MITIGATION OF INTERFERENCE IN COLOCATED WIRELESS SYSTEMS USING BASEBAND QPSK POST DISTORTION CANCELLATION

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ABSTRACT

Intermodulation interference occurs when transmitters are co-located as well as in nonlinearity of the signal processing during modulation. This distortion in nonlinear systems are not needed in radio signal processing because they generate unwanted spurious emissions which occupy the spectrum of the desired signal frequency as sidebands thereby distorting or masking the desired signal. A post distortion cancellation technique is proposed, using quadrature phase shift keying (QPSK) baseband receiver that is capable of cancelling the intermodulation interference. In the proposed model, an estimated copy of the distortion is coupled to a QPSK baseband receiver to be out of phase to each other to cancel out the intermodulation interference using structured system analysis and design methodology. This proposed technique was carried out using MATLAB/SIMULINK software where an intermodulation distortion is generated using two local co-located transmitters that have hit the desired signal and recover the transmitted message successfully. This technique is capable of cancelling intermodulation interference that occurs in co-located setting and is able to recover the transmitted signal that gets to the receiver, achieving a low bit error rate (BER) of 0.00064, high gain of 40dB in signal-to-noise ratio (SNR) and

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1.0 INTRODUCTION

Intermodulation (IM) interference is the interference or distortion that occurs in non-linear systems as a result of amplitude modulation of signals comprising of two or more different frequencies. This occurs as a result of behaviour of the non-linearity of signal processing involved in modulation. Intermodulation between two frequency components is capable of producing further frequency components that are sum and difference of two original frequencies and several frequencies of the sum and difference of the frequency components. Intermodulation is not needed in radio or audio signal processing, since it generates unwanted spurious emissions which can be in the form of sidebands. For radio transmissions, intermodulation results in increase in the occupied bandwidth which can lead to adjacent channel interference. This leads to increase in spectrum usage and reduction in audio clarity (Widrow et al, 1975).

Expansion in mobile/wireless communication systems has pushed telecommunication companies to mount base stations on a common site. Placing many radio antennas close to each other is termed colocation. Colocation of multiple transceiver antennas that operate on different power and frequency at the same location enhances the possibility of mutual interference due to closeness of the antennas (Ho et al, 1989). In a colocated setting, there are possibilities of mutual interference resulting from high power interfering signals emanating from one radio transmitter system and radiating into the other radio system. This is a problem that has existed in radio-frequency (RF) systems and has proven to be difficult to tackle in different fields of communication (Faulkner, 2002).

In a co-located setting, strong transmitting signals radiating from base station transmitters are made to fall on neighbouring base-station receivers resulting in the receivers having to receive weak preferred signals due to strong transmitting signals from neighbouring radio transmitters (Ahmed, 2012). This scenario can make the spectrum to be easily congested and results in the desensitization of the receiver and possible formation of intermodulation products (Sithamparanathan and Giorgetti, 2012).

This work proposes the use of baseband quadrature phase shift keying (QPSK) post distortion cancellation that recovers the originally transmitted signal to Mitigate Interference in Co-located Wireless Systems.

2.0 METHODOLOGY

The proposed method is to use a QPSK baseband receiver model to cancel out the intermodulation distortion that has corrupted the transmitted signal. Being a baseband simulation model, the received signals are plain text. As a post distortion model, it implies that the distortion has already masked the transmitted signal and a regenerated estimate of the distortion is been fed back to the system to aid cancellation. Block diagram of the simulation architectural model is shown in figure 1, while the complete simulation architecture is shown in figure 2.

