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SIGNAL RECEPTION VIA MULTI-PLATFORM RECEIVERS

by

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SIGNAL RECEPTION VIA MULTI-PLATFORM RECEIVERS

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ABSTRACT

In this thesis a reference-based successive interference cancellation (RSIC) scheme is proposed for mitigating interference in multi-platform communications. The performances of two RSIC techniques (Non-Demodulated and Demodulated) for quadrature phase shift keying (QPSK) modulation in orthogonal frequency division multiplexing (OFDM) system are analyzed. Simulations show RSIC schemes give considerable increase in performance compared to a system where interference cancellation is not utilized.

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LIST OF ACRONYMS AND ABBREVIATIONS

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CP	Cyclic Prefix
IEEE	Institute of Electrical and Electronic Engineers
OFDM	Orthogonal Frequency Division Multiplexing
QPSK	Quadrature Phase Shift Keying
SIC	Successive Interference Cancellation
SNR	Signal-To-Noise Ratio
SOI	Signal Of Interest
WLAN	Wireless Local Area Network

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I INTRODUCTION

A. BRIEF OVERVIEW

Successive interference cancellation (SIC) is a well-known technique to extract the target signal from multiple signals. The multiple signals are unwanted interferences caused by signal collision or overlapping. SIC uses successive signal subtraction using strong reference signals. Conventional SIC technique is normally applied by one receiver intercepting various signals from multiple transmitters. Signal of interest could be strongly contaminated, i.e. signal strength might be weak compared to interference, which causes the signal of interest not to be extracted or demodulated.

In certain applications, multiple receivers are available. A new scheme called referenced-based SIC (RSIC) is proposed. RSIC successively subtracts interferences by using a relatively clean signal from an initial receiver in a multiplatform receiver system. By deploying a receiver in a favored area, an initial target signal can be chosen which is free of interference (except receiver noise), which is referred to as reference signal. This signal can be subtracted in a receiver placed in another area where this signal is considered the only interference (again except for its own receiver noise). Thus the second receiver cancels this interference. The procedure is applied to the rest of the platform. Therefore the final target signal can be extracted, i.e. performance of the system is greatly improved.

Two different reference-based SIC techniques are analyzed in this thesis: Non-Demodulated RSIC and Demodulated RSIC.

B SCOPE AND ORGANIZATION

Two signal models (for Non-Demodulated RSIC and Demodulated RSIC signal extraction schemes) are proposed, coded and simulated using Matlab in the following chapters. Three important variables are introduced: the amplitude gain of an interference signal (α), its estimate (β), and their difference (γ). In order to illustrate the effect of the performance of one variable (say γ), we fix the value of that variable while varying the another (say α). In this work, we will implement this approach to only one receiver in a multiple receiver scenario (specifically to the second receiver referred to as Receiver 2).

In Chapter II, we discuss the concept of a reference-based SIC (both Non-Demodulated and Demodulated). We discuss how to configure (by positioning) the multi-receiver platform such that a reference signal can be received by the initializing receiver.

In Chapter III, we examine the proposed scheme by simulating multiple quadrature phase shift keying (QPSK) receivers using Matlab. Both Non-Demodulated RSIC and Demodulated RSIC are simulated.

In Chapter VI, we examine both RSIC schemes with multiple quadrature phase shift keying (in OFDM) receivers.

In Chapter V, we conclude the thesis and provide recommendations for future research.

II REFERENCE-BASED SUCCESSIVE INTERFERENCE CANCELLATION (RSIC)

Receivers pick up unwanted signals, noise, and interferences from targeting areas. The signal/s of interest (SOI) is/are buried among noise and interferences. Using estimated reference signals, the successive interference cancellation (SIC) technique can be applied to eliminate the interferences and extract a target signal.

The conventional SIC works with one receiver [1]. In a multiple receiver platform, a new approach called reference-based successive interference cancellation (RSIC) is proposed. This concept involves: deployment of multiple receivers in favorable targeting areas and then the receivers subtract interference using the reference signals passed from prior receivers until SOI (or SOIs) is decoded.

Two reference-based successive interference cancellation techniques (Non-Demodulated and Demodulated RSIC) are addressed in this chapter. Obtaining an initial reference signal is crucial and is the very first step to the success of this reference-based successive interference cancellation process.

A. OBTAINING THE REFERENCE SIGNAL

For the RSIC procedure to be successful, proper configuration or positioning of the receivers is necessary.

The first reference signal in a multiple receiver platform is crucial to the performance of the whole system. Thus, it must not be contaminated with the signals from the other emitters. This non-interfered reference signal could be obtained by positioning the receiver such that other interference signals are not present. We assume that the receiver is not noise-limited, i.e. that the receiver has a good signal-to-noise ratio (SNR).

Conventional cellular system employs sectoring antennas to reduce co-channel interference in order to improve link reliability. Shown in Figure 1, four base stations employ 120° antennas, which create four overlapping areas. By positioning the receiver in

Sector A, only the radio signal from base station 1 is received, and it is used as the initial reference signal. Radio signals from both base station 1 and 2 are received by Receiver 2 in Sector B. The rest of the receivers can be positioned in Sector C and D to intercept multiple signals.

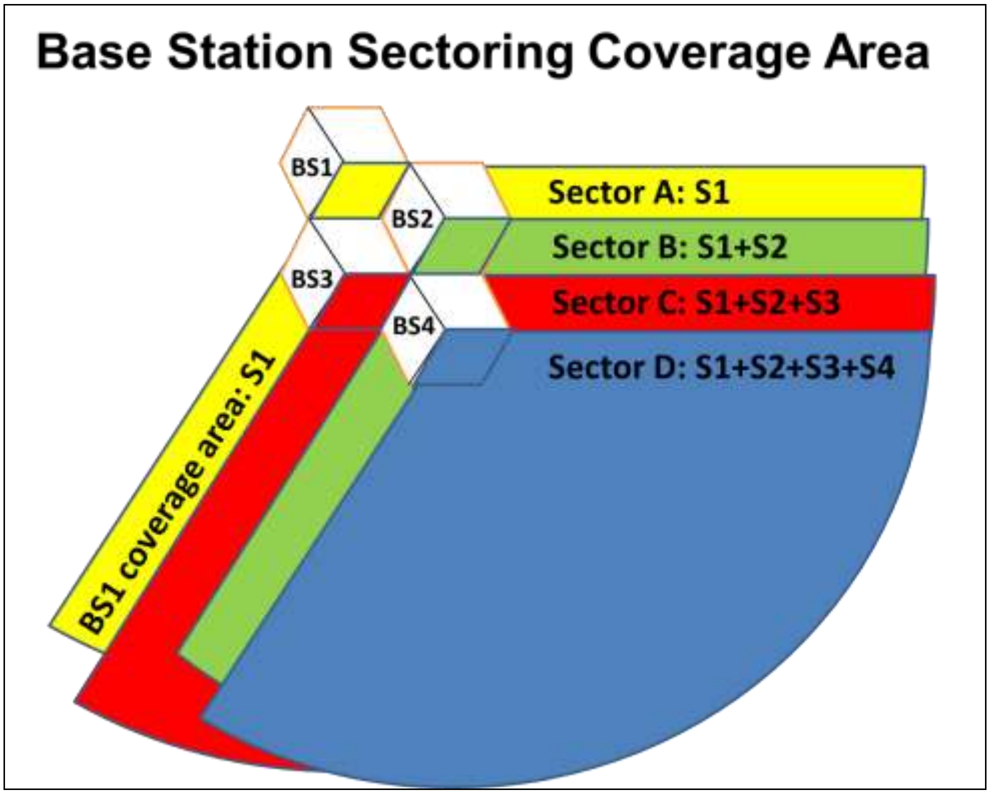

Figure 1. Multiple signals received in various sectors (overlapping antenna coverage).

B. NON-DEMODULATED RSIC

Consider the case of deploying four receivers in four targeting areas to intercept all of the four base station radio signals. In Figure 1, a signal receiver is placed in each sector (Sector A, B, C and D) ensuring that a diversity of reception is achieved.

According Figure 1, the signals received from various sectors are listed in Table 1 if the signals are of equal energy (or power).

Table 1. List of receiving signals in each sector

Sector	Receivers	Intercepted signals
A	Receiver 1	$s_1 + n_1$
B	Receiver 2	$s_1 + s_2 + n_2$
C	Receiver 3	$s_1 + s_2 + s_3 + n_3$
D	Receiver 4	$s_1 + s_2 + s_3 + s_4 + n_4$

The symbol s_m represents a signal from base station *m,* and n_n is the addictive white Gaussian noise (AWGN) at receiver *n*.

Clearly, signal 2 (s_2) can be extracted from Receiver 2 by subtracting s_1. An estimate of s_1 can be sent from Receiver 1 to Receiver 2. The signal sent from Receiver 1 to Receiver 2 for subtraction is called a reference signal. Repeating the same procedure, signals 3 and 4 can also be extracted from Receivers 3 and 4 by using the subsequent reference signal passed from a prior receiver. The beauty of this algorithm is that the receivers do not need knowledge of the information content. A receiver simply passes the reference signal to subsequent receivers for interference cancellation.

Assuming equal energy for all signals is impractical. Thus, the wireless transmission amplitude loss or gain needs to be considered in the model. Three interference-related variables are used to model received signals. Alpha, $\alpha_{m,n}$, is the amplitude gain of unwanted signals S_m from base station (emitter) BS_m leaking into receiver R_n. Beta, $\beta_{m,n}$, is the estimate of $\alpha_{m,n}$ (amplitude gain of reference signal S_m) passed from prior receiver R_m to subsequent receiver R_n. We can designate $\gamma_{m,n}$ to be the difference between α and β, i.e.

$$\gamma_{m,n} = \alpha_{m,n} - \beta_{m,n} \tag{2.1}$$

Thus the received signal for Receiver 1 is

$$y_1 = s_1 + n_1 \tag{2.2}$$

where the received signal, y_n, for an arbitrary receiver R_n is:

$$y_2 = s_2 + \alpha_{1,2} s_1 + n_2 \tag{2.2}$$

$$y_3 = s_3 + \alpha_{2,3} s_2 + \alpha_{1,3} s_1 + n_3 \tag{2.3}$$

$$y_4 = s_4 + \alpha_{3,4} s_3 + \alpha_{2,4} s_2 + \alpha_{1,4} s_1 + n_4 \tag{2.4}$$

The amplitude gain, α_1 is assumed fixed in this thesis. In practice, it may have to be estimated since it may be random in nature. For example, it may be distributed from 0.8 to 1.2, where the 0.4 deviation maybe due to proximity of receptors in relation to emitter.

If we let $\hat{s}_1 = s_1 + n_1$ be the estimate of desired signal in Receiver 1, then $\hat{s}_1$ is the initial reference signal and is passed from Receiver 1 to Receiver 2 for cancellation procedure. Receiver 2 receives the reference signal $\hat{s}_1$, including its own AWGN noise. It performs the reference-based interference cancellation process as dictated by

$$\begin{aligned} \hat{s}_2 &= y_2 - \beta_{1,2}(s_1 + \hat{n}_2) \\ &= \left(s_2 + \alpha_{1,2} s_1 + n_2\right) - \beta_{1,2}\left(s_1 + n_1 + \hat{n}_2\right) \end{aligned} \tag{2.5}$$

Assuming $\hat{n}_2$ is negligible (due to possibly shorter distance between two receivers compared to distance from emitters) then

$$\hat{s}_2 = s_2 + \left(\alpha_{1,2} - \beta_{1,2}\right) s_1 + n_2 - \beta_{1,2} n_1 \tag{2.6}$$

$$\gamma_{1,2} = \alpha_{1,2} - \beta_{1,2} \tag{2.7}$$

Thus,

$$\hat{s}_2 = s_2 + \gamma_{1,2} s_1 + n_2 - \beta_{1,2} n_1 \tag{2.8}$$

At Receiver 3, reference signal $\hat{s}_3$ can be calculated via

$$y_3 = s_3 + \alpha_{2,3} s_2 + \alpha_{1,3} s_1 + n_3 \tag{2.9}$$

$$\hat{s}_3 = s_3 - \beta_{2,3} s_2 - \beta_{1,3} \hat{s}_1 \tag{2.10}$$

$$\hat{s}_3 = \left(s_3 + \alpha_{2,3}s_2 + \alpha_{1,3}s_1 + n_3\right) - \beta_{2,3}\left(s_2 + \gamma_{1,2}s_1 + n_2 - \beta_{1,2}n_1\right) - \beta_{1,3}\left(s_1 + n_1\right), \tag{2.11}$$

where we assume the noises due to the receipt of reference signals are negligible. Thus,

$$\begin{aligned}\hat{s}_3 = s_3 + \left(\alpha_{2,3} - \beta_{2,3}\right)s_2 + \left(\alpha_{1,3} - \beta_{1,3} - \beta_{2,3}\gamma_{1,2}\right)s_1 \\ -\beta_{2,3}n_2 + \beta_{2,3}\beta_{1,2}n_1 - \beta_{1,3}n_1 + n_3\end{aligned} \tag{2.12}$$

$$\gamma_{2,3} = \left(\alpha_{2,3} - \beta_{2,3}\right) \tag{2.13}$$

$$\gamma_{1,3} = \left(\alpha_{1,3} - \beta_{1,3}\right) \tag{2.14}$$

Then,

$$\begin{aligned}\hat{s}_3 &= s_3 + \gamma_{2,3}s_2 + \left(\gamma_{1,3} - \beta_{2,3}\gamma_{1,2}\right)s_1 - \beta_{2,3}n_2 + \beta_{2,3}\beta_{1,2}n_1 - \beta_{1,3}n_1 + n_3 \\ &= s_3 + \gamma_{2,3}s_2 + \left(\gamma_{1,3} - \beta_{2,3}\gamma_{1,2}\right)s_1 - \beta_{2,3}n_2 + \left(\beta_{2,3}\beta_{1,2} - \beta_{1,3}\right)n_1 + n_3\end{aligned} \tag{2.15}$$

