EEE317–Modeling and Simulation

Project Report

IQ Imbalance Compensation by Using a Blind Algorithm

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1. Abstract

Amplitude and phase imbalances between the in-phase and quadrature components of quadrature oscillators seriously degrade the accuracy of signal modulations and demodulations [1]. In this report, we firstly show how IQ imbalance affects a signal in different modulations. Then we introduce a blind compensation algorithm to minimize the imbalance. Lastly this algorithm is tested with signals infused with IQ imbalance and white noise. The blind compensation algorithm studied to be effective against amplitude and phase imparities.

2. Introduction

Local oscillators in receiver structures are commonly used to move RF signals to baseband frequency in order to perform digital demodulation. This is achieved by the use of quadrative signals, where the oscillator produces two signals, In phase signal(I) and quadrative signal(Q)[2]. The signal produced by the local oscillator commonly defined as $e^{j\omega_c t}$ and the real and imaginary parts of the signals are labeled as I and Q.

$$x_{LO}(t) = e^{j\omega_c t} = \cos(\omega_c t) + jsin(\omega_c t) = x_i(t) + jx_q(t) \quad (2.1)$$

$$x_i(t) = \cos(\omega_c t) \quad (2.2)$$

$$x_q(t) = \sin(\omega_c t) \quad (2.3)$$

2.1 PSK Modulation

Phase shift keying or PSK is a method to modulate digital signals into analog carriers. The modulation is achieved by changing the phase shift between the I and Q channels [3]. The values of the I and Q signals are placed on a constellation diagram for a selected phase difference. In the case of QPSK, the modulation stars at 45° and each carrier phase is selected 90° apart.

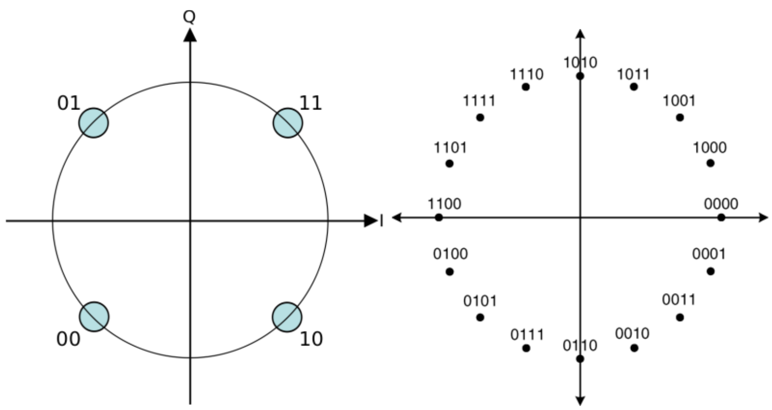

Figure 1 (Constellation Diagram of QPSK and 16PSK Modulation)

2.2 QAM

Quadrature amplitude modulation (QAM) is a type of digital modulation where I and Q channels of the carrier signal is added to find the symbol. The I and Q channels are out of phase with each other by 90°. At the receiver, the two signals can be demodulated because they are orthogonal to each other.[4]

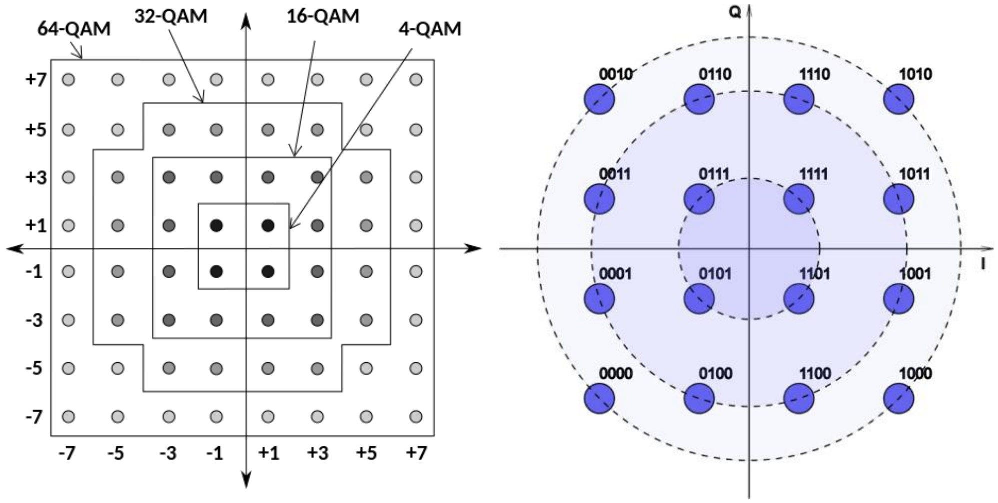

Figure 2 (Constellation Diagram of QAM modulations)

3.IQ Imbalance

An ideal quadrative oscillator produces two signals with same amplitude and with 90° phase difference. In real circuits however, this can never be fully achieved. There are two factors that can cause IQ imbalance.

- Amplitude Imbalance: If the amplifier gain of I and Q signals are not equal, the amplitude imbalance $\boldsymbol{\varepsilon}$ can occur.
- Phase Imbalance: If the phase difference between I and Q signals is not exactly 90°, the phase imbalance $\boldsymbol{\Delta\varphi}$ can occur.