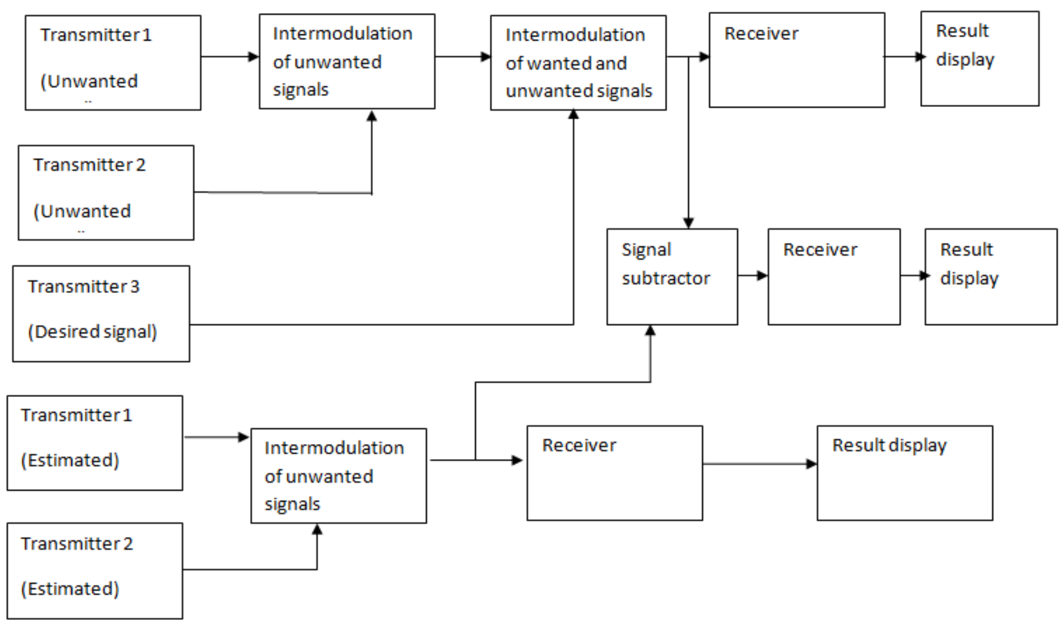


Figure 1: Block Diagram of a Complete Simulation Design Architecture

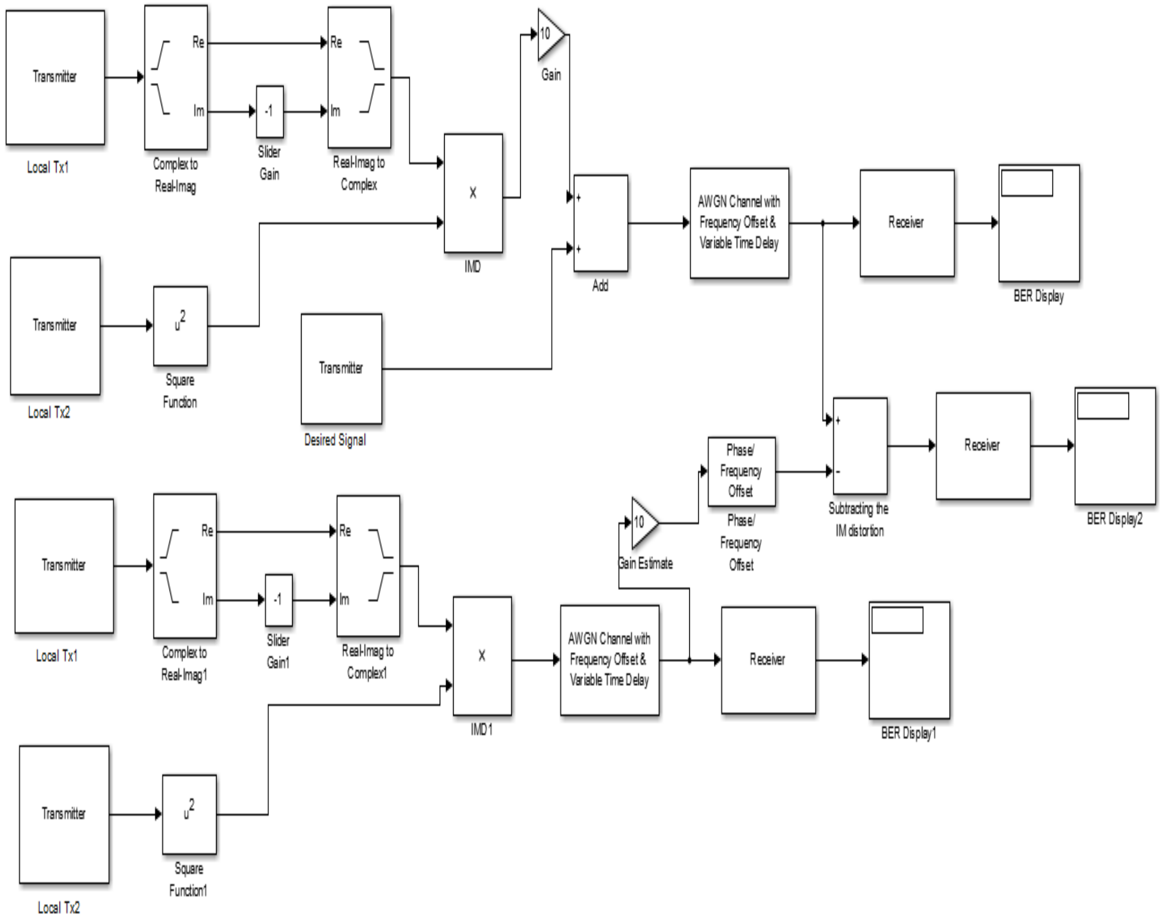


Figure 2: Complete Simulation Design Architecture

Figure 2 shows the block diagram of the simulation design architecture. This architecture simulates the QPSK transceiver which has been corrupted by an intermodulation distortion. The architecture prevents the formation of intermodulation distortion that has mixed with the desired signal at the receiver. The system addresses real-world wireless interference communications problems such as intermodulation distortion, Adaptive White Gaussian Noise (AWGN), timing recovery, variable time delay, frame synchronisation, carrier frequency offset and phase offset.

3.0 QUADRATURE PHASE SHIFT KEYING (QPSK)

Quadrature phase shift keying (QPSK) is digital modulation technique. Each signal point of a QPSK encoding scheme represents two bits and it is bandwidth efficient. It uses a phase shift of 90 degrees multiples and can be expressed mathematically as:

Input bits of '11'

$$\boldsymbol{S(t) = A\cos\left(2\pi F_c t + {}^{\pi}/_{4}\right)} \quad (3.1)$$

Input bits of '01'