With Receiver 4, reference signal $\hat{s}_4$ can be extracted via

$$y_4 = s_4 + \alpha_{3,4}s_3 + \alpha_{2,4}s_2 + \alpha_{1,4}s_1 + n_4 \tag{2.16}$$

$$\hat{s}_4 = y_4 - \beta_{3,4}s_3 - \beta_{2,4}\hat{s}_2 - \beta_{1,4}s_1 \tag{2.17}$$

Thus,

$$\begin{aligned}\hat{s}_4 = &\left(s_4 + \alpha_{3,4}s_3 + \alpha_{2,4}s_2 + \alpha_{1,4}s_1 + n_4\right) \\ &-\beta_{3,4}\left[s_3 + \gamma_{2,3}s_2 + \left(\gamma_{1,2} - \beta_{2,3}\gamma_{1,2}\right)s_1 - \beta_{2,3}n_2 + \left(\beta_{2,3}\beta_{1,2} - \beta_{1,3}\right)n_1 + n_3\right] \\ &-\beta_{2,4}\left(s_2 + \gamma_{1,2}s_1 + n_2 - \beta_{1,2}n_1\right) - \beta_{1,4}\left(s_1 + n_1\right)\end{aligned} \tag{2.18}$$

Then,

$$\begin{aligned}\hat{s}_4 = s_4 + \gamma_{3,4}s_3 + \left(\gamma_{2,4} - \beta_{3,4}\gamma_{2,3}\right)s_2 - \left[\beta_{3,4}\left(\gamma_{1,3} - \beta_{2,3}\gamma_{1,2}\right) + \beta_{2,4}\gamma_{1,2}\right]s_1 \\ -\beta_{3,4}n_3 + \left(\beta_{3,4}\beta_{2,3} - \beta_{2,4}\right)n_2 + \left[\beta_{2,4}\beta_{1,2} - \beta_{1,4} - \beta_{3,4}\left(\beta_{2,3}\beta_{1,2} - \beta_{1,3}\right)\right]n_1 + n_4\end{aligned} \tag{2.19}$$

Non-Demodulated RSIC technique does not require the receivers to demodulate the intercepted signals to perform interference cancellation. The information of the signal content is not required. If demodulation is of interest then it can be done after the fact.

C. DEMODULATED RSIC

In developing the algorithm of reference-based successive interference cancellation technique, an interesting question is raised. What if the receiver demodulates its SOI and sends the demodulated SOI as reference? Is there a performance improvement? In the demodulated scheme (now appropriately called D-RSIC), demodulation is performed in each receiver, which allows receivers to make decisions (detections) on intercepted signals based on the modulation technique the target emitters are using.

As in Non-Demodulated RSIC, reference signals come from prior receivers. The major difference is that the reference signal will be demodulated and re-modulated before transmission to the subsequent receiver. The advantage of this extra step mitigates noise prior to transmission. It prevents noise and error accumulation in the reference signal. Subsequent receivers, especially those at the latter part procedure, benefit from this step.

Adding the demodulation procedure into Receiver 1, the detection is given by:

$$\tilde{s}_1 = dec\left(s_1 + n_1\right) \tag{2.20}$$

where $\tilde{s}_1$ is the new initial reference signal and is sent from Receiver 1 to Receiver 2 and the operation "dec" means decide which symbol is received.

At Receiver 2, received reference signal 1 is used for interference cancellation procedure. Reference signal 2, $\tilde{s}_2$, can be calculated by demodulating (2.8) via

$$\tilde{s}_2 = dec\left(y_2 - \beta_{1,2}\tilde{s}_1 + \hat{n}_2\right) \tag{2.21}$$

The same demodulation and interference cancellation procedures are repeated at subsequent receivers. Simulations are reported in Chapter III, where significant improvement in receiver performance utilizing this technique compared to Non-demodulated RISC is demonstrated.

III QPSK SIMULATION

A. COMPARISON OF NON-RSIC, NON-DEMODULATED, AND DEMODULATED RSIC TECHNIQUE

1. Comparison of Three Techniques in a Two Receiver System

Simulations are coded in Matlab to demonstrate Non-RSIC, Non-Demodulated RSIC, and Demodulated RSIC techniques with a two-receiver system using Matlab. The signals are QPSK-modulated. The first technique (Non-RSIC) is one without benefit of any cancellation schemes. Receiver 2's received signal includes signals from base stations 1, 2 and noise. The Non-RSIC scheme demodulates the intercepted signals without the benefit of RSIC. In the second technique (ND-RSIC), Receiver 2 demodulates the intercepted signals by subtracting the reference signal received from Receiver 1. In third technique (D-RSIC), reference signal 1 is demodulated and re-modulated by the Receiver 1 prior to sending to Receiver 2. With this extra detection step at Receiver 1, the noise of intercepted signal 1 is mitigated which benefits the subsequent receiver dramatically (by using a "cleaner" reference signal).

In Figure 2, we show the results from simulation, which show bit error rate (BER) performances for QPSK-modulated signals utilizing the three techniques. The outer curve, Non-RISC, gives us a baseline for comparison. Without any interference cancellation technique, the interference and noise cause substantial performance degradation. The second curve is the BER curve for ND-RISC which shows substantial improvement. The benefit of D-RSIC further increases the performance. This is the curve closest to the theoretical QPSK BER curve.

In this simulation, the interference amplitude gain factor $\alpha_{1,2}$ is set to 0.5 and $\gamma_{1,2}$ ($\alpha_{1,2}$ minus $\beta_{1,2}$) is set to -0.05.

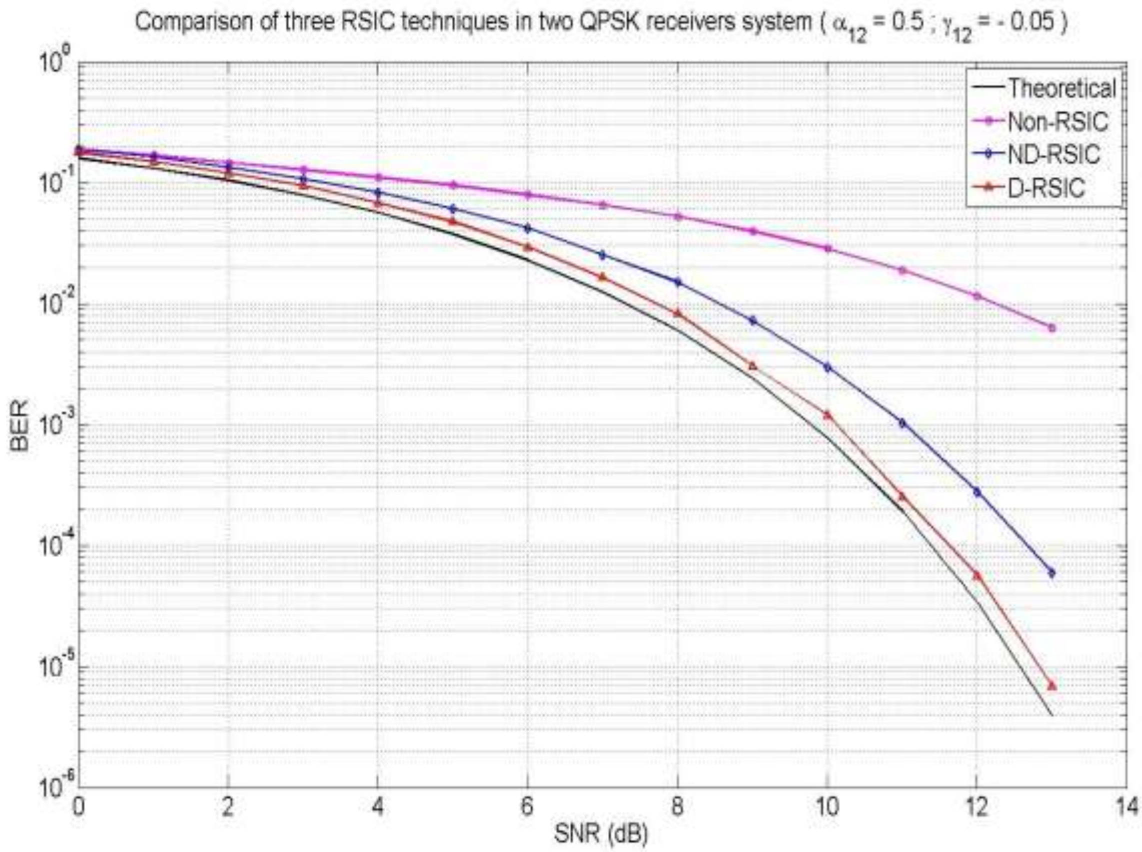

Figure 2. Comparison of three techniques at Receiver 2 with two receivers where signals are QPSK-modulated

2. Comparison of Receiver Performance in a Four-Receiver System

a. Noise Accumulation in Subsequent Receivers

In this simulation, four receivers are considered. With ND-RSIC, Receiver 2 sends non-demodulated reference signal 2 to Receiver 3 for SIC procedure. Receiver 3 follows the same procedure where the non-demodulated reference signal 3 is passed to Receiver 4. All α and γ values used in this simulation model are shown in Table 2.

Table 2. Interference amplitude gain factors used in the simulation

Amplitude gain factors	Value	|Note
$\alpha_{1,2}$	0.50	
$\alpha_{1,3}$	0.90	
$\alpha_{1,4}$	0.90	
$\alpha_{2,3}$	0.80	
$\alpha_{2,4}$	0.80	
$\alpha_{3,4}$	0.70	
$\beta_{1,2}$	0.55	$\beta_{1,2} = \alpha_{1,2} - \gamma_{1,2}$
$\beta_{1,3}$	0.95	
$\beta_{1,4}$	0.95	
$\beta_{2,3}$	0.90	
$\beta_{2,4}$	0.90	
$\beta_{3,4}$	0.90	
$\gamma_{1,2}$	-0.05	

Various target signals broadcasted from multiple base stations can be intercepted in this multiplatform receiver system. A signal of interest (SOI) can be extracted from a specific receiver according to Chapter II. It may be that the performance is worse for latter receivers than earlier receivers in the procedure. But this really depends on the α s', β s' as will be shown later. For example, if the broadcasted signal from base station 4 is the SOI, the demodulated signal quality (bit error rate, BER) at Receiver 4 may be the worst due to noise accumulation in the reference signal as it is passed along from receiver to receiver.

In Figure 3, we show the results of four Non-Demodulated RSIC (ND-RSIC) QPSK receivers (with fixed α and γ value). The ND-RSIC BER performance of Receiver 2 is better than that of a Non-RSIC Receiver 2. This is due to the cleaner reference signal from Receiver 1 (but without demodulation). The performances of the subsequent receivers are degraded due to noise accumulation in the reference signals. The BER performance for Receiver 3 and Receiver 4 are also shown.

