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Personal Area Network용 무선 송신부의 EVM을 만족하기 위한 I/Q mismatch의 영향 분석

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An Analysis of the effect of I/Q mismatch on EVM in the transmitter of PAN

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Abstract -The modulation quality of the RF transmitter in a wireless communication system usually affects system performance and it mostly depends on both a nonlinearity and a distortion, from the intermodulation products and the I/Q mismatch such as I/Q amplitude error and a local phase error, respectively. This paper focused on how much the error vector magnitude(EVM) which describes the modulation accuracy changes according to the variation of the I/Q mismatch components at I/Q modulator. For this work, the equation for the EVM including the I/Q mismatch components can be induced and calculated in accordance with the variation of the I/Q mismatch components. Consequently, the effect of I/Q mismatch components on the EVM, which is required in the transmitter specification of Personal Area Network, can be clearly analyzed.
Keywords: EVM, I/Q mismatch, RF transmitter

1. Introduction

Recently, the increased demand for higher data rate wireless communications requires the system to adopt high modulation orders over M-PSK. Therefore, the importance of the modulation quality in the I/Q modulator has been emphasized more than before[1]. Since the modulation signal can be usually degraded by both intermodulation products and I/Q mismatch such as I/Q amplitude error and local phase error, the effects of I/Q mismatch components on the I/Q modulator and the consequent EVM performance need to be analyzed. Though the Volterra Series is well known for the efficient nonlinear distortion analysis[2], it is very complex and difficult to apply to arbitrary circuits. The proposed model equations using power series make it easy to precisely calculate the powers of a variety of signals at the I/Q modulator output. The transmitted signals from a baseband are assumed to be ideal inphase and quadrature symbols and are usually distorted through the I/Q modulator. This paper also assumes that the receiver demodulates the transmitted signals with the same carrier frequency as the transmitter to isolate frequency offset effect. In this work, the nonlinear models for a mixer, the I/Q modulator and the EVM estimation are expressed in Section 2. And then, the simulation results of the effect of I/Q mismatch components on EVM performance are presented in Section 3. Finally, the conclusion is represented in Section 4.

2. The Analysis Model of the I/Q modulator

2.1 A Mixer Model

The nonlinear mixer model to estimate the powers of a variety of output signals is as follows. For simplicity, input signal x(t) and output signal y(t) are assumed to be[2]

$$x(t) = Acos\omega_1 t + Acos\omega_2 t \qquad (1)$$

$$y(t) \approx \alpha_1 x(t) + \alpha_2 x(t)^2 + \alpha_3 x(t)^3 \qquad (2)$$

In (2), the higher order terms are excluded because they are not a matter of concern in this analysis. From (1) and (2), the fundamental and intermodulation products are obtained as follows.

$$\omega_1, \omega_2 : \left(\alpha_1 A + \frac{9}{4}\alpha_3 A^3\right) cos\omega_{1,2} t \qquad (3)$$

$$\omega_1 \pm \omega_2 : (\alpha_2 A^2) cos\left((\omega_1 \pm \omega_2)t\right) \qquad (4)$$

$$2\omega_1 \pm \omega_2 : \left(\frac{3}{4}\alpha_3 A^3\right) cos\left((2\omega_1 \pm \omega_2)t\right) \qquad (5)$$

In this paper, the key point is to derive the relations among the coefficients of α_1, α_2 and α_3. From a basic definition on IIP_3[3].

$$\alpha_1 A + \frac{9}{4}\alpha_3 A^3 = \frac{3}{4}\alpha_3 A^3 \qquad (6)$$

Solving the equation for variable *A, and* A_{IIP3} becomes

$$A_{IIP3} = \sqrt{-\frac{2\alpha_1}{3\alpha_3}} \qquad (7)$$

Since OIP_3 is equal to be IIP_3 plus Gain, using (7), the relation between α_1 and α_3 is obtained as follows.

$$\alpha_3 = -\frac{\alpha_1}{150\times 10^{\frac{OIP3-Gain-30}{10}}} \qquad (8)$$

From a basic definition on IIP_2[3].

$$\alpha_1 A + \frac{9}{4}\alpha_3 A^3 = \alpha_2 A^2 \qquad (9)$$

Since OIP_2 is equal to be IIP_2 plus Gain, inserting (8) into (9), the relation between α_1 and α_2 is obtained as well.

$$\alpha_1 = \frac{8c}{16-9mc^2}\alpha_2 \qquad (10)$$

$$\left(m = \frac{1}{150\times 10^{\frac{OIP3-Gain-30}{10}}}, c = \sqrt{400\times 10^{\frac{OIP2-Gain-30}{10}}}\right)$$

From the basic function of a mixer on conversion gain and (4), the equation about α_2 leads to.

$$\alpha_2 = \frac{1}{10^{log_{10}A}} \times \sqrt{10^{\frac{Gain}{10}}} \qquad (11)$$