$$\boldsymbol{S(t) = A\cos\left(2\pi F_c t + \left({}^{3\pi}/_{4}\right)/4\right)} \quad (3.2)$$

Input bits of '00'

$$\boldsymbol{S(t) = A\cos\left(2\pi F_c t - \left({}^{3\pi}/_{4}\right)/4\right)} \quad (3.3)$$

Input bits of '10'

$$S(t) = A\cos\left(2\pi F_c t - {}^{\pi}/_{4}\right) \qquad (3.4)$$

Where:

$S(t)$ is the complex signal

A is the amplitude

F_c is the carrier frequency

t is the time

Here 4 represents 4 phase (45,135,225,315), in which carrier is sent. QPSK has 4 possible states i.e. QPSK can encode 2 bit per symbol. It provide phase shift of Pi/2 (90°) multiple times as shown in table 3.5

Table 1: Four phase of QPSK technique

Phase	**Data**
45˚	00
135˚	01
225˚	11
315˚	10

QPSK converts the two input binary bits to complex signal$S(t)$. Based on the two binary digits, one out of the four phases of the complex signal is selected and the state of each complex signal is known as a symbol.

3.1 QPSK Modulation

Modulation in QPSK is symbol based. The basic functions for modulation in QPSK are taken as two sinusoids (sin and cos). The QPSK constellation diagram above shows the four constellation points on the X and Y axis. This implies that there is an in-phase component and a quadrature component in the modulated QPSK signal.