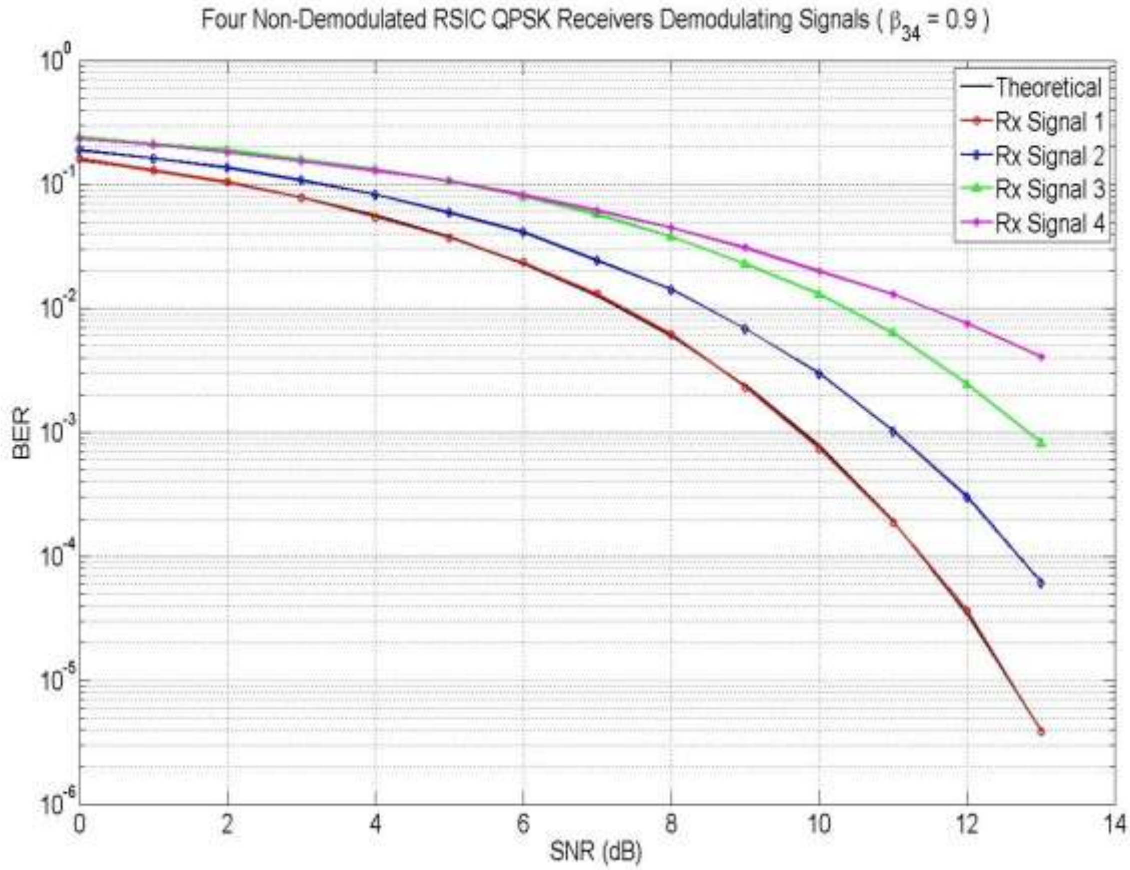

Figure 3. Four ND-RSIC QPSK receiver system (noise accumulation causes signal degradation)

b. Adjusting α and β Value Enables Subsequent Receivers to Outperform Prior ones

We understand that noise accumulated in the prior reference signals causes performance degradation in subsequent receivers. However, it is possible for a latter receiver to outperform a prior receiver. The performance is a function of γ and β. For example, by changing $\beta_{3,4}$ value from 0.90 to 0.65 (rest of the variables in Table 2 are remaining the same), Receiver 4 outperforms Receiver 3. The result is shown in Figure 4.

Thus, the performance of receivers can be affected by the estimates of the amplitude gains. In general, the better estimates yield performance gain (modest or otherwise).

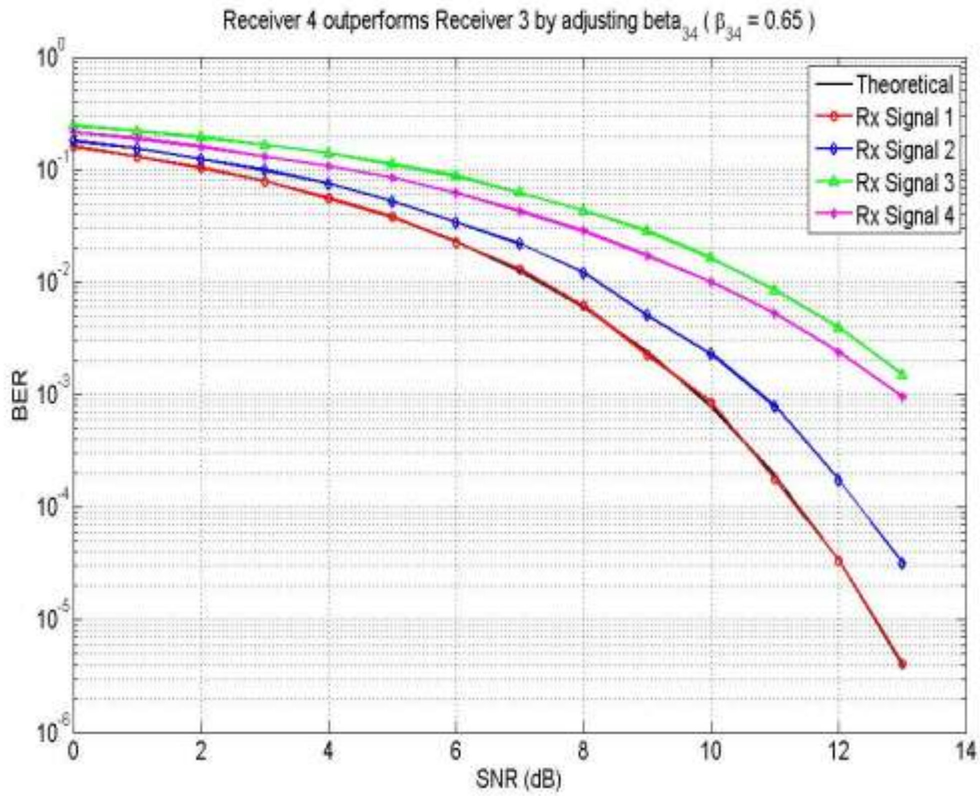

Figure 4. Receiver 4 outperforms Receiver 3 by reducing β value from 0.95 to 0.65

B. COMPARISON OF NON-RSIC, NON-DEMODULATED, AND DEMODULATED TECHNIQUE AS A FUNCTION OF α

To further understand the influence of interference factor α and γ, various α and γ values are tested in the simulation. For simplicity, α or γ is only allowed to vary in Receiver 2 of the multiplatform receiver system. This helps to observe the variation of receiver performance.

In this section, two-receiver and four-receiver systems with various α scenarios are coded in Matlab for simulation.

1. Two Receivers

A two QPSK-receiver system is tested with the three techniques as in previous experiments, but with various α . Thus, $\alpha_{1,2}$ is the only variable that varies in this simulation.

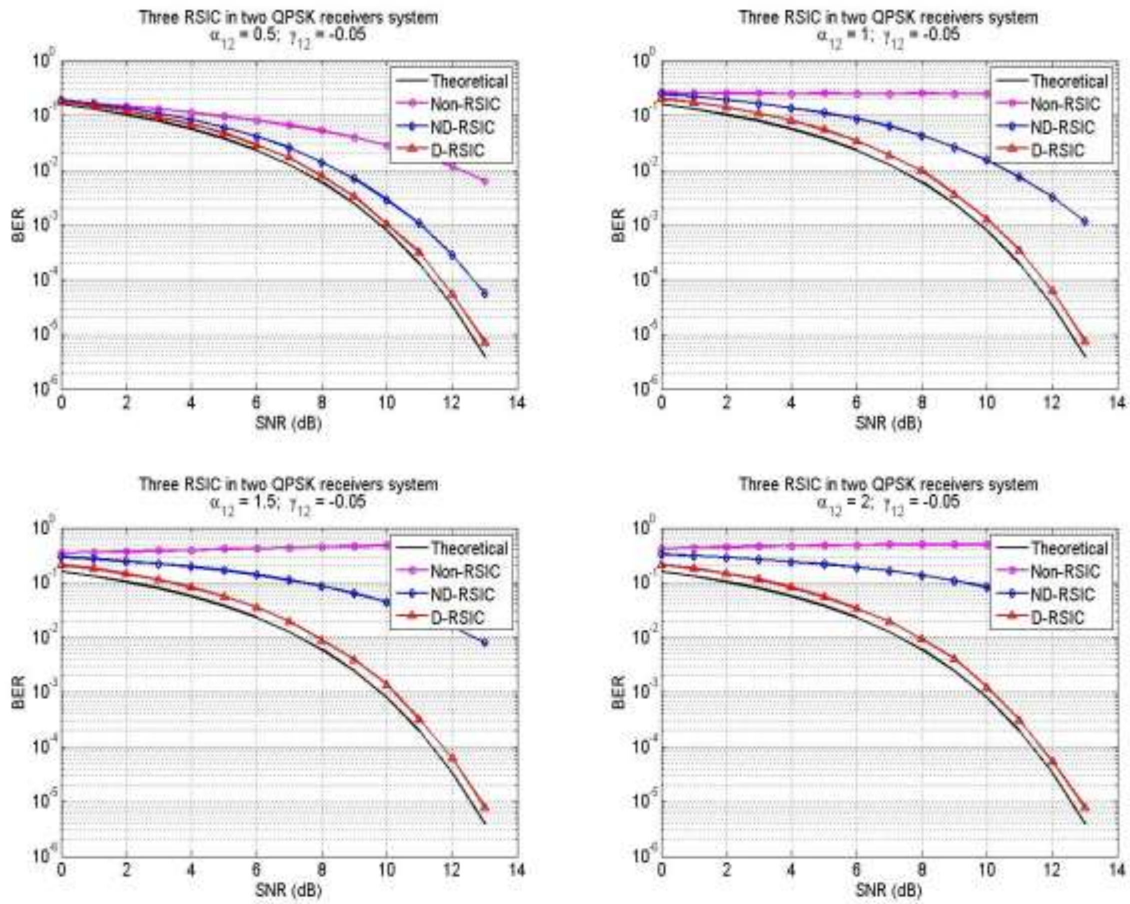

Figure 5. Comparison of three techniques in a two QPSK receiver system with various α and fixed γ

Shown in Figure 5, all three techniques are tested with four $\alpha_{1,2}$ values which is increased from 0.5 to 2 with 0.5 increments. The outer curve (labeled Non-RSIC) shows that without the benefit of RISC, the BER performances suffer greatly when $\alpha_{1,2}$ is increased. For example, with Non-RISD it would be difficult to extract SOI when $\alpha_{1,2}$ is greater than 1. With ND-RSIC technique, the performance of the receiver starts to suffer as $\alpha_{1,2}$ values increase despite corresponding increase in the estimates (recall that the γ is fixed). However, D-RSIC receivers perform extremely well regardless the increasing of $\alpha_{1,2}$ value. In conclusion, BER improves dramatically with the benefits of RSIC techniques.

2. Four Receivers

In Figure 6, we show the performance of four ND-RSIC receivers demodulating target signals of interest. The four plots are produced using the values of variables in Table 2, except $\alpha_{1,2}$ at Receiver 2 is changed from 0.5 to 2.0 with 0.5 increments. Clearly it can be seen that the performance of Receiver 2 is greatly influenced by increasing $\alpha_{1,2}$ value despite corresponding increase in the estimates. The BER performances suffer greatly as a function of increasing $\alpha_{1,2}$.

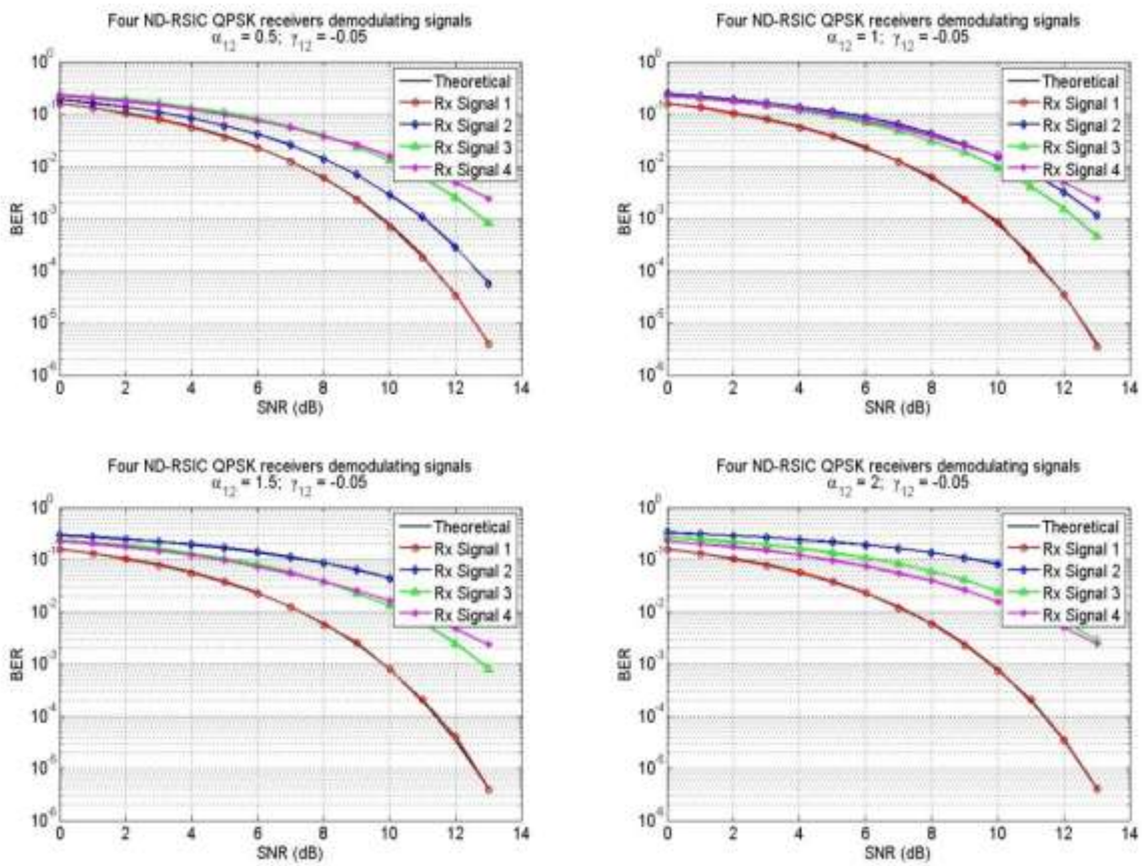

Figure 6. BER performances of a four ND-RSIC QPSK receiver system with various α

Despite the impact of the increasing $\alpha_{1,2}$ at Receiver 2, the performances of the subsequent receivers (Receivers 3 and 4) are minimally affected since their amplitude gains and corresponding estimates are not allowed to vary in the simulation.