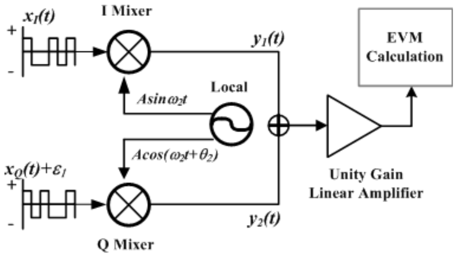

Fig 2. I/Q modulator with random variable inputs

2.2 A I/Q Modulator Model for the EVM

Generally, the $x_I(t)$ and $x_Q(t)$ are defined as time-variant instant symbols which are described as $\sqrt{2}cos\frac{k(t)}{4}\pi$ and $\sqrt{2}sin\frac{k(t)}{4}\pi$, (k(t)=1,3,5,7), respectively. Using a similarity to section 2.1, the model equations of the I/Q modulator as shown in Fig 2 become.

$$\begin{aligned} y_1(t) &= \alpha_1(x_I(t)+Asin\omega_2 t)+\alpha_2(x_I(t)+Asin\omega_2 t)^2 \\ &\quad +\alpha_3(x_I(t)+Asin\omega_2 t)^3 \\ y_2(t) &= \alpha_1((x_Q(t)+\varepsilon_1)+Acos(\omega_2 t+\theta_2)) \\ &\quad +\alpha_2((x_Q(t)+\varepsilon_1)+Acos(\omega_2 t+\theta_2))^2 \\ &\quad +\alpha_3((x_Q(t)+\varepsilon_1)+Acos(\omega_2 t+\theta_2))^3 \end{aligned} \tag{12}$$

Only the meaningful products, which have local carrier frequency, are obtained at the upper and lower arms, respectively, and a total of signals of interest lead to.

$$\begin{aligned} &\{\alpha_2 2Ax_I(t)+\alpha_3 3Ax_I^2(t)\}sin\omega_2 t + \\ &\{\alpha_2 2A(x_Q(t)+\varepsilon_1)+\alpha_3 3A(x_Q(t)+\varepsilon_1)^2\}cos(\omega_2 t+\theta_2) \end{aligned} \tag{13}$$

Assuming that the modulated signal is demodulated by the same local frequency and filtered through a low pass filter to obtain I and Q signals at the receiver, and then recovered by baseband algorithms having functions such as symbol time recovery, frequency offset compensation and equalizer, the received signals become

$$\begin{aligned} &r_I(t)=(m-nsin\theta_2),\ r_Q(t)=ncos\theta_2 \\ &(m=\{\alpha_2 2Ax_I(t)+\alpha_3 3Ax_I^2(t)\} \\ &\quad n=\{\alpha_2 2A(x_Q(t)+\varepsilon_1)+\alpha_3 3A(x_Q(t)+\varepsilon_1)^2\}) \end{aligned} \tag{14}$$

Before calculating EVM[4], the important observation is that the received r_I and r_Q signal defined in (14) should be normalized with some factor to represent ideal signal transmission without distortion. Therefore, the measured I and Q signals should adopt the normalization factor of $\alpha_2 2A$ corresponding to the ideal transmission case, which can be inferred from (13), the measured signals become

$$\widetilde{x_I(t)}=\frac{r_I(t)}{\alpha_2 2A},\ \widetilde{x_Q(t)}=\frac{r_Q(t)}{\alpha_2 2A} \tag{15}$$

Consequently, the equation for EVM including the nonlinearity and imperfection features of the I/Q modulator can be expressed as follows.

$$\mathrm{EVM}=\frac{\sqrt{(\widetilde{x_I(t)}-x_I(t))^2+(\widetilde{x_Q(t)}-x_Q(t))^2}}{\sqrt{x_I(t)^2+x_Q(t)^2}} \tag{16}$$

3. Simulation Results

The simulations were performed using derived equations. The effects of the I/Q mismatch on EVM are simulated under assumption that input sinusoidal signals to the I/Q modulator have the peak values of ±0.5V, OIP_2 of 60dBm, OIP_3 of 40dBm and conversion gain of 10 dB, satisfying the condition that the P_1dB is theoretically under 9.6 dB to IIP_3 [3], for the I/Q modulator to operate below a saturation power. In addition, I and Q random variables as much as 1000 symbols, which has rectangular pulses with a height of 0.5V in the QPSK modulation as shown in Fig. 2, are used for this simulation. In addition, the transmitted signals from a baseband are assumed to be ideal inphase and quadrature symbols and are usually distorted through the I/Q modulator. This paper also assumes that the receiver demodulates the transmitted signals with the same carrier frequency as the transmitter to isolate frequency offset effect.

Assuming a maximum 10% of I/Q gain error to input I/Q signals and 3° of local phase error, the curves relating the I/Q amplitude mismatch to EVM in Fig 3 and 4 represent that the degradation of EVM increases as mismatch variation grow. Moreover, the curves in Fig 5 and 6 shows that the performance of EVM is more degraded than the case of Fig 3 and 4, when the I/Q modulator has both I/Q amplitude mismatch and local phase mismatch at once. While it is considered that the EVM requirements in WPAN transmitter is less than 25% and the values of mismatch components in the simulation are relatively large, it is shown that the quantity of I/Q mismatch components suggested above are good enough to satisfy the EVM specification.