In QPSK, modulation is always symbol based, where one symbol contains 2 bits. The following equation outlines QPSK modulation technique.

$$S_i\,(t) = \sqrt{\frac{2E_s}{T}} * \cos\left(2\pi f_c t + (2n-1)\frac{\pi}{4}\right), \text{ n=1, 2, 3, 4}$$

When n=1, the phase shift is 45 degrees. This is called pi/4 QPSK

Euler's relations state the following:

Now consider multiplying two sine waves together, thus:

$$\sin^2 \omega t = \frac{e^{j\omega t} - e^{-j\omega t}}{2j} x \frac{e^{j\omega t} - e^{-j\omega t}}{2j} = \frac{e^{2j\omega t} - 2e^{0} + e^{-2j\omega t}}{-4}$$

$$= \frac{1}{2} - \frac{1}{2}\cos 2\omega t \qquad (3.5)$$

From equation 3.5, it can be seen that when two sine waves are multiplied together (one sine is the incoming signal, the other is the local oscillator at the receiver mixer) results in an output frequency $\frac{1}{2}\cos 2\omega t$ double that of the input (at half the amplitude) superimposed on a DC offset of half the input amplitude.

Similarly, multiplying sin ωt by cosωt gives:

$$\sin \omega t \times \cos \omega t = \frac{e^{2j\omega t} - e^{-2j\omega t}}{4j}$$

$$= \frac{1}{2} \sin 2\omega t \qquad (3.6)$$

To prove this:

$$\sin \omega t \times \sin(\omega t + \phi) = \frac{e^{j\omega t} - e^{-j\omega t}}{2j} \times \frac{e^{j(\omega t+\phi)} - e^{-j(\omega t+\phi)}}{2j}$$

$$= \frac{e^{j(2\omega t+\phi)} - e^{j(\omega t-\omega t-\phi)} - e^{j(\omega t+\phi-\omega t)} + e^{-j(2\omega t+\phi))}}{-4}$$

$$= \frac{\cos(2\omega t + \phi)}{-2} - \frac{e^{j\phi} + e^{-j\phi}}{-4}$$

$$= \frac{\cos(2\omega t + \phi)}{-2} + \frac{\cos\phi}{2}$$

$$= \frac{\cos\phi}{2} - \frac{\cos(2\omega t + \phi)}{2} \qquad (3.7)$$

Proving this, expanding on the above mathematics, is shown below.

Thus:

$$\cos \omega t \times \sin(\omega t + \phi) = \frac{e^{j\omega t} + e^{-j\omega t}}{2} \times \frac{e^{j(\omega t+\phi)} - e^{-j(\omega t+\phi)}}{2j}$$

$$= \frac{e^{j(2\omega t+\phi)} - e^{j(-\phi)} + e^{j(\phi)} - e^{-j(2\omega t+\phi))}}{4j}$$

$$= \frac{\sin(2\omega t + \phi)}{2} + \frac{e^{j\phi} - e^{-j\phi}}{4j}$$

$$= \frac{\sin(2\omega t + \phi)}{2} + \frac{\sin\phi}{2} \qquad (3.8)$$

3.2 QPSK Demodulation

In QPSK demodulation, the receiver must have knowledge of the carrier frequency and phase of the modulated signal. The receiver can achieve this using phase lock loop (PLL). The receiver can use the PLL to access the incoming carrier frequency so as to monitor the variation in frequency and phase.

Binary data is often transmitted with the following signals:

$$S_n\ (t) = \sqrt{\frac{2E_s}{T}} * \cos\left(2\pi f_c t + (2n-1)\frac{\pi}{4}\right) \tag{3.9}$$

This yields the four phases: π/4, 3π /4, 5π/4, 7π/4

This results in a two-dimensional signal space two basic functions:

$$\Phi_1(t) = \sqrt{\frac{2}{T_s}} * \cos(2\pi f_c t) \tag{3.10}$$

And $\Phi_2(t) = \sqrt{\frac{2}{T_s}} * \sin(2\pi f_c t)$ (3.11)

E_b = energy per bit

Es = energy per symbol = nE_b with n bits per symbol

T_b = bit duration

Ts = symbol duration

QPSK - bit error rate

QPSK can be seen as two independently modulated quadrature carriers; the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier, Binary Phase Shift keying, BPSK is used on both carriers and they can be independently demodulated.

Consequently, the probability of bit-error for QPSK is the same as for BPSK.

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{3.12}$$

Q is complementary error function

Q(x) gives the probability that a single sample taken from a random process with zero-mean and unit-variance Gaussian probability density function will be greater or equal to x.

Gaussian error function represents white Gaussian noise (AWGN).