If both amplitude and phase imbalances affect the quadrative oscillator, Eq. 2.1 becomes:

$$x(t) = \cos(\omega_c t) + (1+\varepsilon)jsin(\omega_c t + \Delta\varphi) = x_i(t) + jx_q(t) \quad (3.1)$$

$$x_I(t) = \cos(\omega_c t) \quad (3.2)$$

$$x_Q(t) = (1+\varepsilon)sin(\omega_c t + \Delta\varphi) \quad (3.3)$$

IQ imbalance affects PSK and QAM modulations in the following way:

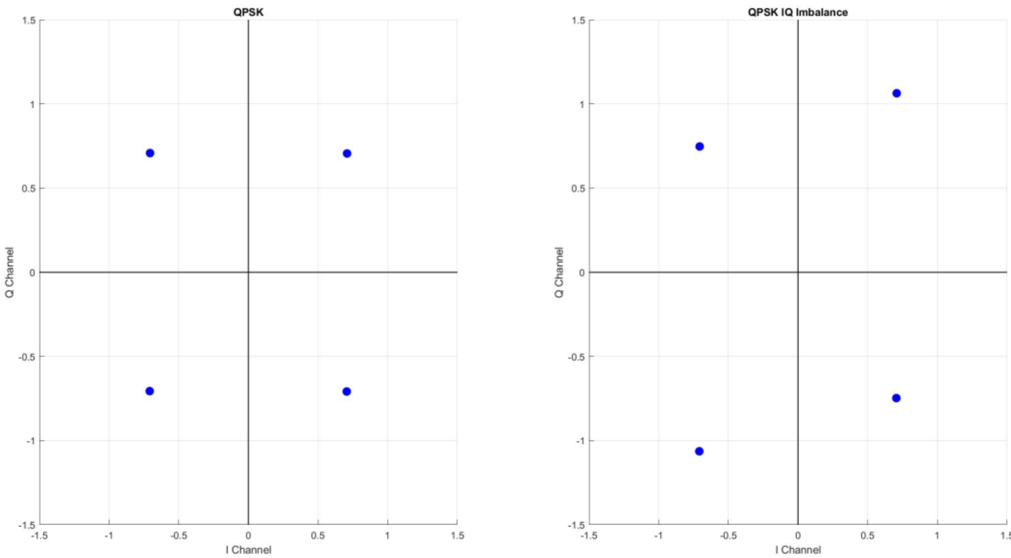

Figure 3 (Effect of IQ Imbalance on QPSK Modulated Signal)

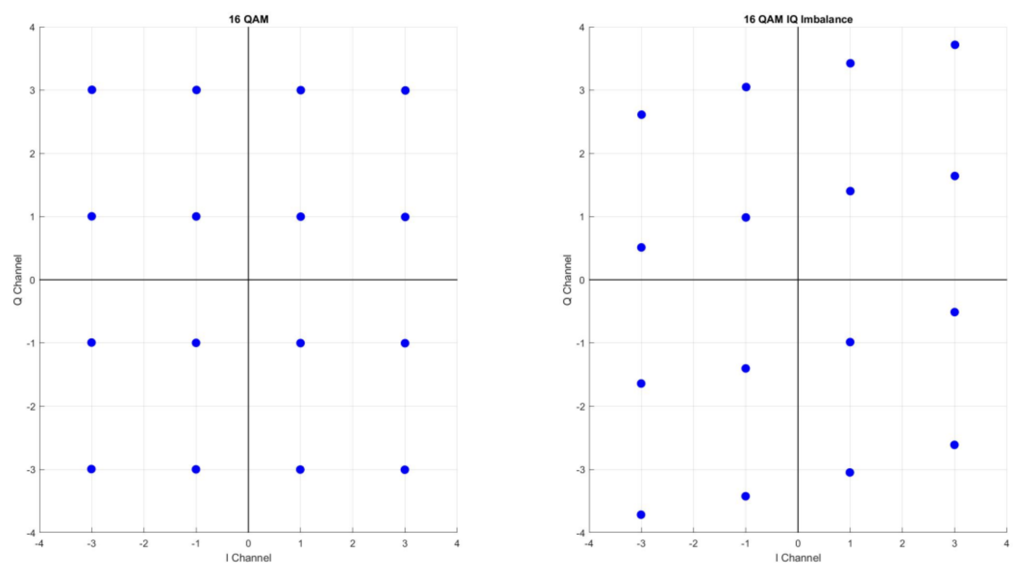

Figure 4 (Effect of IQ Imbalance on 16QAM Signal)

4.IQ Imbalance Compensation

A blind compensation algorithm is used to minimize the effect of IQ imbalance on the modulations. The imbalanced signal shows an elliptical constellation diagram rather than a circular one. To correct the imbalance, I and Q channels can be amplified by some weights to correct the diagram to a circular one. The compensation algorithm estimates three parameters α_1, α_2 and α_3. These three parameters are used to find weights c_1 and c_2 which will be used as coefficients of the I and Q signals [5].

$$\alpha_1 = -1 * mean(sign(x_I(t))x_Q(t)) \quad (4.1)$$

$$\alpha_2 = mean(|x_I(t)|) \quad (4.2)$$

$$\alpha_3 = mean(|x_Q(t)|) \quad (4.3)$$

Weights c_1 and c_2 are calculated by using these parameters.

$$c_1 = \frac{\alpha_1}{\alpha_2} \quad (4.4)$$

$$c_2 = \sqrt{((\alpha_3{}^2 - \alpha_1{}^2)/\alpha_2{}^2)} \quad (4.5)$$

After finding the weights c_1 and c_2, IQ compensated wave ***w(t)*** calculated as following:

$$w_I(t) = c_2 * x_I(t) \quad (4.6)$$

$$w_Q(t) = c_1 * x_I(t) + x_Q(t) \quad (4.7)$$

$$w(t) = [w_I(t) + j\, w_Q(t)]/c_2 \quad (4.8)$$

Compensated signal increases the accuracy of the modulation in PSK and QAM modulations. Adding AWGN to the signal can show the performance of the algorithm clearer. In the following examples IQ imbalance is chosen as ε=0.3 and $\Delta\varphi$=5°.