4. Conclusion

In summary, it was key point to obtain the power series coefficients of α_1, α_2 and α_3 represented with the system parameters of OIP_2, OIP_3 and conversion gain for modeling the I/Q modulator. As a result of that, analytical expression for a variety of output signal at the I/Q modulator are derived. Moreover, the equation for EVM including the I/Q mismatch components is also induced. Consequently, it is clearly shown that the EVM value increases according to the increment of the I/Q mismatch components such as input amplitude and local phase factors, meaning that the more EVM[%] grows, the worse system performance.

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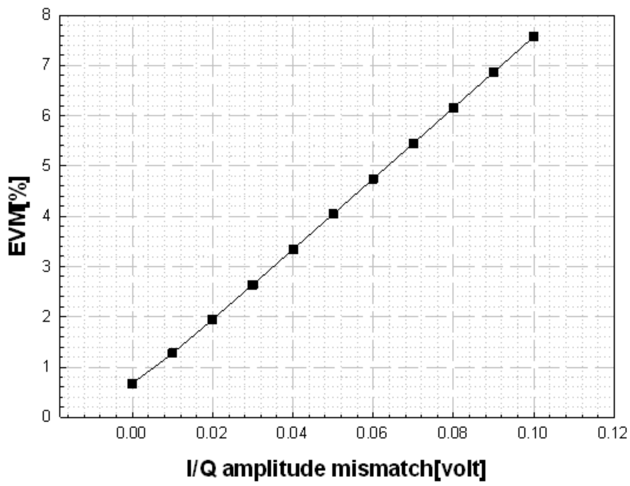

Fig 3. EVM vs I/Q amplitude mismatch with $\Theta_2 = 0°$

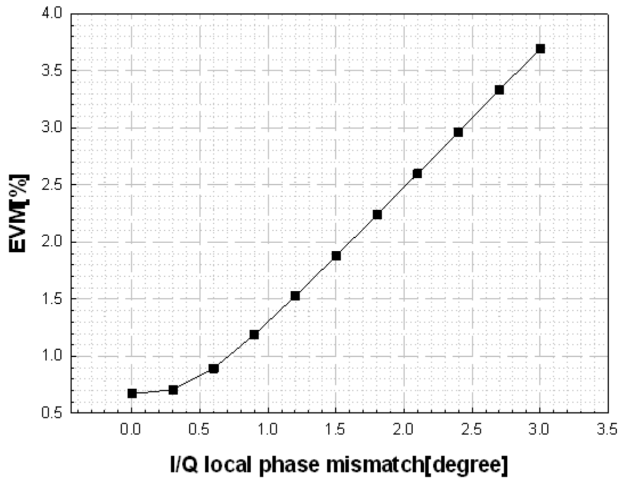

Fig 4. EVM vs I/Q local phase mismatch with $\varepsilon_1 = 0$

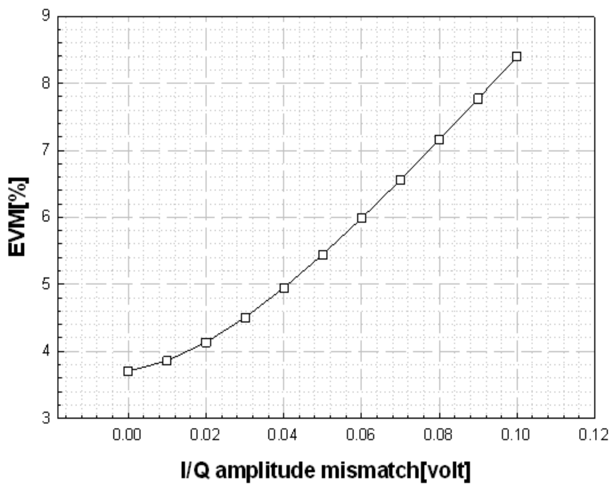

Fig 5. EVM vs I/Q amplitude mismatch with $\Theta_2 = 3°$

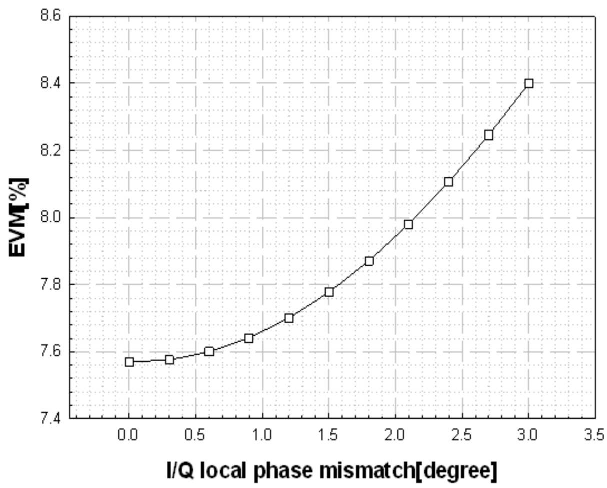

Fig 6. EVM vs I/Q local phase mismatch with $\varepsilon_1 = 0.1$