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{\frac{-t^2}{2}} dt \qquad \text{for } x>0 \tag{3.13}$$

Nevertheless, in order to achieve the same bit-error probability as BPSK, QPSK uses twice the power (since two bits are transmitted simultaneously).

The symbol error rate is given by

$$P_s = 1-(1-P_b)^2 = 2 * Q\left(\sqrt{\frac{2E_b}{N_0}}\right) - Q^2\left(\sqrt{\frac{2E_b}{N_0}}\right) \tag{3.14}$$

It may be approximated to:

$$P_s = 2 * Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \tag{3.15}$$

where N_0 = noise power

4.0 ARCHITECTURE OF THE SYSTEM

The system components consist mainly of intermodulation distortion components, transmitter subsystem, channel subsystem, receiver subsystem and display.

4.1 Intermodulation Distortion Components

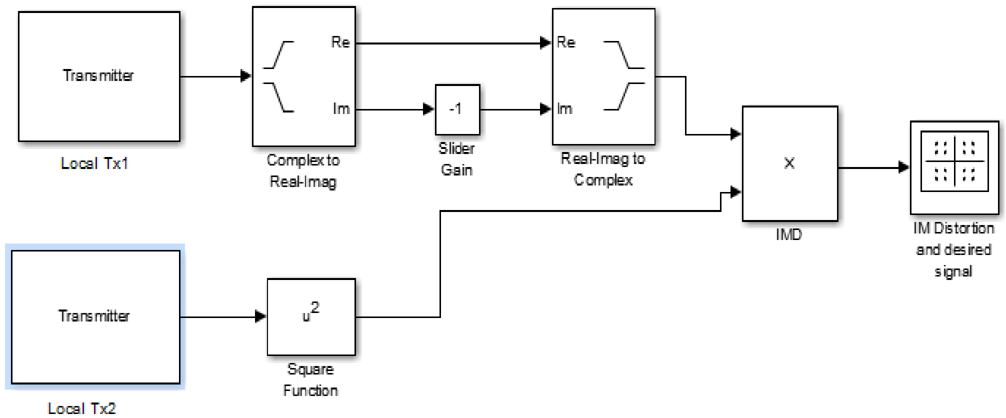


Figure 3: Intermodulation Generation.

Figure 3 shows the intermodulation distortion components that are made up of two local transmitters, polynomial function and a constellation point diagram for display of the intermodulation distortion. The local transmitters (Tx1 and Tx2) are used to generate the IM distortion products. Transmitter 1 (Tx1) and transmitter 2 (Tx2) are local transmitters that are co-located with the transmitter of the desired signal. The two signals are added together and coupled to a polynomial function to generate intermodulation distortion. The nonlinear polynomial function is made up of a square function, complex conjugate and a multiplier. The interaction of these two signal resulted in the generation of IM distortion.

4.0 RESULTS AND ANALYSIS

In this chapter, the demonstration of how the desired transmit signal was received successfully without IM interference was carried out, the effect of IM interference hitting the desired signal and the cancellation of the IM interference. The transmitted message are ASCII codes generated by the bit generation block as binary and converted by the receiver as plain text. The receiver is tuned to receive this signal generated by the bit generator in the transmitter subsystem and decoded as plain text 'Sweet Jesus 000' in a repeating sequence of 001, 002,….., 099.

