distortion EVM = 7.84 %
Average on 4 sequences EVM = 5.81 %
Result distortion EVM = 4.95 %, error = 0.16 %
Result noise EVM = 6.078 %, error = 0.308 %

The result is good on the distortion and a little less accurate on the noise because the measurement itself is random as can be seen on two different measurements of one sequence giving 7.721 % and 7.84 %.

With these equations, it is possible to reduce the measurement time to a small multiple of the measurement time for one sequence.

IV. CONSTELLATIONS WITH DISTORTION AND RANDOM NOISE

if we subtract the averaged sequence from the non-averaged one, the deterministic distortion is removed from the signal and only the noise is left (with a small error on its power).

Remark that the ideal signal sequence is also removed, so that we must add it again to get a constellation with only the noise added to it.

In the following figures 1 to 3, we compare a constellation with additional noise only, a constellation with distortion only, a constellation with both noise and distortion.

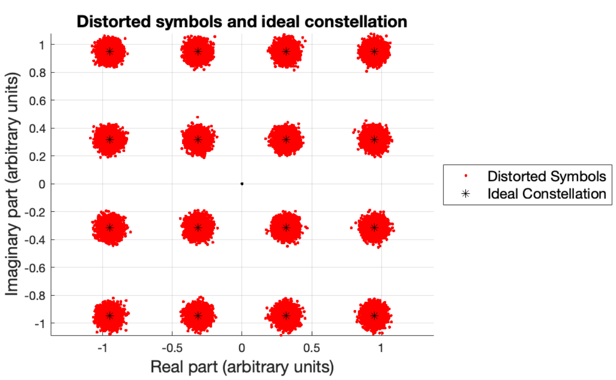

Figure 1: Constellation generated with noise only.

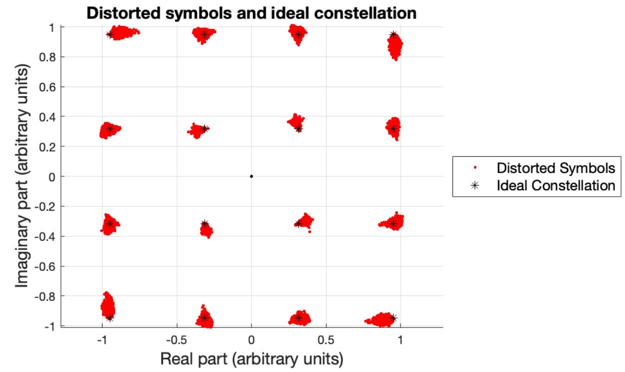

Figure 2: Constellation generated with distortion only

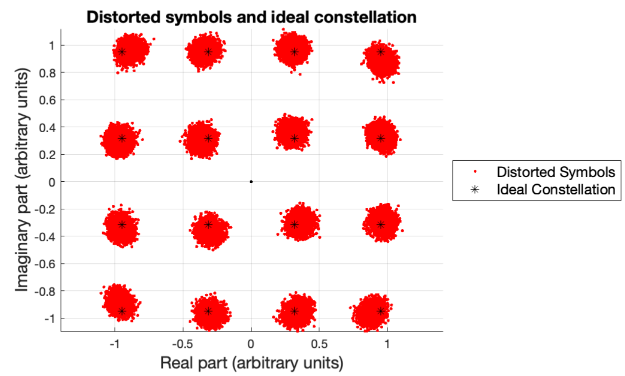

Figure 3: Constellation generated with noise and distortion.

Figure 4 is the averaged constellation with $N = 4$. This constellation is different from the constellation in Fig. 2 obtained with distortion only because about one quarter of the noise power is still present after averaging with N=4.

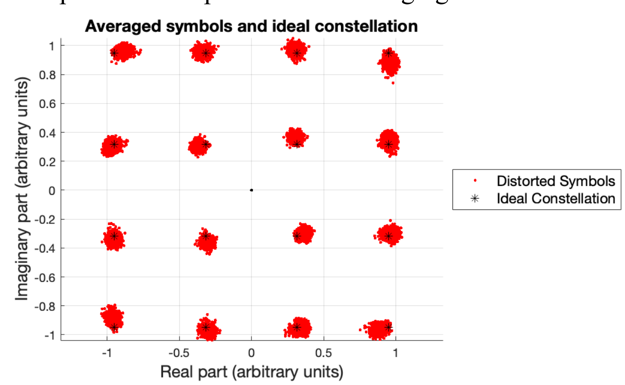

Figure 4: Averaged constellation with $N = 4$.

