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Preliminary Results for EOS based EVM Measurement and Correction

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Abstract

We firstly proposed an error vector magnitude (EVM) measurement and correction method for wideband digital modulation signal using electro-optic sampling (EOS) technique. The waveform of a QPSK signal with 1Gbaud/s and 40GHz carrier is measured with EOS system, and after a series of processing like carrier-recovery, time-recovery, frequency and phase shift estimation and correction, the EVM of the signal is reduced from 17.5% to 3.6%.

1 Introduction

Applications of complex digital modulation signals increase rapidly with the insurgence of high-speed communication requirements. Since Error vector magnitude (EVM) comprehensively evaluates the magnitude error and phase error of the digital modulation signals, it is the most important performance metric for assessing the quality of digitally modulated signals.

Vector signal analyzers (VSA), digital sampling oscilloscopes and real-time digital oscilloscopes [1-3] are typical instruments used to measure EVM value of digital modulation signals, but the bandwidth, sample rate and vertical resolution of these instruments limit their EVM measurement capability.

EOS systems are used as primary standard for high-speed electrical measurements at several national metrology institutes [4-6]. Bandwidth of EOS system theoretically exceeds 500GHz, and the waveform measurement result can be traced to SI. In this paper, we demonstrate an EOS based EVM measurement and correction method.

2 Measurement system setup

The schematic of our EVM measurement system is shown in Fig.1. In contrast to typical synchronous electro-optic sampling (SEOS) technique, asynchronous electro-optic sampling (ASEOS) technique is applied in our system for larger time-window and higher measurement speed[7].

To generate wideband digital modulation signals, an arbitrary waveform generator (AWG) and an up-converter constitute a millimeter-wave vector signal generator (VSG). Maximum bandwidth and carrier frequency of the VSG are 2GHz and 40GHz, respectively. The VSG generates digital modulation signals repeatedly to reduce noise and drift in the measurement result, and repetition rate of these signals is f_{r1}=100MHz. The digital modulation signals then propagate to a coplanar waveguide (CPW) through a microwave probe. The CPW consists of a center strip conductor with two ground planes on both sides respectively. The microwave probe is attached at the left end of the CPW structure. Another probe is attached at the right end of the CPW structure and terminated by a 50Ω load at coaxial connector to minimize the signal reflections.

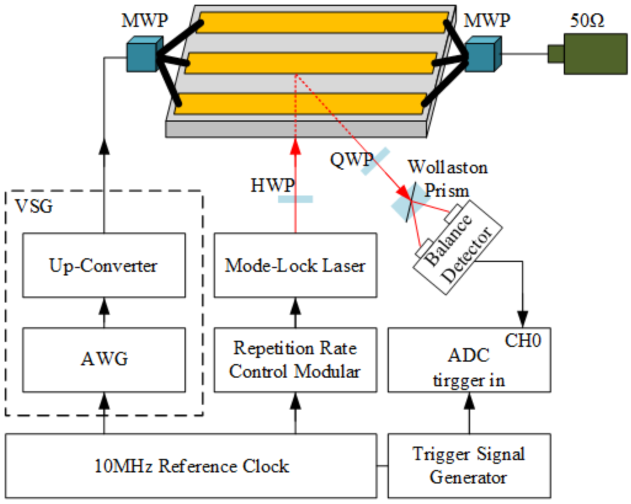

Figure 1. Schematic of EOS based EVM measurement system

An mode-lock laser, which operates at 1560nm and emits <150fs duration optical pulses, is used to probe the digital modulation signals generated by the VSG. The repetition rate of the mode-lock laser is set to f_{r2}=100.0001MHz. Then the laser beam is focused onto the center strip conductor from backside of the CPW at the center of the CPW. Since the CPW is fabricated on GaAs EO crystal, the electric field parallel to the laser beam changes the polarization of the laser beam back reflected from the center strip conductor. The changes proportional to the electric field could be detected by polarization detector consisting of quarter-wave plate (QWP), Wollaston prism and balance detector and acquired by an analog-to-digital converter (ADC).

The ADC works at external trigger mode and the trigger signal is fed with a signal generator. Frequency of the trigger signal is the repetition rate difference ($\Delta f = f_{r1} - f_{r2} =$

100Hz) between the digital modulation signals and mode-lock laser. That the VSG, laser repetition rate control modular and trigger signal generator using a common 10MHz reference allow us to accurately characterize the waveform of the digital modulation signals. Due to the repetition tunable ability of mode-lock laser, the time-window of measurement is limited to 10ns, so we use segmental measurement and waveform concatenation approach to achieve the entire waveform measurement.