To combat the impact of the increasing alpha on receiver performance, the Demodulated RSIC technique is implemented in Matlab involving four receivers. The simulation results are shown in Figure 7. Notice the dramatic improvement regardless of the $\alpha_{1,2}$ value.

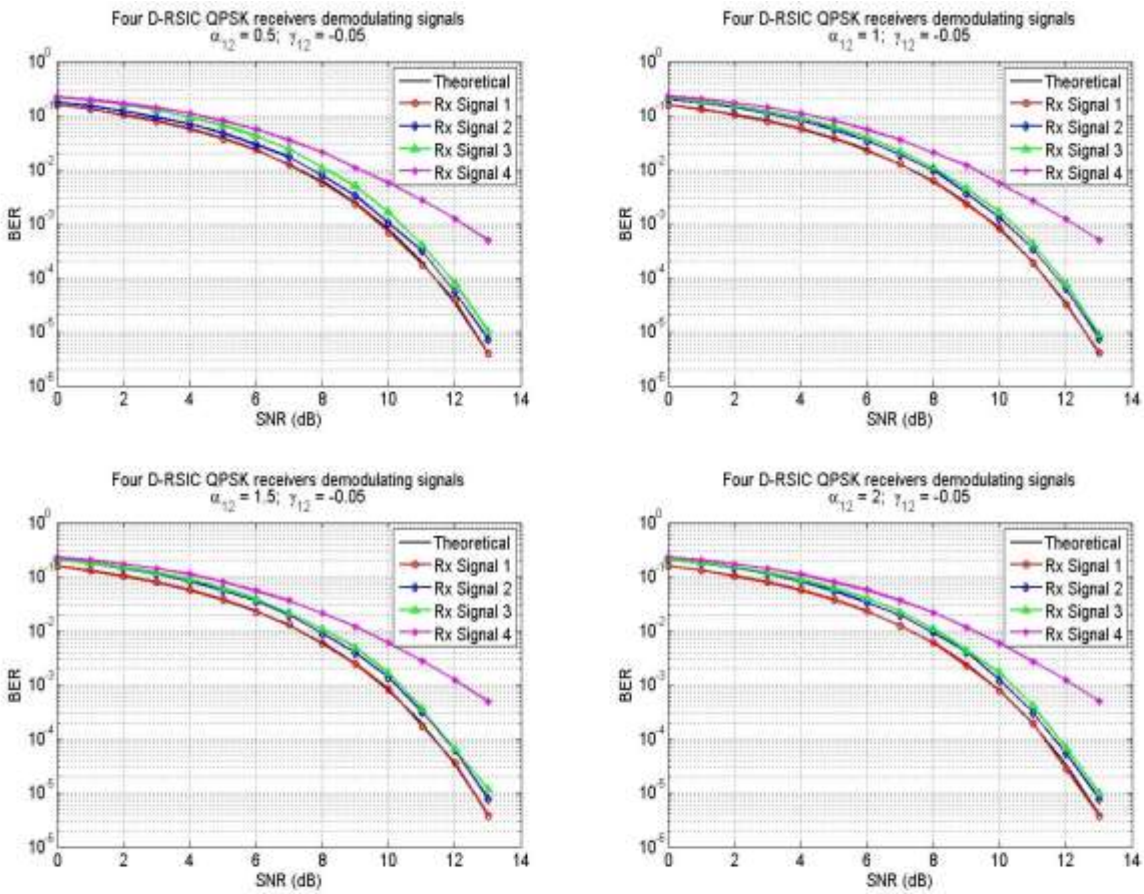

Figure 7. BER performances of four D-RSIC QPSK receiver system with various α values

The D-RSIC BER improvements for Receiver 3 and Receiver 4 (compared to ND-RSIC Receiver 3 and Receiver 4 BERs) are worth mentioning. First, the performances of both receivers greatly improve (compared to ND-RSIC performances) since accumulated noises in the reference signals are mitigated. Receiver 3's BER benefits more and performs as well as Receiver 2. Second, Receiver 4 no longer outperforms Receiver 3 as shown in the ND-RSIC simulation (Figure 6). The influence of the amplitude gains is mitigated when the demodulation procedure is added. This is another advantage of the D-RSIC technique.

In retrospect, there could be a concern regarding the addition of the demodulation procedure to the receiver. It may worsen the estimate of the reference signal due to decision making error. Once the error is made, the original transmitted signal is not fully recovered (re-created) due to few eventual errors contributed by the random nature of receiver noise. But, the previous simulation results prove the benefit of actually making decisions to mitigate the AWGN noise.

Another benefit of adding demodulation procedure is shown in Figure 8. The plot on the left shows ND-RSIC QPSK Receiver 2 demodulating signals with four different $\alpha_{1,2}$ values. The BER plot on the right (using the same α values) corresponds to where D-RSIC technique is implemented. The effect of noise accumulation in the reference signals is nullified by D-RSIC technique regardless of increasing $\alpha_{1,2}$ values.

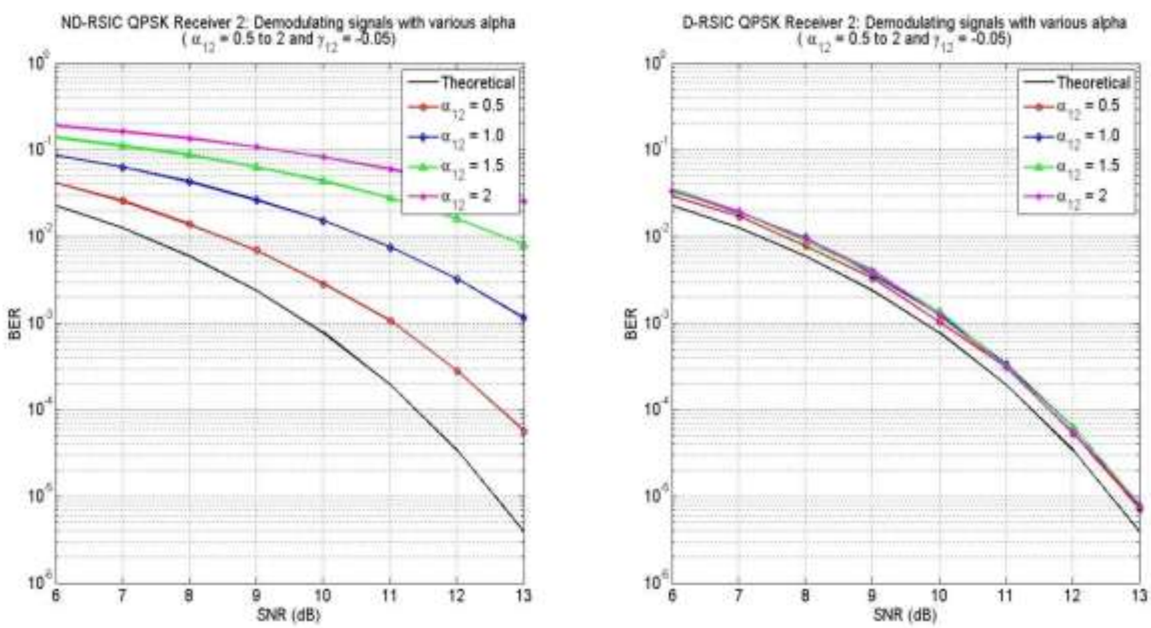

Figure 8. Comparison of ND-RSIC and D-RSIC QPSK Receiver 2 with various α values

C. COMPARISON OF NON-RSIC, NON-DEMODULATED, AND DEMODULATED TECHNIQUE AS A FUNCTION OF γ

In this section, the influence of interference factor γ is analyzed. In the simulation the γ values are varied to investigate the effects on BER.

1. Two Receivers

In this simulation, $\gamma_{1,2}$ is the variable allowed to vary. Since $\gamma_{1,2}$ is the difference between $\alpha_{1,2}$ and $\beta_{1,2}$ ($\gamma_{1,2} = \alpha_{1,2} - \beta_{1,2}$), changing $\gamma_{1,2}$ value (with fixed $\alpha_{1,2}$ scenario) is literally changing $\beta_{1,2}$ value as well.

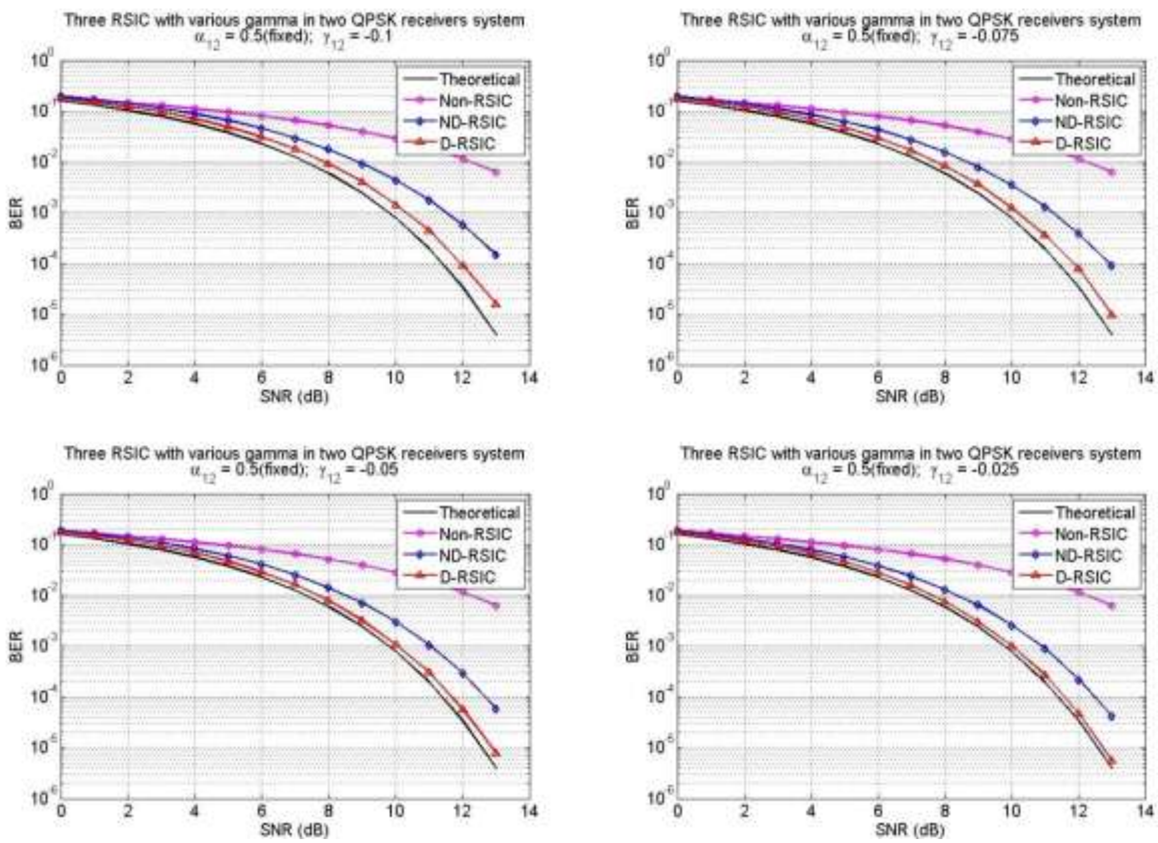

Figure 9. Comparison of three techniques in a two QPSK receiver system with fixed α and various γ values

In Figure 9, the comparison of three techniques with various $\gamma_{1,2}$ in a two QPSK-receiver system is tested. The value of $\gamma_{1,2}$ is varied from -0.1 to -0.025 with 0.025

increments. The deviations between these four BER plots are very small. The performances of two RSIC techniques are slightly improved when the absolute value of $\gamma_{1,2}$ is decreased. The factor $\gamma_{1,2}$ is the difference between amplitude gain and its estimate of reference signal 1 as received by Receiver 2. With fixed $\alpha_{1,2}$ value, $\beta_{1,2}$ value is increased and the absolute value of $\gamma_{1,2}$ is decreased. The result is modest improvement in BER as the estimates get closer to amplitude gains.

The influence of changing γ on ND-RSIC receivers seems to be not as significant when compared to changing α value (with fixed γ). Note however that the γ variation is smaller compare to α variation used in previous experiment.

2. Four Receivers

The simulation results of a four ND-RSIC QPSK-receiver system demodulating signals with various $\gamma_{1,2}$ are shown in Figure 10. The $\gamma_{1,2}$ value is varied from -0.1 to -0.025 with 0.025 increments. The simulation results show minor variation with various $\gamma_{1,2}$ values. Receiver 3 is outperforms Receiver 4 due to specially assigned $\beta_{3,4}$ value according to Table 2.