Figure 5 is the resulting noisy constellation after removing the distortion from Fig. 4. This constellation is also different from the constellation in Fig. 3 because the averaging of the noise in Fig. 4 is not perfect.

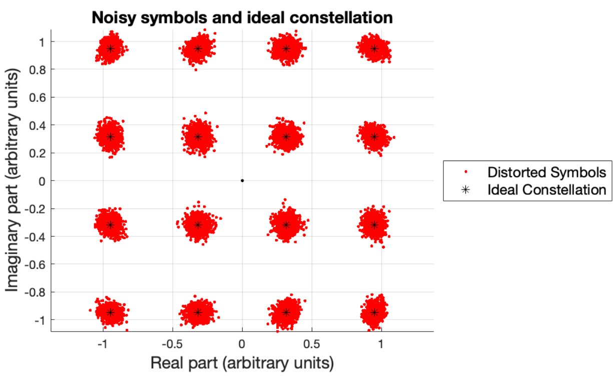

Figure 5: Constellation after removing the distortion averaged with $N = 4$.

The averaging with $N = 4$ is sufficient for the computation of both distortion EVM and random EVM using equations 3 and 4 but the averaged constellation contains too much noise, and the noise constellation contains toot much distortion. The quadratic sum of the EVMs computed on these two constellations is higher than the total EVM.

Constellations obtained with average factor $N = 100$ are shown in the following figures.

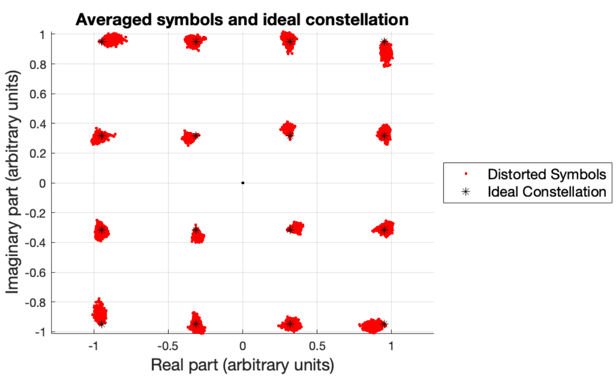

Figure 6: Averaged constellation with $N = 100$.

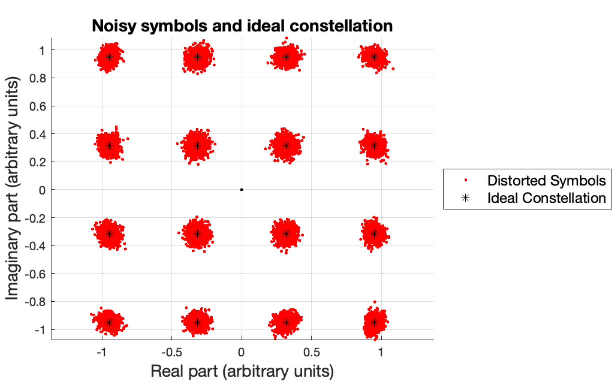

Figure 7: Constellation after removing the distortion averaged with $N = 100$.

They are nearly identical to constellations obtained with either noise only or distortion only.

The averaged constellation in Fig. 6 can be used for further identification of AM/AM and AM/PM distortion as presented in [6].

As the noise has been added before the non-linearity, some compression is visible on the highest amplitude points of the noise constellation in Fig. 7.

V. Measurement Results

Measurement have been done by CNES using a Rohde & Schwarz SMW200A generator and an FSW67 receiver with an option for synchronization on DVB/S2 headers.

A 16 APSK modulation has been used.

The DUT is a non-linear amplifier that may be followed by attenuators to represent the noisy conditions of an OTA measurement. The test bench is shown in Fig. 8.

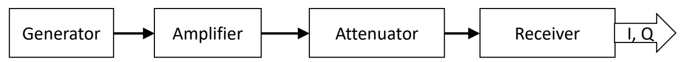

Figure 8: Test bench with DUT.

The measured and averaged constellations are given in the following figure.