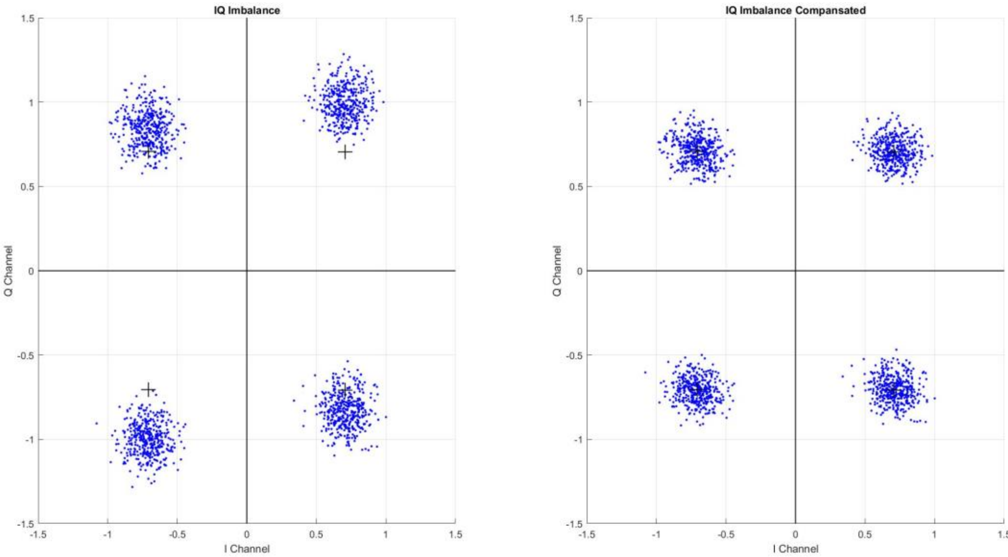

Figure 5 (IQ Imbalance Compensation In QPSK)

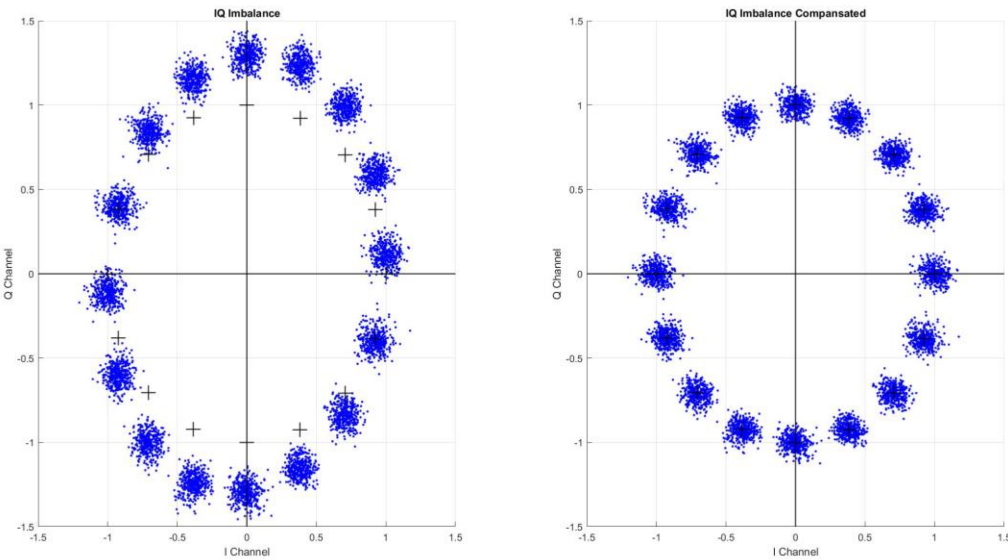

Figure 6 (IQ Imbalance Compensation In 16PSK)