The advantage of D-RSIC technique in four-receiver system is shown in Figure 11. The performance of the receiver BERs is increased compared to ND-RSIC BERs in Figure 10. The performance impact of improving $\gamma_{1,2}$ value is modest. Again, the γ variation is smaller compared to α variation used in a previous experiment.

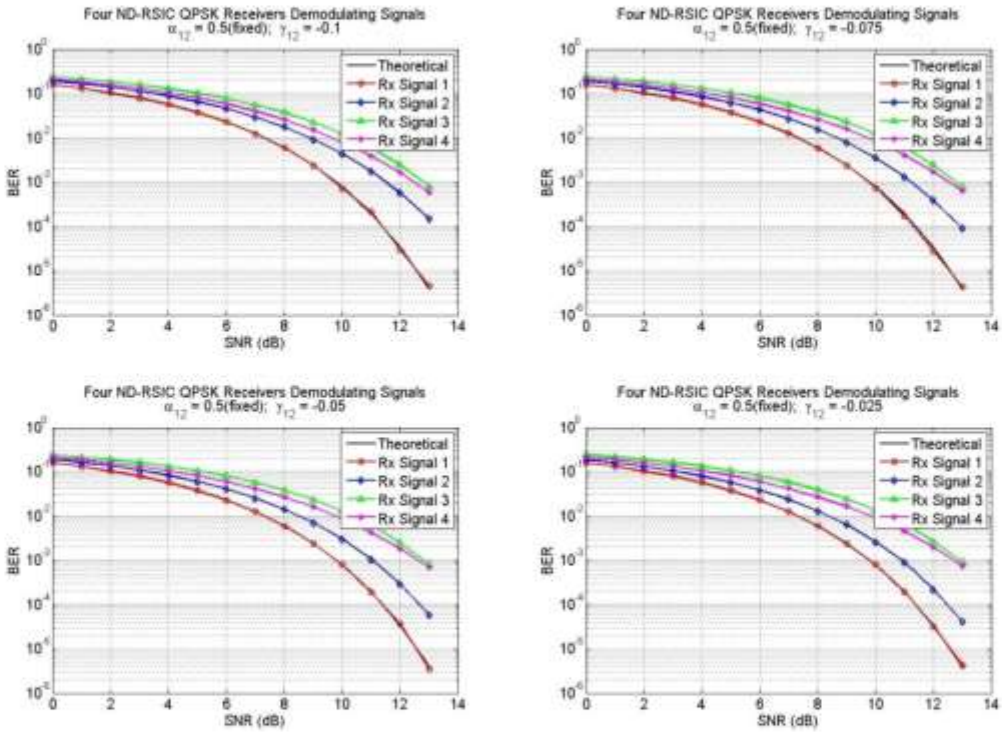

Figure 10. BER performances of a four ND-RSIC QPSK receiver system with various γ

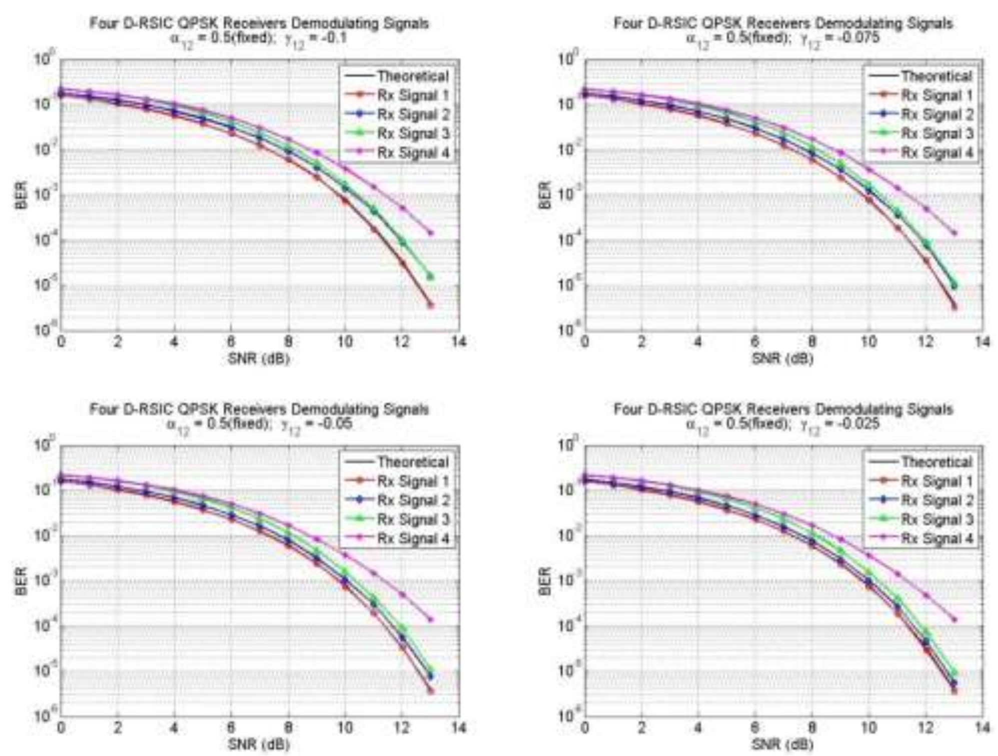

Figure 11. BER performances of a four D-RSIC QPSK receiver system with various γ

The γ value is the measurement of how close the β approaches to α value. Clearly, closer the two values are in terms of absolute value is the better. Theoretically, the interference can be totally eliminated if $\gamma = 0$ ($\alpha = \beta$).

Shown in Figure 12, BER performance of Receiver 2 is improved slightly when $\gamma_{1,2}$ (which is negative in value) increases. However, it decreases in absolute value. When $\gamma_{1,2}$ value increases (positive values as shown in Figure 13), the performance worsens for both schemes. However, D-RSIC scheme is clearly more robust than ND-RSIC scheme.

These two scenarios illustrate that the lower absolute $\gamma_{1,2}$ value results in the BER performance gain.

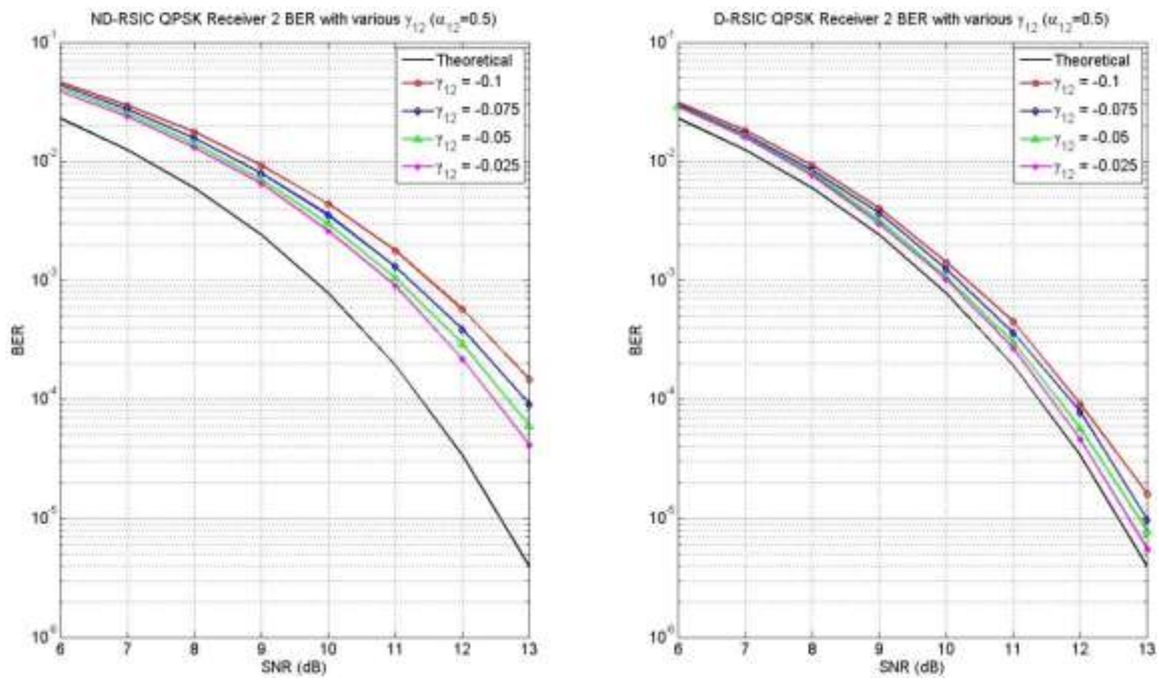

Figure 12. Comparison of ND-RSIC and D-RSIC QPSK Receiver 2 with various γ (negative γ values)

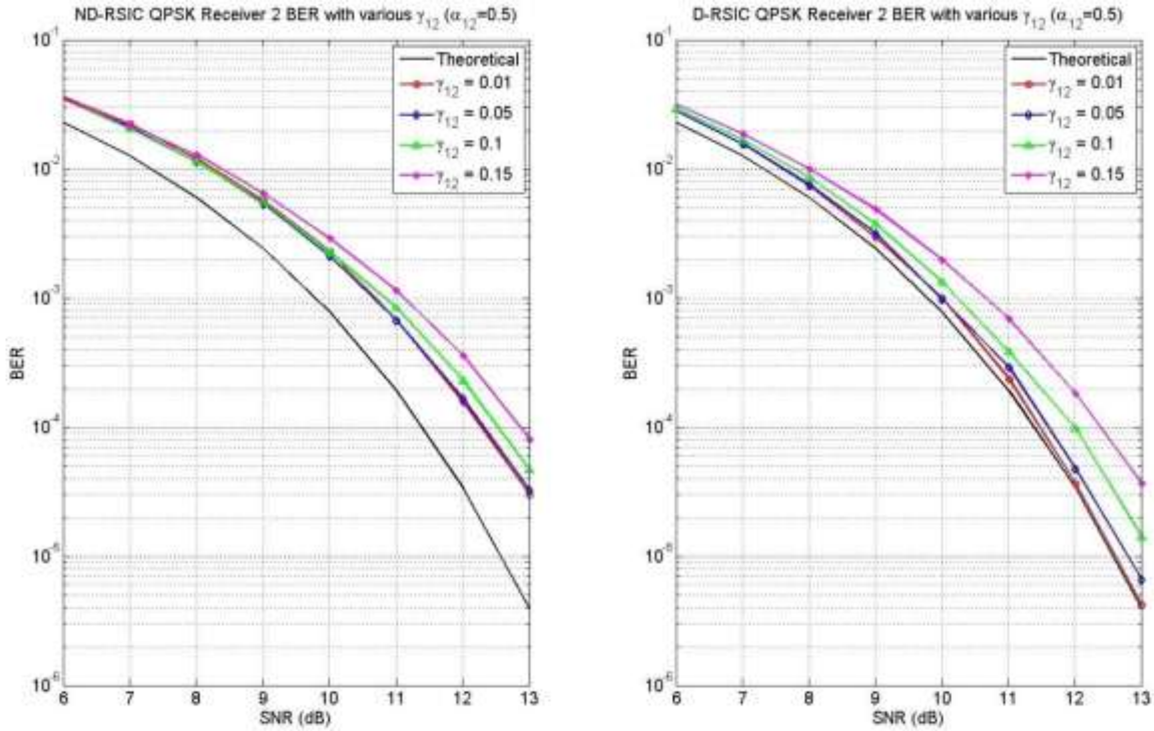

Figure 13. Comparison of ND-RSIC and D-RSIC QPSK Receiver 2 with various γ (positive γ values)

In Figure 13, the BER variation is very small when $\gamma_{1,2}$ value is below 0.1. D-RSIC receiver has better immunity to changing $\gamma_{1,2}$ values. As mentioned before, overall D-RSIC BER performances are better than ND-RSIC BER performances.

The simulations in this chapter prove that RSIC techniques boost receiver performance in multi-platform systems. The interference factor α seems to significant degradation on receiver performance compared to that of the γ factor. But we note however that the γ variation is smaller compared to α variation used.

D-RSIC is shown to be the better cancellation technique compared to ND-RSIC. This multi-platform receiver system can benefit applications designed to extract multiple signals from target areas.

IV OFDM SIMULATION

A. COMPARISON OF NON-RSIC, NON-DEMODULATED, AND DEMODULATED TECHNIQUE AS A FUNCTION OF α

In this chapter, the RSIC techniques are tested with the orthogonal frequency division multiplexing (OFDM) technique which is now widely used in many wireless systems including the popular IEEE 802.11a,g WLAN [2,3]. Simulations utilizing OFDM with 64 QPSK modulation subcarriers with 6 symbols cyclic prefix (CP) are coded using Matlab.

The base simulation model uses the same scenario discussed in the previous chapter, only one receiver's (Receiver 2) variable (α or γ) is allowed to vary at a time during the simulation. The values for these variables are configured using Table 2.