3 EVM measurement

A QPSK signal with 40GHz carrier frequency, 1Gbaud/s symbol rate is generated here. We first generate a pseudo-random binary sequence (PRBS) and then transfer it to QPSK format. After up-sampling and root raised cosine filter (with a roll-off factor of 0.35), the signal is modulated with the IF carrier whose frequency is 4GHz. Then we upload the IF signals to the AWG and frequency convert the IF signals to 40GHz RF signals with the up-converter. The RF signals are measured using our ASEOS system. Fig.2 shows a certain epoch of QPSK signal waveform measured with ASEOS system comparing with ideal waveform.

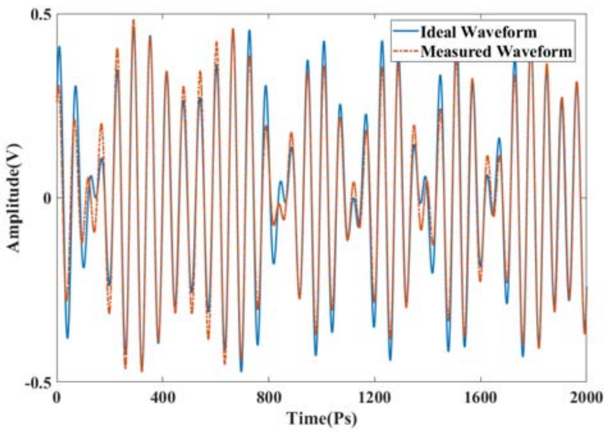

Figure 2. Waveform measured by the ASEOS system (red) comparing with ideal waveform (blue) . comparison figure of waveform measured with ASEOS system and ideal waveform

After carrier recovery, matched filtering, time recovery, frequency shift estimation, and phase rotation algorithms, the EVM of the received symbols is 17.5%, as shown in Fig.3.

The EVM of the signal measured by the ASEOS system is not good enough, because nonlinearity in the AWG and up-converter introduces magnitude and phase distortion into the signals at the output. To correct this nonlinearity, we use a predistortion step to modify the signal that is uploaded to the AWG to compensate for the nonlinearity of the source [8-10]. The step of the method is illustrated below:

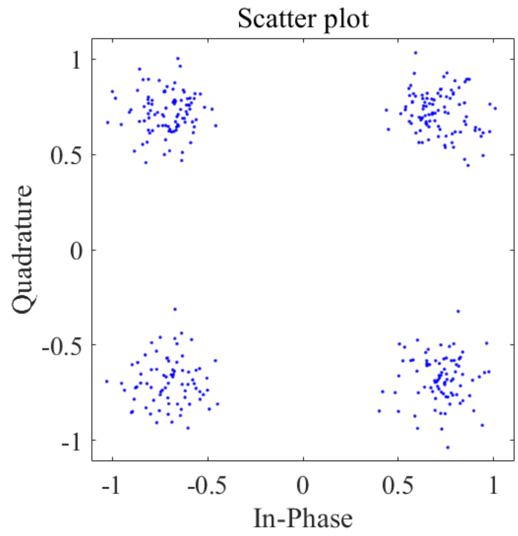

Figure 3. Scatterplot of the symbols directly measured by the ASEOS system.

1) Transfer the signal that is uploaded to the AWG and the signal measured by the ASEOS system to frequency domain using digital Fourier transform (DFT).

2) The nonlinearity of the AWG and up-converter can be estimated by the following equation:

$$H_{est\_1}(f)=Y_1(f)/X_1(f) \quad (1)$$

Where $Y_1(f)$ is the frequency-domain representation of the signal measured by the ASEOS system and $X_1(f)$ is the frequency-domain representation of the signal uploaded to the AWG.

3) The frequency-domain representation of the corrected signal uploaded to the AWG can be obtained using the equation below:

$$X_2(f)=X_1(f)/\ H_{est\_1}(f) = X_1^2(f)/\ Y_1(f) \quad (2)$$

4) Then we upload time-domain representation of $X_2(f)$ to the AWG, and measure the output signal $y_2(t)$ of the AWG using ASEOS system to obtain the frequency-domain representation $Y_2(f)$; the remaining linearity can be estimated by the equation below:

$$H_{est\_2}(f)=Y_2(f)/X_2(f) = Y_2(f)\ Y_1(f)/X_1^2(f) \quad (3)$$

5) The frequency-domain representation of the twice corrected signal uploaded to the AWG can be obtained using the equation below:

$$X_3(f)=X_1(f)/\ H_{est\_2}(f) = X_1^3(f)/\ Y_2(f)\ Y_1(f) \quad (4)$$

6) After five or six iterations, the EVM of the measured signal reduces to 3.7%, as shown in Fig.4.