4.1 Results

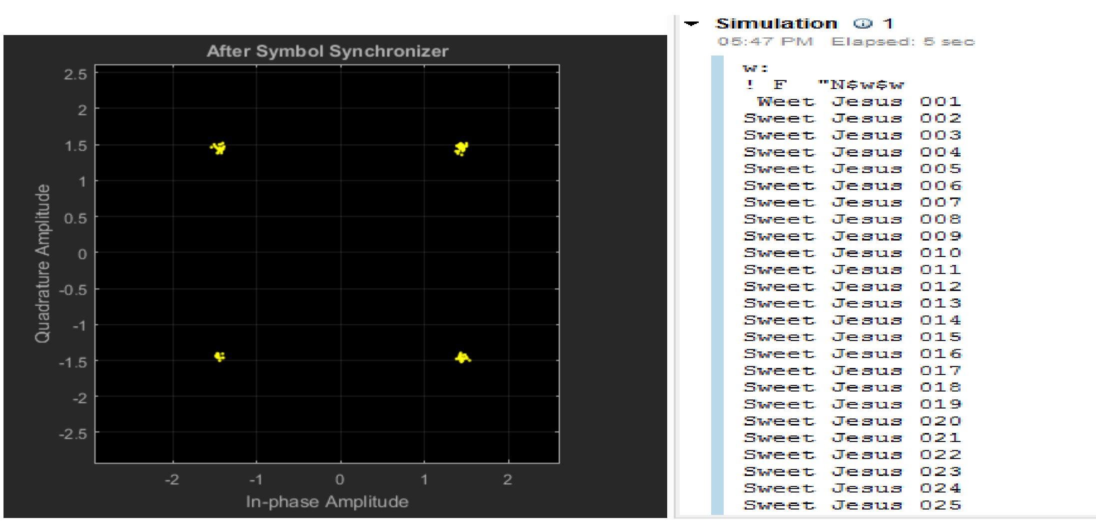


Figure 4: Received Constellation and Transmitted Message.

Figure 4 is the received constellation point diagram and transmitted message of the desired signal, constellation point and the transmitted message of the desired signal without intermodulation interference. The figure shows the constellation diagram on the left and received message on the right. The figure shows that transmitted message was received successfully and few bits were in error due to channel impairments. The model utilized a signal-to-noise ratio (SNR) of 35dB. The transmitted message did not suffer intermodulation interference and hence its message was successfully received and the sequence was correctly decoded.

4.1.1 Effect of Intermodulation Distortion on the Desired Signal

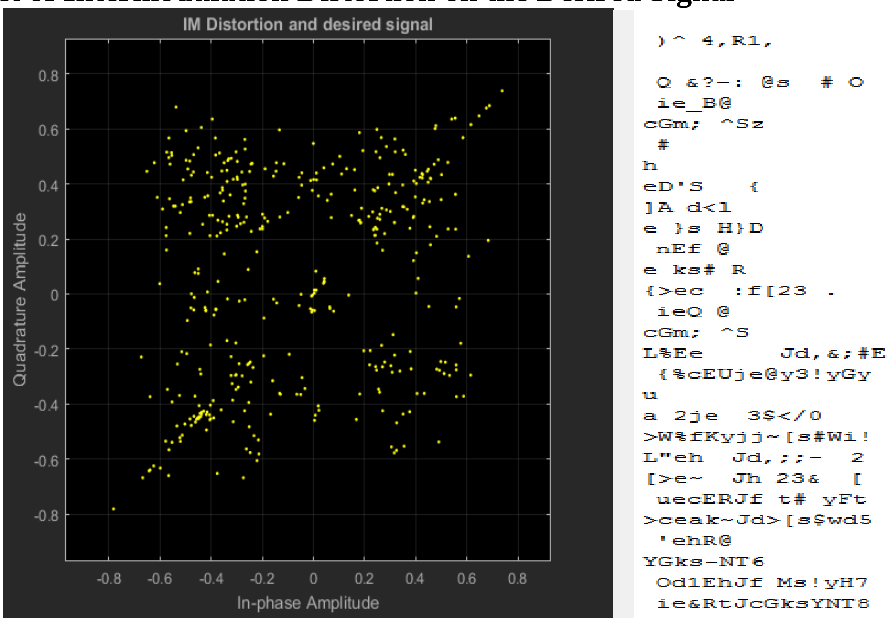


Figure 5: Effect of Intermodulation Distortion

Figure 5 shows the effect of intermodulation distortion (constellation diagram and corrupt message). The diagram shows the effect of intermodulation distortion on the desired signal. The IM distortion generated by the two local transmitters completely masked the desired transmit signal coming from the desired transmitter. This automatically leads to receiver insensitivity and result to loss of transmitted message. This was due to the colocation of the three transmitters. The signals coming from the local transmitter generates an IM distortion that fell on the desired transmit signal leading to loss of transmit message. The constellation diagram on the left and the received corrupt signal on the right show that the transmitted message was totally distorted and the receiver completely desensitized.