1. Two Receivers

In Figure 14, we show Receiver 2 BER results with the three previous techniques in a two-OFDM receiver system. The $\alpha_{1,2}$ value is varied from 0.5 to 2 with 0.5 increments. Despite the additional complexity of the OFDM modulation, the BER results are almost the same as the performance shown in Chapter IV using QPSK receivers. This is due to the orthogonal nature of the modulation. With non-RSIC, the BER suffers performance degradation with increasing $\alpha_{1,2}$ value. With ND-RSIC, BER performance is better compared to not doing any cancellation (Non-RSIC). The D-RSIC technique provides the best performance.

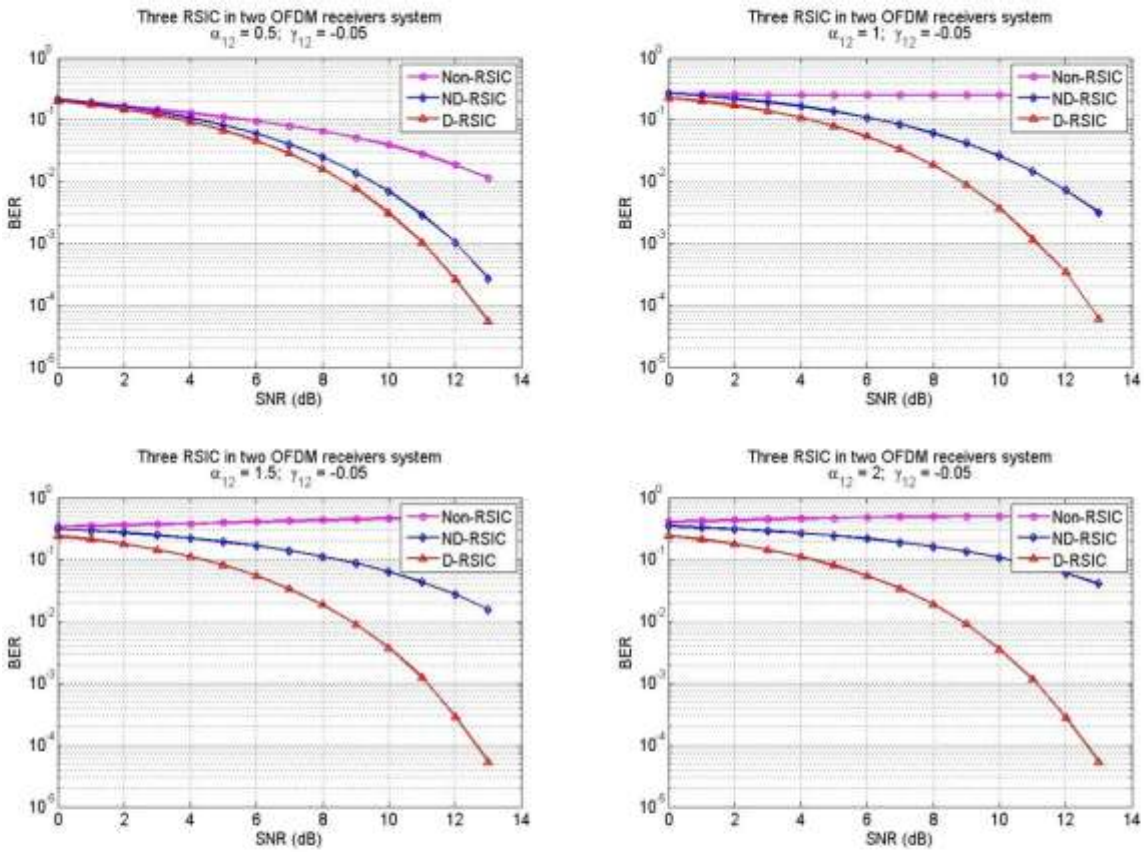

Figure 14. Comparison of three techniques in a two-OFDM receiver system with various α and fixed γ values

The BER performance of OFDM in AWGN is the same as the BER performance of the underlying modulation scheme (QPSK in this case) due to orthogonality of the subcarriers as mentioned before.

Cyclic prefix (CP) is a guard time added to the start of an OFDM symbol to eliminate intersymbol interference (ISI) [4]. The drawback of adding CP is a loss in throughput. In our simulation, the number of samples is increased from 64 to 80, which also increases symbol energy. Thus the signal level needs to be scaled down by a factor of $\sqrt{64/80}$ to keep the total symbol energy at the same level. This causes nearly a 1dB loss in BER performance as shown in this chapter.

2. Four Receivers

In a system of four OFDM receivers the value of $\alpha_{1,2}$ is increased from 0.5 to 2 in 0.5 increments. Both ND-RSIC and D-RSIC techniques are tested. The simulation results are shown in Figures 15, 16 and 17. By demodulating the reference signals, the BER performances of D-RSIC technique are better than that of ND-RISC technique.

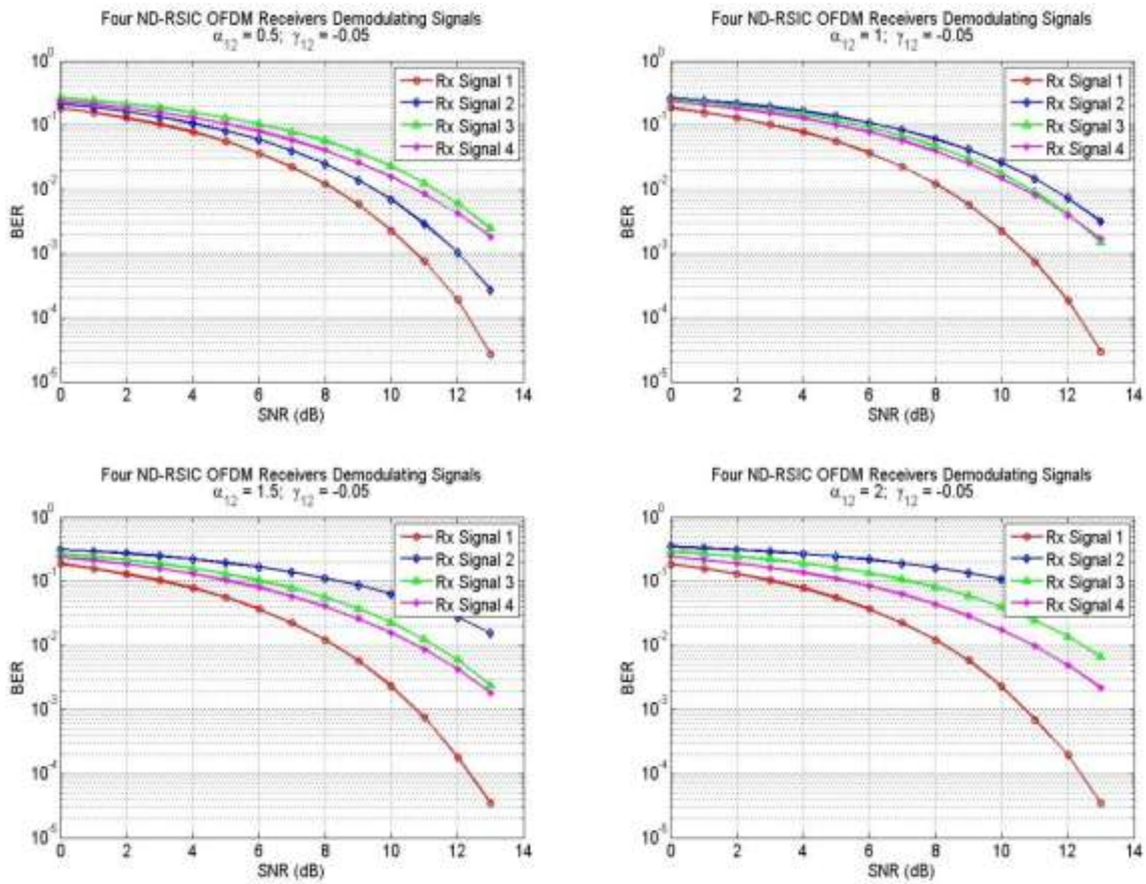

Figure 15. BER performances of a four ND-RSIC OFDM receiver system with various α values

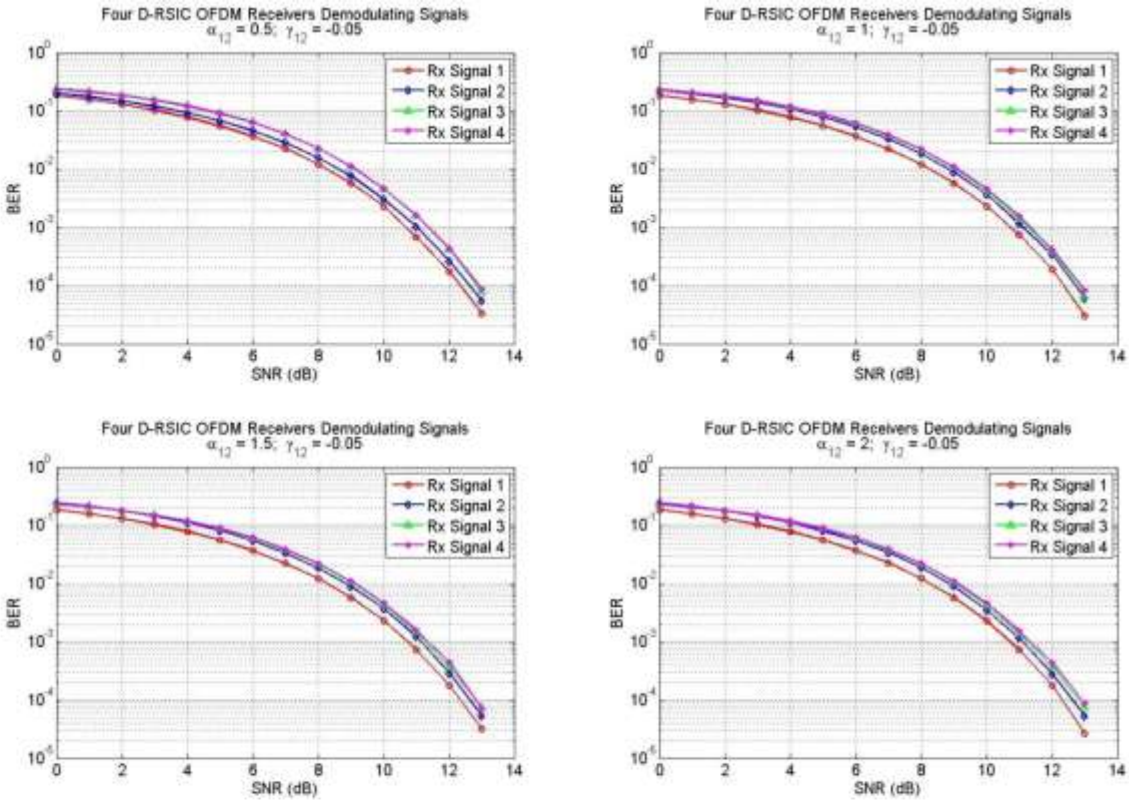

Figure 16. BER performances of a four ND-RSIC OFDM receiver system with various α values

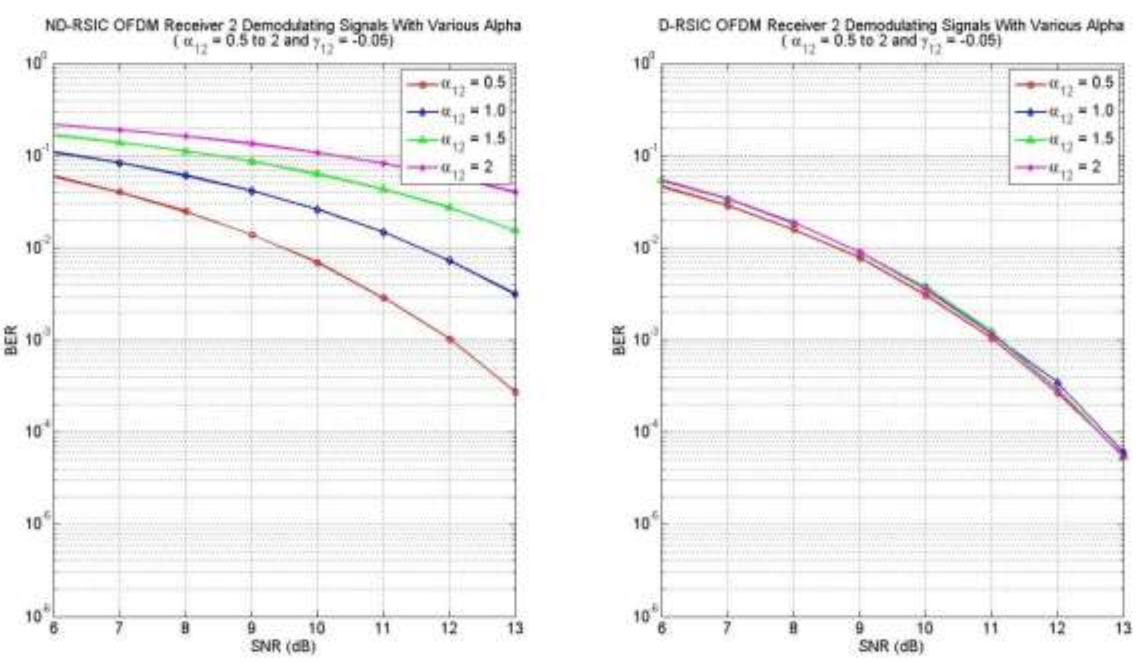

Figure 17. Comparison of ND-RSIC and D-RSIC OFDM Receiver 2 with various α

B. DEMODULATED TECHNIQUE AS A FUNCTION OF γ

In this section, the influence of difference factor γ is analyzed. According to the QPSK receiver simulation in Chapter IV, the influence of the difference factor γ is not as dramatic as varying amplitude gain factor α although we note that the γ variation used is smaller compared to α variation used in the experiments in Chapter IV.