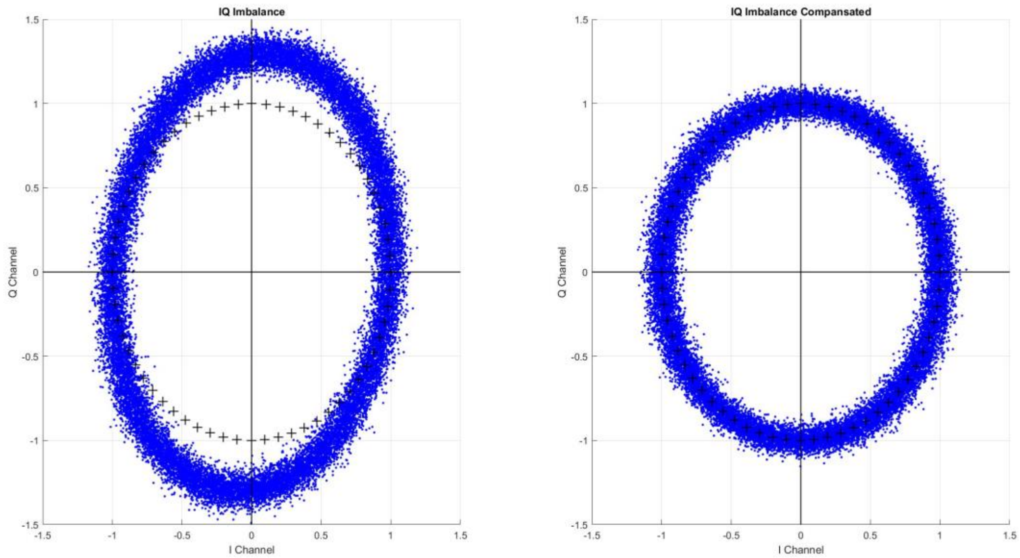

Figure 7 (IQ Imbalance Compensation In 64PSK)

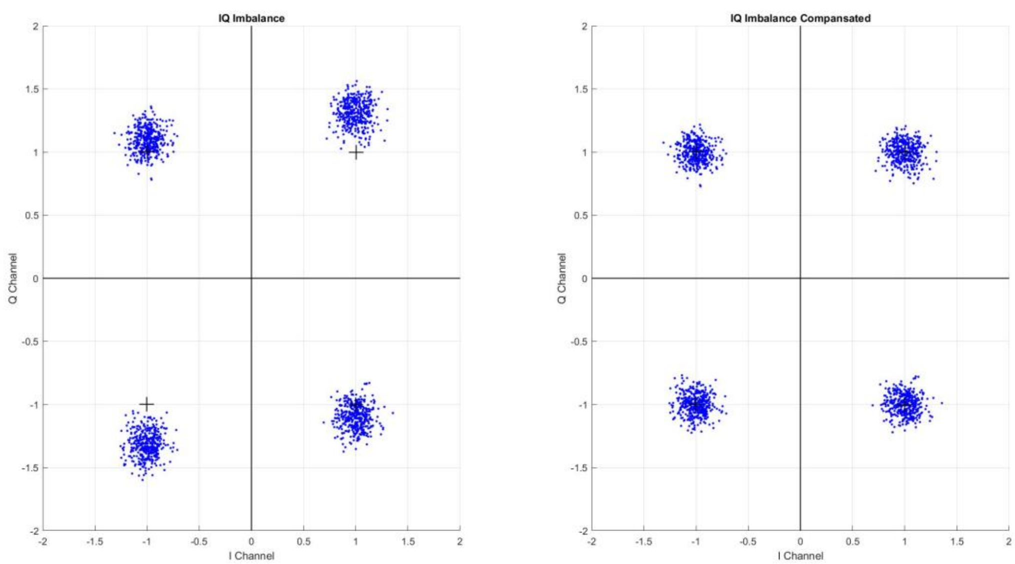

Figure 8 (IQ Compensation In 4QAM)

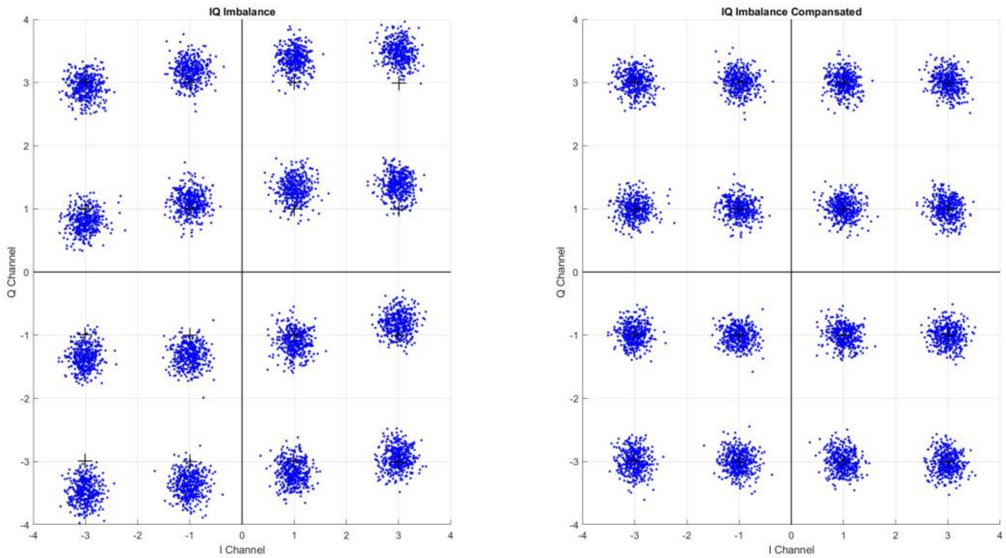

Figure 9 (IQ Imbalance Compensation In 16QAM)

5.Performance Evaluation

To measure the accuracy of the algorithm, the symbol error rate (SER) of the signal is measured under AWGN channels with different signal to noise ratios (SNR). A symbol is considered an error when it appears in an undesired point in the constellation diagram, where it can be interpreted as other symbols. Different methods are used in each of the modulations to find the error symbols.

In PSK modulation, amplitude of the signal does not matter since the zones for each symbol is divided like cake slices where only the phase angle of the signal is needed to determine the symbol. To find error symbols, two straight lines are driven from the origin and any point that are not between these two lines are considered as an error. The angle between these two lines changes with the modulation.

$$\theta_{line} = \frac{360°}{Number\ of\ Symbols} \quad (5.1)$$

The phase angle of the lines is $\pm\theta_{line}/2$ apart from the reference symbol.