4.1.2 Recovering the Desired Transmitted Signal (Message)

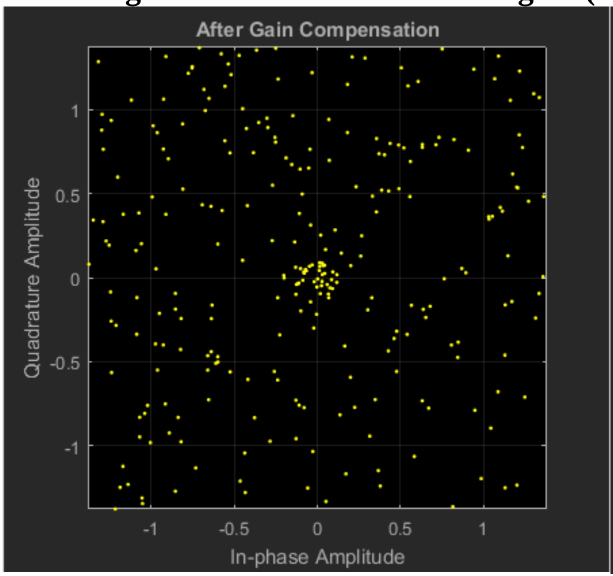


Figure 6: Signal after gain compensation.

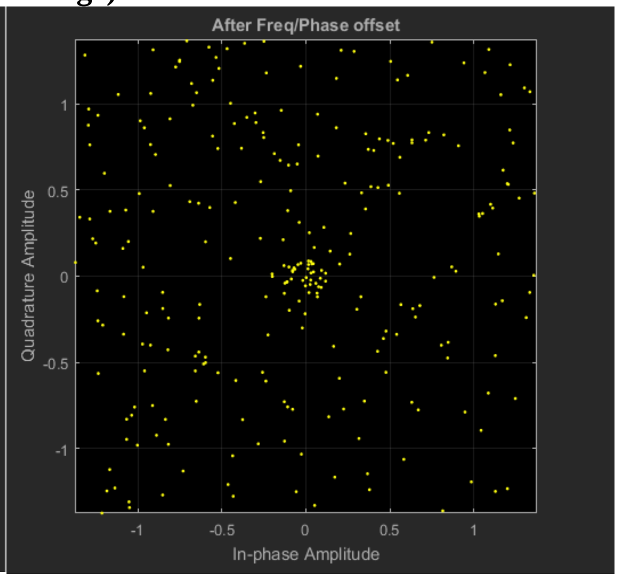
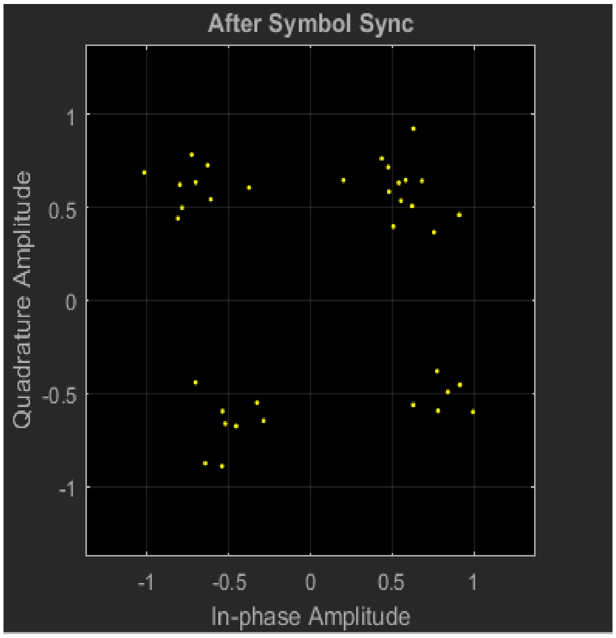