1. Two Receivers

In Figure 18, we show the comparison of three techniques in a two OFDM receiver system with fixed $\alpha_{1,2}$ value (0.5) and various $\gamma_{1,2}$ values. The value of $\gamma_{1,2}$ are negative. It is increased from -0.1 to -0.025 with 0.025 increments (decrease in absolute values).

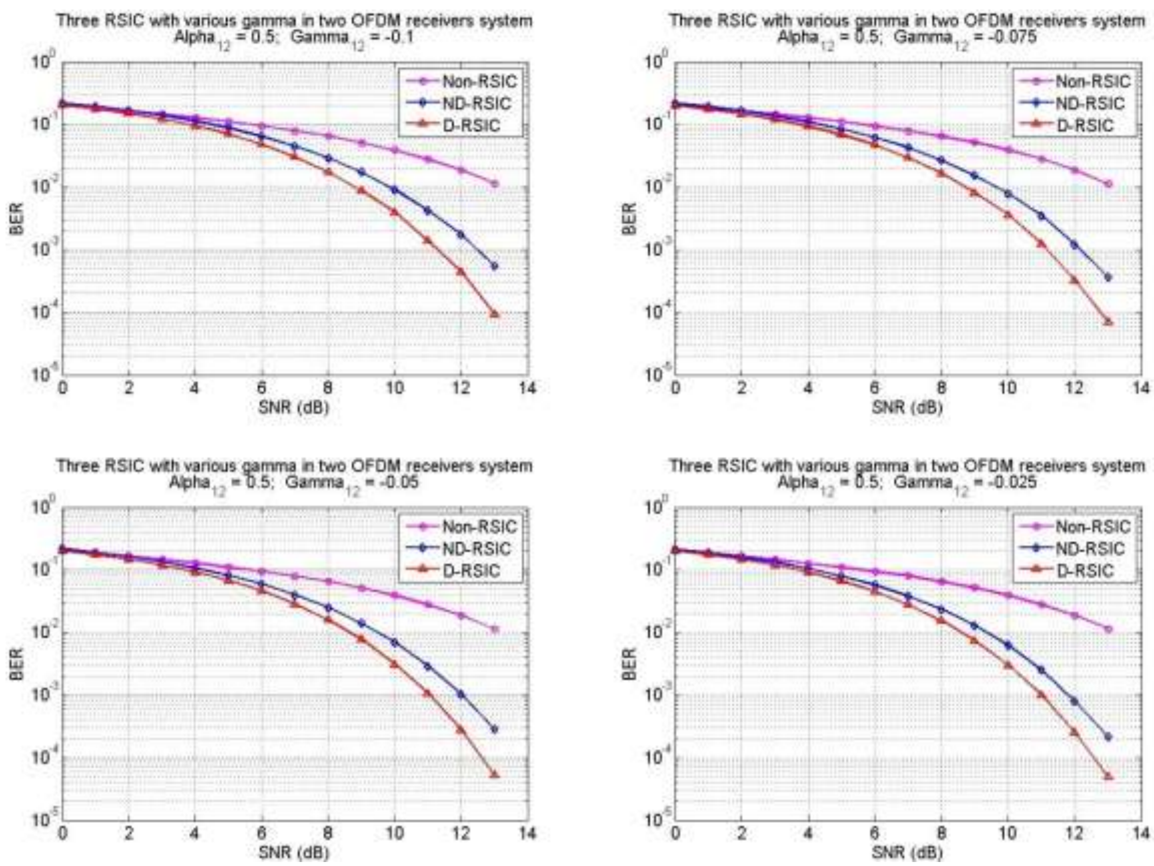

Figure 18. Comparison of three techniques in a two OFDM receiver system with fixed α and various γ values

2. Four Receivers

In Figures 19 and 20, we show the BER results of two cancellation techniques. As now expected, D-RSIC technique is superior to ND-RISC in terms of performance.

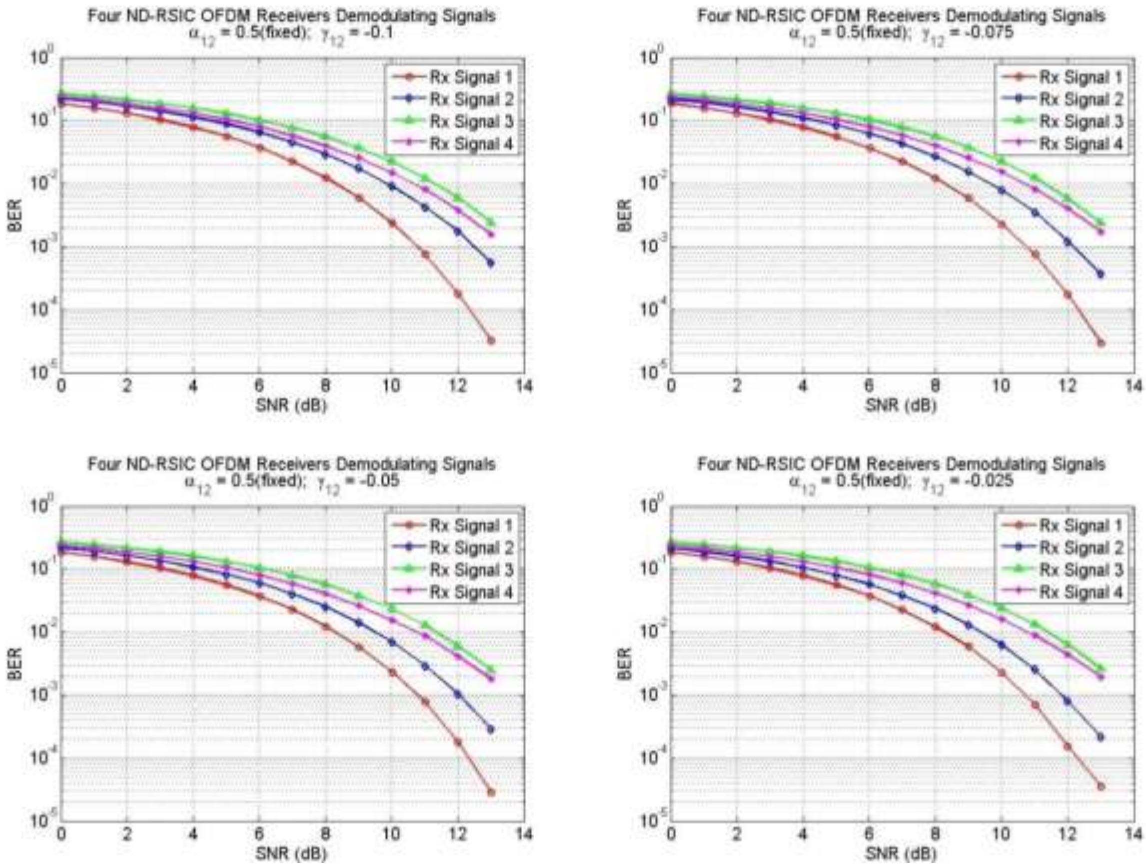

Figure 19. BER performances of a four ND-RSIC OFDM receiver system with γ various value

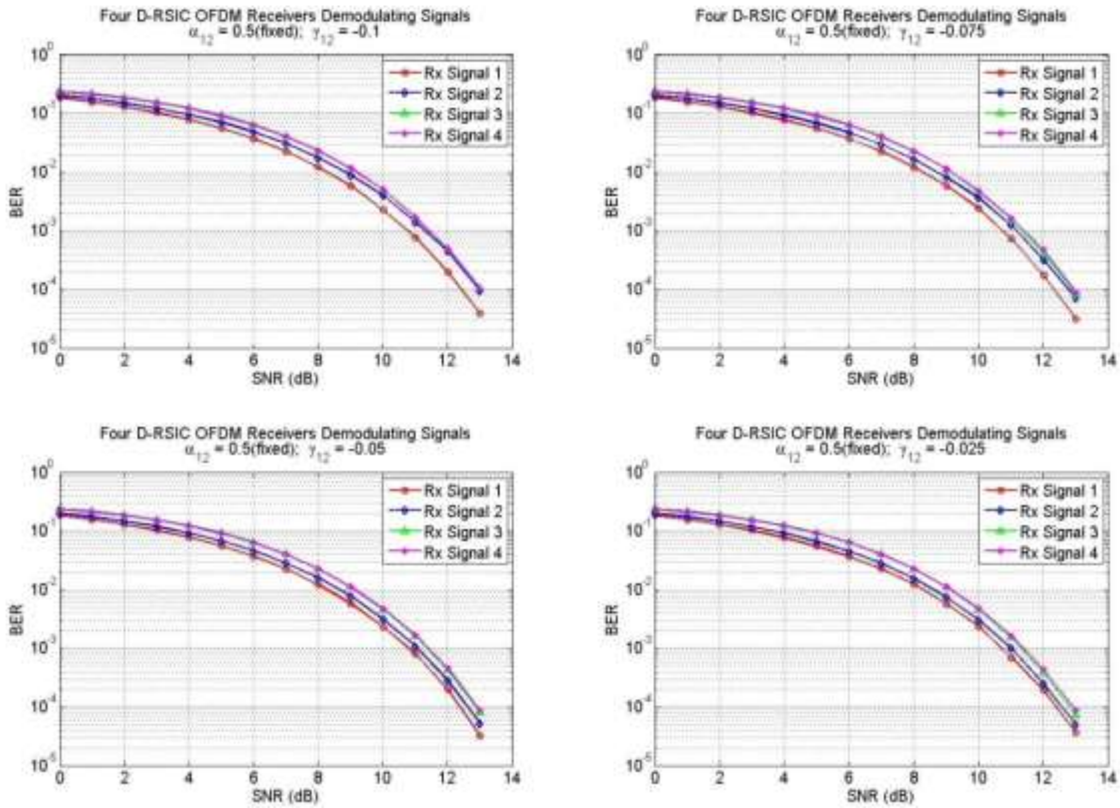

Figure 20. BER performances of a four D-RSIC OFDM receiver system with various γ value

In Figures 21 and 22, we show the BER curves fir Receiver 2 with various $\gamma_{1,2}$ values. The smaller γ absolute value means BER performance improves correspondingly.

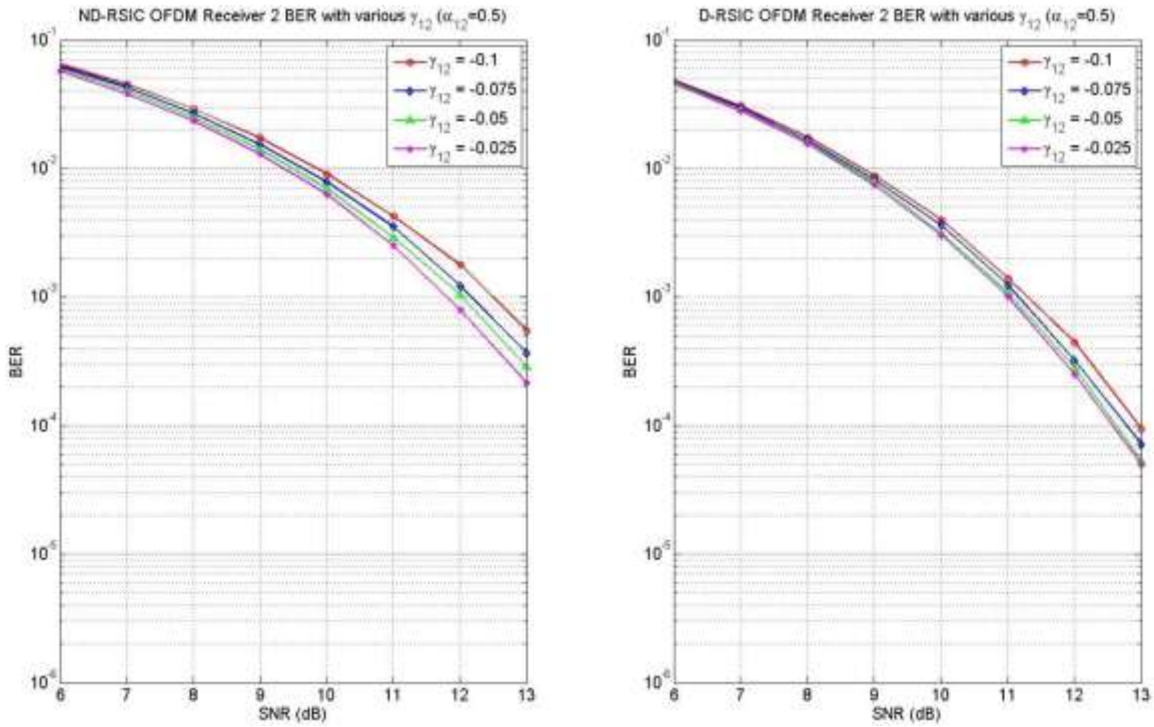

Figure 21. Comparison of ND-RSIC and D-RSIC OFDM Receiver 2 with various γ (negative γ values)