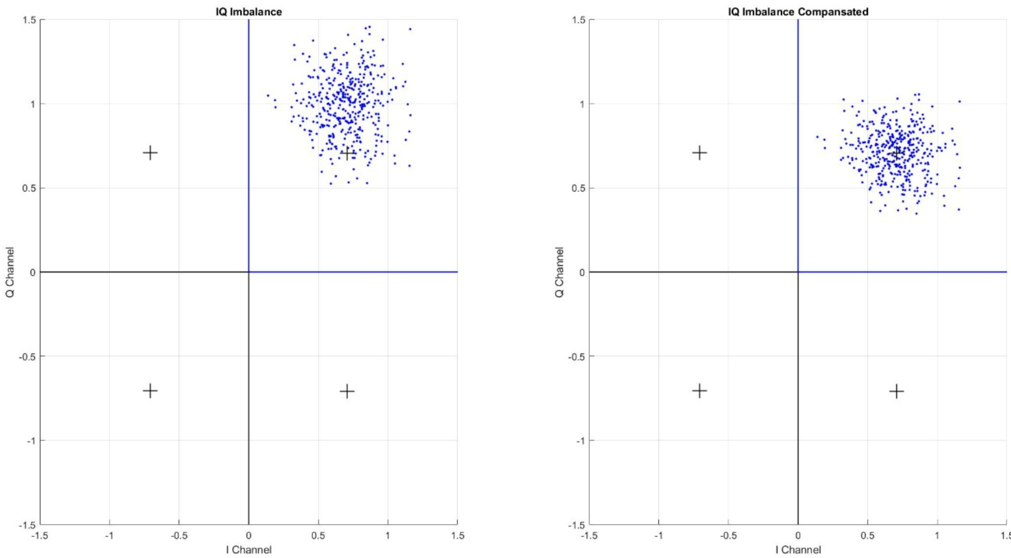

Figure 10 (Determining SER In QPSK)

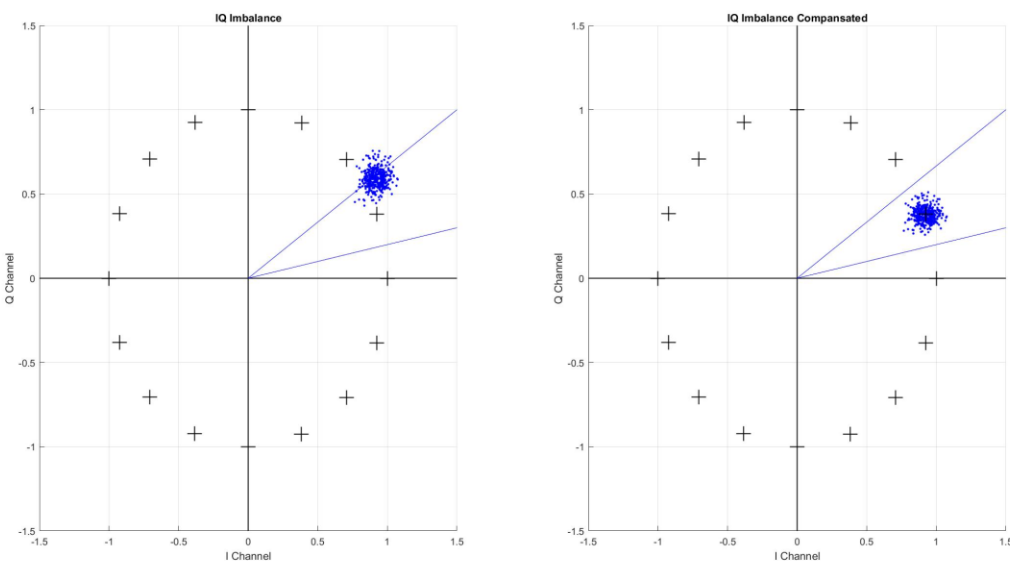

Figure 11(Determining SER In 16PSK)

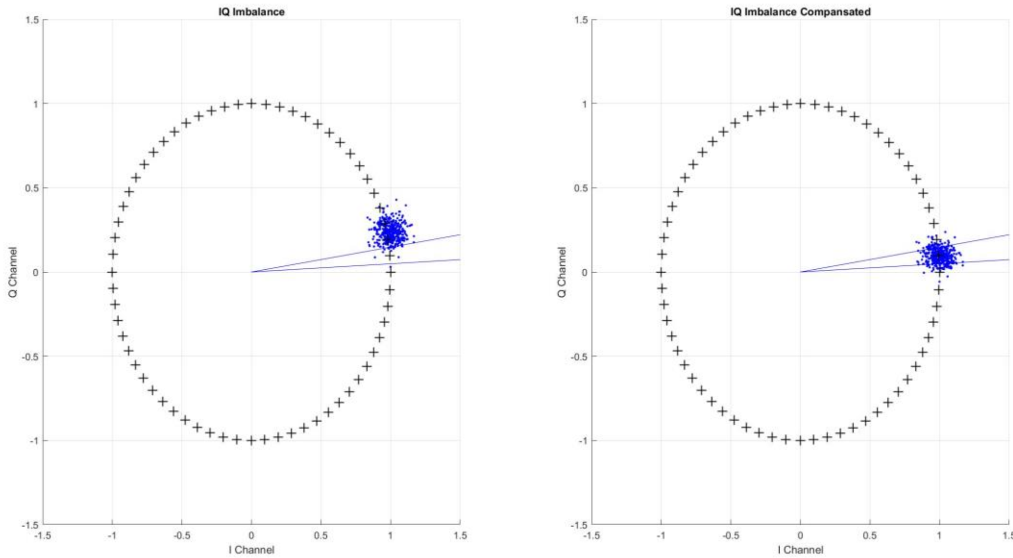

Figure 12 (Determining SER In 64PSK)