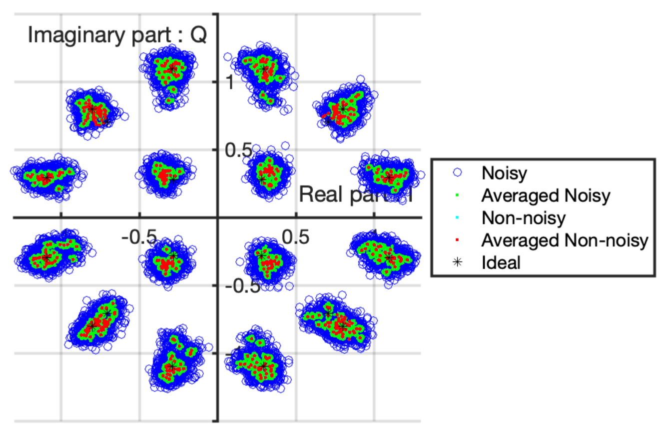

Figure 10: Measured constellations, 1) noisy, black circles; 2) same, averaged, blue dots, 3) non-noisy, green dots, 4) same, averaged, red dots, 4) ideal values, black asterisks.

The results obtained with attenuators are given in the following table.

TABLE I

RESULTS FOR AMPLIFIER WITH ATTENUATORS

N	2		4		16	
	%	dB	%	dB	%	dB
EVM	9.84	20.14	9.83	20.15	9.82	20.15
EVM_N	9.08	20.84	8.65	21.26	8.33	21.58
D	8.23	21.69	8.22	21.70	8.23	21.70
R	5.40	25.36	5.38	25.38	5.38	25.38

As can be seen, the computed distortion and noise are obtained with a good approximation (+ or – one hundredth of % or dB) even with only two independent measurements.

The measurements without attenuators give an EVM of 8.23% or 21.69 dB for all values of N from 2 to 16. This value is equal to the computed distortion (to the second decimal digit in % or dB for $N = 2$ and better for higher values of N).

The residual noise (from amplifier and test bench) is computed to an EVM of 0.13% or 57.7 dB. This is near the test bench threshold in these conditions.

VI. Measurement of Echoes

Echoes will generally strongly degrade the EVM measurement. If the echoes are stationary (amplitudes and delays not varying in time) or varying slowly compared to the frame duration, and not too high, a receiver will be able to remove their effect by equalizing the frequency response of the channel.

If the echoes vary widely and rapidly, such as in a reverberation chamber, the receiver will not be able to correct the frequency response in real time or rapidly enough.

One possible method is to move the steerers slowly enough or step-by-step, if possible.

Generally, reverberation chambers provide a riche isotropic multipath (RIMP) or non-line of sight (NLOS) channel without a direct line-of-sight (LOS) component. It may be necessary to add this LOS component to the measured signal. Then the reverberation chamber, together with the LOS component at given power ratio, compose a hardware emulator of a Rician channel and a controlled environment for test of the receiver capability to equalize echoes.

VII. Measurement of Interference

In most cases, the interference is not synchronized with the signal, and it will appear as a random noise in the averaging of N sequences.

If the interference is synchronized with the signal, it will appear as distortion in the averaging of N sequences.

If it is possible to either synchronize or not synchronize the sequence on the interference, we will obtain two different measurements of distortion and random noise by applying the equations 3 and 4.

In one of them the interference effect is added to the distortion and in the other one the interference effect is added to the random noise.

This synchronization can be obtained by changing the interference frequency in laboratory or by changing slightly the frequency of the measured signal sequence rate if the interference cannot be changed. For a continuous wave (CW) interference it is sufficient that the phase of the interference is the same at the beginning of each sequence of measured signal.

Alternatively, it may be possible to measure without the interference, at least for some time.

When we have two measurements of D and R with indices s for synchronized interference and n for non-synchronized interference, we can write:

$$\begin{cases} D_s^2 = D_0^2 + I^2 & R_s^2 = R_0^2 \\ D_n^2 = D_0^2 & R_n^2 = R_0^2 + I^2 \end{cases} \tag{7}$$

So that two values of the interference can be obtained, that should be equal if the synchronization is perfect.

$$I^2 = D_s^2 - D_n^2 = R_n^2 - R_s^2 \tag{8}$$

The difference between the two values of EVM generated by interference in equation 8 would give and idea of the residual error in the synchronization.

When the interference is synchronized with N times the sequence rate but not with the sequence rate, the phase of the interference at the beginning of each sequence is uniformly distributed on the 360° circle. The average of the interference is 0 and its power appears only on the random noise value.

VIII. Conclusion

Simulation and measurement validate a method that can be used to discriminate between deterministic distortion and random noise in the measurement of EVM with application to OTA measurements.

Good results (to the second decimal digit) are obtained with a limited number of measurements, down to $N = 2$, much less than would be necessary for brute force reduction of noise by averaging a great number of measurements.

This method is under study for application to echoes and interference which are neither deterministic and synchronized with the signal nor random.

Acknowledgement

The DUT was measured by CNES Space Telecommunication System entity on the Telecommunication Engineering Laboratory test bench.

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