Figure 7: Signal after frequency/phase offset

The diagram (figure 4) shows the constellation point diagram after gain compensation of the intermodulation estimate of the distortion. The gain compensation helps to get an exact match of the IM distortion that hit the transmitted signal. The diagram (figure 5) shows the constellation point signal after frequency and phase compensation of the IM distortion estimate. The idea was to match the frequency and phase offset of the IM distortion that corrupted the transmitted message.




```
w:
! F   "N$w$w
 Weet Jesus 001
Sweet Jesus 002
Sweet Jesus 003
Sweet Jesus 004
Sweet Jesus 005
Sweet Jesus 006
Sweet Jesus 007
Sweet Jesus 008
Sweet Jesus 009
Sweet Jesus 010
Sweet Jesus 011
Sweet Jesus 012
Sweet Jesus 013
Sweet Jesus 014
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Sweet Jesus 016
Sweet Jesus 017
Sweet Jesus 018
Sweet Jesus 019
Sweet Jesus 020
Sweet Jesus 021
Sweet Jesus 022
Sweet Jesus 023
Sweet Jesus 024
Sweet Jesus 025
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Figure 8: Recovery of the Corrupt Signal (Constellation diagram and recovered message)

The figure shows the bit error rate display of the three receivers in the system architecture. The first row indicates the bit error rate (BER), the second row is the number of bits (transmitted message) in error and the third row is the number of bits transmitted. The figure clearly indicates the recovered transmitted messages. The number of bits corrupted by IM distortion is 4.253e+04 as shown in the BER display of distorted signal (first from left). If this is converted to signal-to-noise ratio, it yields 1.53dB. This cancellation technique was able to recover a greater percentage of the bits that were in error as compared to the number of bits transmitted and the ones corrupted by IM distortion. This yields approximately 40dB gain of the recovered signal. This clearly makes it an effective cancellation technique.

The proposed technique recovered a greater percentage of the corrupted signal successfully and it validates the method employed to cancel out IM distortion.

$$SNR = \frac{1}{\sqrt{BER}} \quad (4.1)$$

SNR=Signal-to-Noise Ratio
BER=Bit Error Rate
From figure 4.7, the bit error rate of the distorted signal is 0.4253

Therefore, $SNR = \frac{1}{\sqrt{0.4253}} = 1.53dB$ (4.2)

The BER of the recovered signal is 0. 00064

Therefore, $SNR = \frac{1}{\sqrt{0.00064}} \approx 40d\boldsymbol{B}$ (4.3)

The simulation model tries to cancel out post distortion intermodulation interference. The QPSK receiver simulation model uses appropriate gain and phase scaling to estimate the intermodulation distortion product. To successfully cancel out the intermodulation interference, it requires knowledge of the amplitude, phase, timing and frequency in the synthesized interference. Sampling clock is used to achieve timing accuracy, correction algorithm is used to achieve gain-phase correction. Nonlinear interfering signals are known to contain frequency offsets and bandwidth expansion, they sample rates are made reasonably high in other to compensate for these problems. A timing fidelity is achieved in the cancellation by using a large over sampling rate (infinite sample) and it is also capable of handling most contingencies.

CONCLUSION

This work on interference mitigation on collocated wireless system has been extensively analyzed and a solution proposed to solve this problem that has been a major issue for radio frequency engineers. This work proposed a distortion cancellation technique using quadrature phase shift keying (QPSK) baseband transceiver model. The distortion is assumed to have occurred and an estimate of it is regenerated and fed back in a way that it is out of phase with the original distorting signal that has corrupted or masked the transmitted signal.

The proposed technique that involved the use QPSK baseband Receiver model cancels IM interference generated by two local transmitters colocated with the desired transmitter. It was possible to model a QPSK transmit and receive model without interference. An IM distortion using two local transmitters transmitting different messages and both are colocated together was generated and mixed it with the desired signal (message) in other to show the effect of IM distortion hitting a transmitter. A modeled QPSK receiver put in place to aid the cancellation. This technique is flexible and can be applied to scenarios that involve multiple sources of intermodulation (IM) interference and distortion harmonics.

The cancellation process started from the channel with good signal-to-noise (SNR) ratio to aid filtration of the corrupted signal, a regenerated estimate of the IM distortion to aid in cancelling the distortion in the desired transmitted signal and a receiver that compensates and cancels out a greater percentage of the distortion.

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