In QAM, both amplitude and phase information are needed to determine the symbol. The acceptable positions for our signal can be modeled as a circle centered around the intended symbol with the radius of the amplitude of the signal. Any point outside of this circle would be considered as an error.

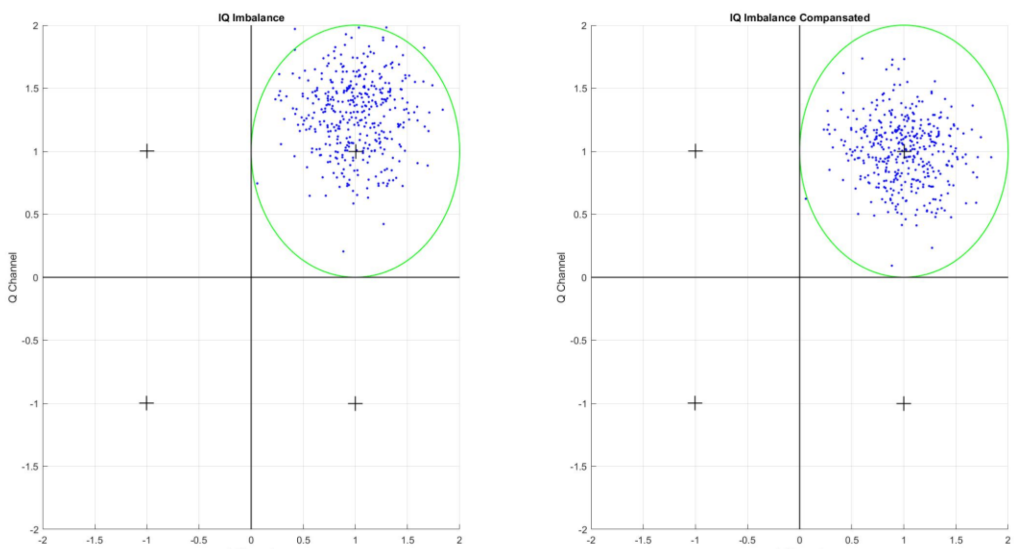

Figure 13(Determining SER In 4QAM)

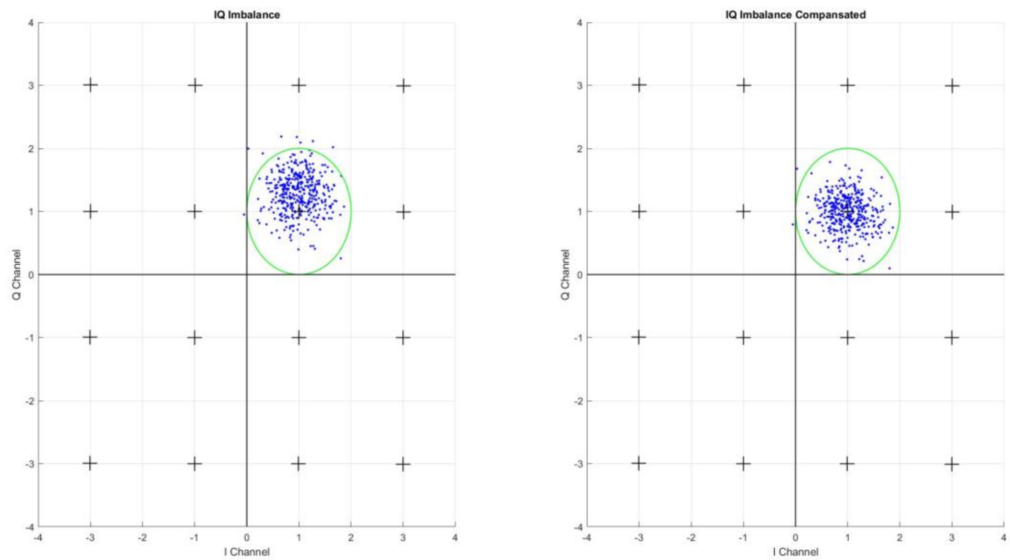

Figure 14(Determining SER In 16QAM)

In both cases, ten thousand signals in AWGN channel are compensated with the blind algorithm and their SER are compared. The results show that, the blind algorithm decreases the errors during the modulation significantly, especially in QAM.