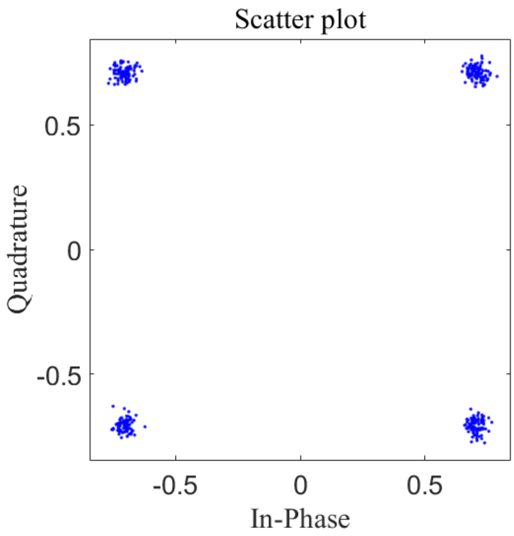

Figure 4. Scatterplot of the symbols after nonlinearity correction.

4 Conclusions

We have demonstrated a preliminary EVM measurement and correction result for a wideband digital modulation signals using electro-optic sampling (EOS) technique in this paper. Due to the restriction of experiment instrument and time, the result presented here does not involved higher frequency, larger bandwidth, and more complex modulation format. Furthermore, modification of measurement reference plane is not accomplished in this work. We will finish these cases in our future work.

5 References

1. Remley, Kate & Williams, Dylan & Hale, Paul & Wang, Chih-Ming Jack & Jargon, Jeffrey & Park, Youngcheol. (2015). Millimeter-Wave Modulated-Signal and Error-Vector-Magnitude Measurement With Uncertainty. IEEE Transactions on Microwave Theory and Techniques. 63. 1-12. 10.1109/TMTT.2015.2416180.

2. Humphreys, DAVID & Miall, James. (2013). Traceable Measurement of Source and Receiver EVM Using a Real-Time Oscilloscope. IEEE Transactions on Instrumentation and Measurement. 62. 1413. 10.1109/TIM.2013.2238458.

3. Humphreys, DAVID & Miall, James. (2013). Traceable Measurement of Source and Receiver EVM Using a Real-Time Oscilloscope. IEEE Transactions on Instrumentation and Measurement. 62. 1413. 10.1109/TIM.2013.2238458.

4. Williams, Dylan & Hale, Paul & Clement, Tracy & Wang, Chih-Ming Jack. (2004). Uncertainty of the NIST Electrooptic Sampling System. NIST Tech Note. 1535.

5. Fuser, Heiko & Bieler, Mark. (2011). Strategy for laser-based waveform metrology for frequencies ranging from below 1 GHz to 1 THz.

6. Lee, Ingeun & Kim, Kwang & Choe, Mun Seok & Lee, Dong & Choi, Eunmi. (2014). Precise measurement of field patterns from a TE02 mode converter using the electro-optic probe scanning system. 469-470. 10.1109/IVEC.2014.6857693.

7. Gebs, Raphael & Klatt, Gregor & Janke, Christof & Dekorsy, Thomas & Bartels, Albrecht. (2010). High-speed asynchronous optical sampling with sub-50fs time resolution. First publ. in: Optics Express 18 (2010), 6, pp. 5974-5983. 18. 10.1364/OE.18.005974.

8. C. Krall, C. Vogel, and K. Witrisal, "Time-interleaved digital-to analog converters for UWB signal generation," IEEE Int. Conf. Ultra-Wideband, Singapore, pp. 24-26, Sept. 2007.

9. J. Ortega, W.C. Rheinboldt, "Iterative Solution of Nonlinear Equations in Several Variables", Academic Press, New York, 1970.

10. D. Rabijns, W. Van Moer, G. Vandersteen,"Using multisines to measure state-of-the-art analog-to-digital converters," IEEE Trans. Instrum. Meas., vol. 56, no. 3, June 2007, pp. 1012–1017.