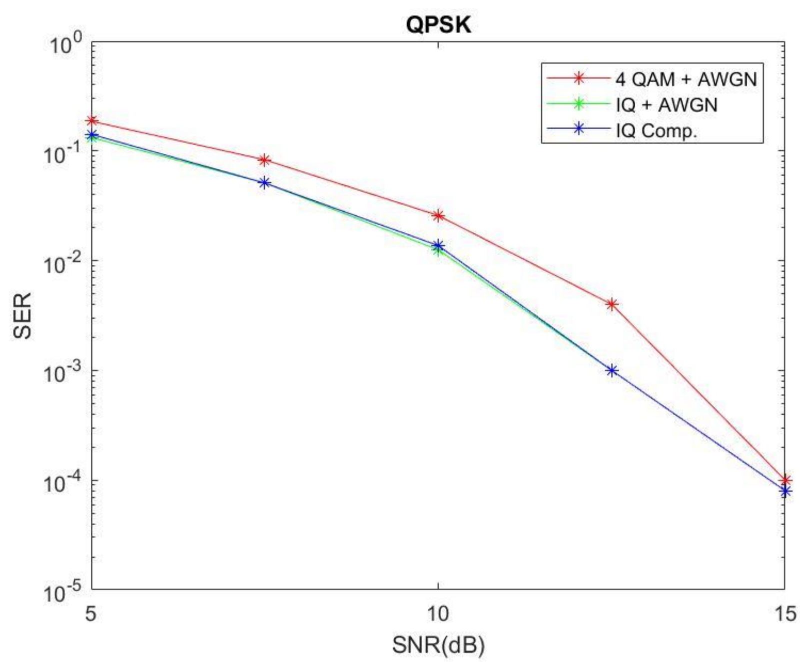

Figure 15 (SER/SNR In QPSK)

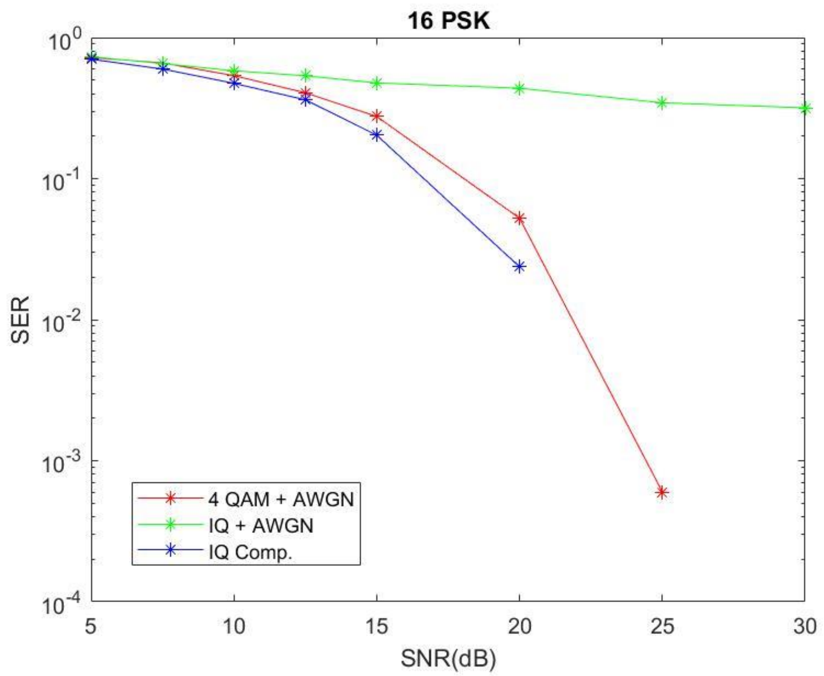

Figure 16(SER/SNR In 16PSK)

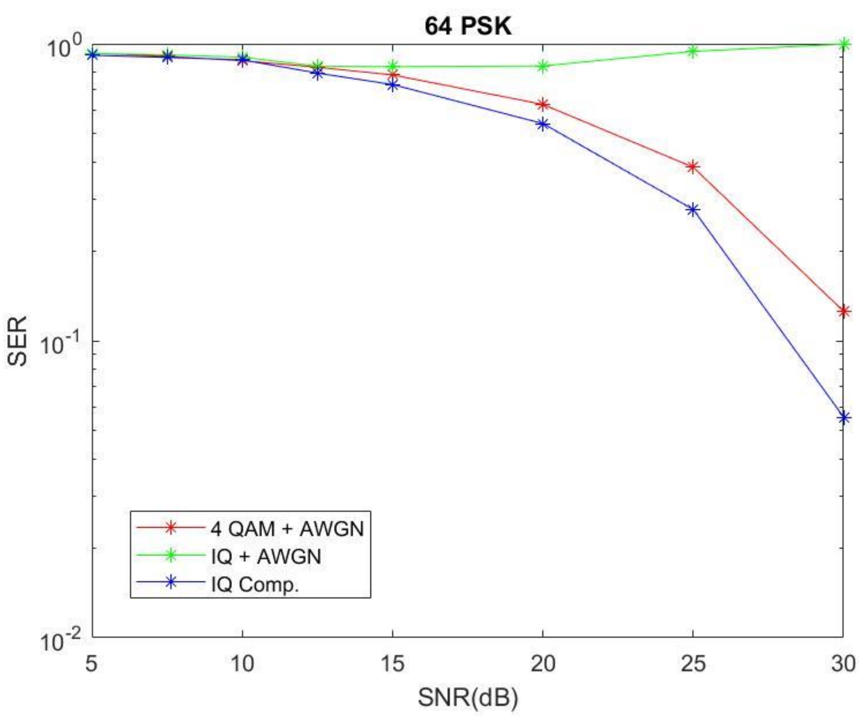

Figure 17(SER/SNR In 64PSK)

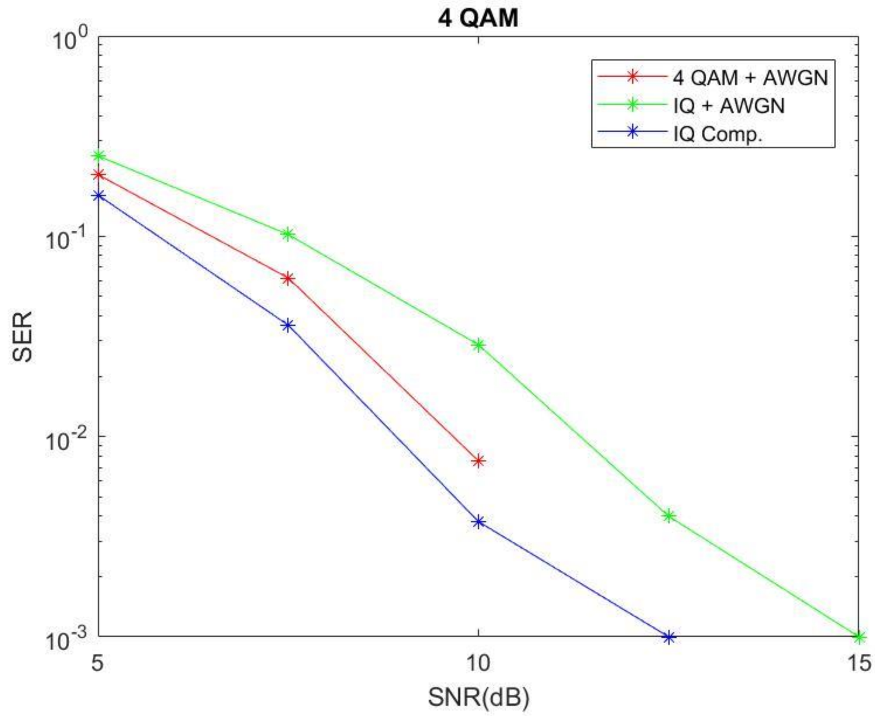

Figure 18 (SER/SNR In 4QAM)

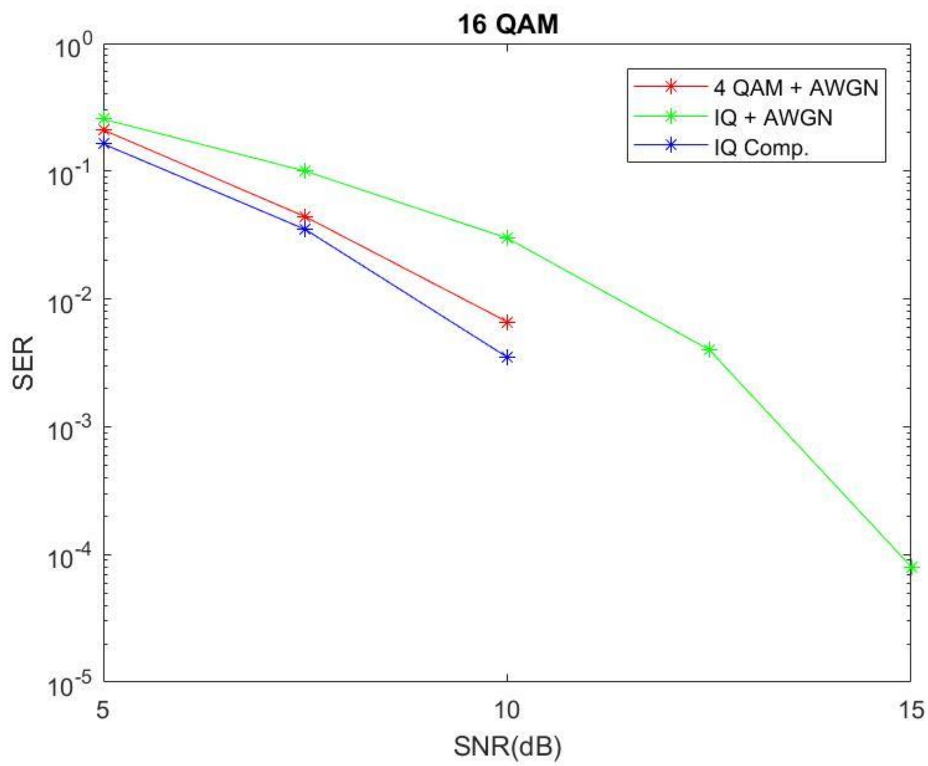

Figure 19 (SER/SNR In 16QAM)

6.Conclusion

IQ imbalance in communication systems results in symbol errors and decreases the efficiency of the transmitter-receiver systems. This report described a blind compensation algorithm where the imbalanced signal is modulated with calculated weights to compensate for the IQ imbalance. SER values of both QAM and SPK modulations with IQ imbalance improved significantly after corrected by the algorithm. By using the previously described algorithm, the IQ imbalance can be reduced with minimal effort, rather than designing more sensitive quadrative oscillators. Since the method is independent of the oscillators, it can be used in any system with quadrature modulations.

7.References

[1] L. Anttila, M. Valkama, M. Renfors ." *Blind Compensation Of Frequency-Selective I/Q Imbalances In Quadrature Radio Receivers: Circularity-Based Approach",2007*

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[5] S. Al-Majmaie "*IQ Imbalance Compensation: Blind versus Pilot-Based Algorithms, using Different IQ Imbalance Models*",2015