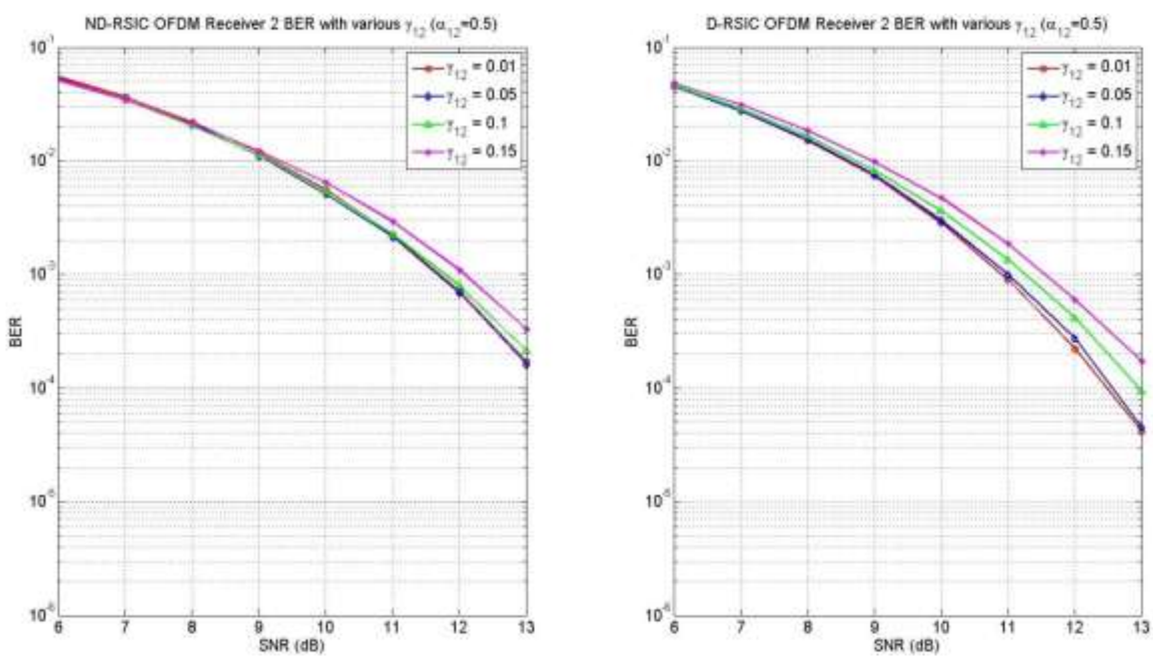

Figure 22. Comparison of ND-RSIC and D-RSIC OFDM Receiver 2 with various γ (positive γ values)

In this chapter, we consider OFDM with QPSK modulation. Both RISC techniques improve the BER performances of multi-platform receivers. The D-RSIC technique performs the best. The interference factor α causes significant impact on receiver. With D-RSIC, the performance is not as sensitive to α variations, which is the great benefit of this technique.

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V CONCLUSIONS

A. SUMMARY

Reference-based successive interference cancellation techniques (RSIC) techniques boost the BER performances of multi-platform receivers. The first intercepted signal (used as initial reference signal) is sent to the subsequent receiver to be subtracted. Once the interference is eliminated, a new reference signal is sent to the next receiver. After the final receiver, the final target signal or signal of interest can be extracted.

One crucial key step in the RSIC procedure is to obtain an interference-free reference signal. This can be achieved by positioning the receiver at a favorable location. The same goes for other receivers.

Three variables, gain factor, its estimate, and difference gain factor, (α, β, and γ) are utilized to model received signals. The amplitude gain α is the gain of unwanted signal leaking into a receiver. The variable β is the estimate of α for that receiver. The variable γ is the difference between α and β.

In our simulations, the performance of a receiver is greatly influenced by changing α. Similarly the performance is also influenced by varying γ. By implementing the D-RSIC technique, significant improvements in BER are realized due to the elimination of the noise accumulation in the reference signals. The D-RSIC technique adds demodulation to each receiver thereby requiring more signal processing, software and processing time compared to ND-RSIC receivers, but the benefits of the extra step pays off tremendously in BER performance.

B. CONCLUSION

The performance of new proposed reference-based successive interference cancellation techniques are validated by Matlab simulations. The BERs are improved. Thus, target SOIs can be extracted.

The D-RSIC technique has more signal processing needs than ND-RSIC but yields a tremendous gain in BER performance.

C. FUTURE WORK

We recommend future studies to explore actual estimation of α with β.

LIST OF REFERENCES

[1] F. Berggren and S.B. Slimane, "Successive Interference Cancellation in Multi-Rate DS-CDMA Systems", IEEE, 2003.

[2] IEEE Standards 802.11a, 1999.

[3] IEEE Standards 802.11g, 2003.

[4] T. T. Ha, "Theory and Design of Digital Communication Systems," Cambridge University Press, New York, 2011.

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APPENDIX A

Figures 2 to 8 (QPSK simulation with various α) and Figures 14 to 17 (OFDM simulation with various α) are generated by the following Matlab codes:

```
% ******************************************************************
% Description:
% 1. Four QPSK/OFDM emitters and receivers
% 2. Three techniques: non-RSIC, Non-Demodulated and Demodulated RSIC
% 3. At Receiver 2, alpha12 changes from 0.5 to 2, Gamma12 = -
0.05(fixed)
% 4. For Thesis Chapter III QPSK and Chapter IV OFDM various alpha
%*******************************************************************
clc; clear all; close all
format long;
% choose simulation model: (1)QPSK; (2)OFDM
disp('RSIC simulation with various alpha and fixed gamma value')
ch = input('Choose (1)QPSK Simulation or (2)OFDM Simulation : ');
tic % start clock to measure performance

% Bit length
if ch == 1 % QPSK simulaiton
    bit_length = 1e6;
elseif ch == 2 % OFDM simulation
    % Bit Length
    M=4;                 % Number of symbols in constellation (QPSK = 4)
    k=log2(M);           % Bits per symbol
    n_fft=64;            % Size of FFT(number of OFDM carriers)
    n_cyc=16;            % Length of cyclic prefix (OFDM)
    n_symbols = 1e4;   % Number of symbols;n_symbols=(bit_count/k)/n_fft
    bit_length=k*n_fft*n_symbols; %bl=(bits/symbol)*(FFTsize)*(symbols)
end
% Range of SNR(dB) to simulate
EbNo = -3: 1: 10;
% Convert Eb/No values to channel SNR
SNR = EbNo + 10*log10(2);
%% Define variables - interference amplitude gain factor
% Alpha: Interference signal amplitude received at receiver
alpha13 = .9; % Signal 1 leaks into Receiver 3
alpha23 = .9; % Signal 2 leaks into Receiver 3
alpha14 = .8; % Signal 1 leaks into Receiver 4
alpha24 = .8; % Signal 2 leaks into Receiver 4
alpha34 = .7; % Signal 3 leaks into Receiver 4
% Beta: Reference signal amplitude received at subsequent receiver
beta13 = .95; %Receiver 1 to receiver 3
beta14 = .95; %Receiver 1 to receiver 4
beta23 = .9;  %Receiver 2 to receiver 3
beta24 = .9;  %Receiver 2 to receiver 4
beta34 = .65; %Receiver 3 to receiver 4
% Various alpha12 and fixed gamma
alpha12 = 0.5: 0.5 :2; % Change from 0.5 to 2 with 0.5 increments
gamma12 = -0.05; % Fixed Gamma value (Gamma = Alpha - Beta)
```

```
%% create BER buffers (to increase Matlab speed, not necessary)
BER = zeros(4,length(SNR));  % 4: FOUR receivers
%save Rcvr2 SNR of various alpha12
BER_ND_RSIC_Rcv2_alpha= zeros(length(alpha12),length(SNR));
BER_D_RSIC_Rcv2_alpha = zeros(length(alpha12),length(SNR));
%% Start various Alpha12 calculation loop
for alpha_count = 1: 1: length(alpha12)  % Calculate each alpha12
    beta12 = alpha12(alpha_count) - gamma12; % Changes with Alpha12
 for RSIC_count = 1 : 1 :3 % Do three RSIC techniques one at a time
     %1: Non-RSIC; 2: Non-demodulated RSIC; 3: Demodulated RSIC
%% Start the main calculation loop for each SNR
 for snr_count = 1: 1: length(SNR)
    % Initiate values for error buffer
    Tx_Errors = [0; 0; 0; 0]; % FOUR rows = FOUR receivers
    Tx_bits   = [0; 0; 0; 0]; % FOUR rows = FOUR receivers
    % Keep running until we get 100 errors in Signal 1
    while Tx_Errors(1,:) < 100
        %% Generate information bits, Four rows for Four
signals(emitters)
        uncoded_bits  = round(rand(4,bit_length)); % 4: FOUR receivers
        %% Split each signal into two streams, for Quadrature Carriers
        I = uncoded_bits(:,1:2:end);     % get odd bits
        Q = uncoded_bits(:,2:2:end);     % get even bits
        % QPSK modulator set to pi/4 radians constellation(Transmitter)
        Tx_sig =...
            ((I==0).*(Q==0)*(exp(1i*pi/4))...
            +(I==0).*(Q==1)*(exp(3*1i*pi/4))...
            +(I==1).*(Q==1)*(exp(5*1i*pi/4))...
            +(I==1).*(Q==0)*(exp(7*1i*pi/4)));
        if ch == 2 % OFDM simulation
            %% OFDM Modulation
            for n = 1 : n_symbols;
              s_ofdm = sqrt(n_fft)*ifft(Tx_sig(:,(n-1)*n_fft+1:...
                  n*n_fft)',n_fft);   %Normalized IFFT operation
              s_ofdm_cyc = sqrt(n_fft/(n_fft+n_cyc)) * [s_ofdm(n_fft...
                 -n_cyc+1 : n_fft,:); s_ofdm]; %Appending cyclic prefix
              OFDM_tx(:,(n-1)*(n_fft+n_cyc)+1 : n*(n_fft+n_cyc))...
                  = s_ofdm_cyc'; % Combine subcarriers into one to tx
            end
            Tx_sig = OFDM_tx;
        end

        %% Gaussian Link Noise
        No = 1/10^(SNR(snr_count)/10); %Noise variance
        Noise = sqrt(No/2)*... % 4 ramdom noises for four channels
                 (randn(4,length(Tx_sig))+1i*randn(4,length(Tx_sig)));
        %% Receiver intercepted signals
        % including target SOI and interferences from adjcent emitters
        Rx_received = zeros(4,length(Tx_sig)); % Create buffer
        % Receiver 1: Signal 1 + Noise 1
        Rx_received(1,:) = Tx_sig(1,:)+ Noise(1,:);
        % Receiver 2: Signal 2 + (alpha12 * S1) + Noise 2
        Rx_received(2,:) = Tx_sig(2,:)+...
          (alpha12(alpha_count) * Tx_sig(1,:))+ Noise(2,:);
        %Receiver 3: Signal 3 +(alpha23 * S2) +(alpha13 * S1) +Noise 3
```

```
        Rx_received(3,:) = Tx_sig(3,:)+ (alpha23 * Tx_sig(2,:))+...
          (alpha13 * Tx_sig(1,:))+ Noise(3,:);
        % Receiver 4: S4 + (a34 * S3) + (a24 * S2) +(a14 * S1) +Noise 4
        Rx_received(4,:) = Tx_sig(4,:)+ (alpha34 * Tx_sig(3,:))+...
          (alpha24 * Tx_sig(2,:))+ (alpha14 * Tx_sig(1,:))+ Noise(4,:);
%%----------------------------------------------------------------------
        %% Reference-based successive interference cancellation
procedures
        %  run one RSIC technique at a time
        %% Non-RSIC
        if RSIC_count == 1
        Rx_proced = Rx_received; % no cancellation procedure

        %% Non-Demodulated RSIC
        elseif RSIC_count == 2
        % Signal 1 is used as reference directly; Intercepted signals
        % will be subtract by reference signal with a factor Beta
        Rx_proced = Rx_received;  % Create buffer and save Signal 1
        Rx_proced(2,:) = Rx_received(2,:)-(beta12 * Rx_proced(1,:));%S2
        Rx_proced(3,:) = Rx_received(3,:) - (beta23*Rx_proced(2,:))...
            - (beta13 * Rx_proced(1,:));  % get Signal 3 only
        Rx_proced(4,:) = Rx_received(4,:) - (beta34*Rx_proced(3,:))...
            - (beta24 * Rx_proced(2,:)) - (beta14*Rx_proced(1,:)); % S4
        %% Demodulated RSIC
        elseif RSIC_count == 3
        % Demodulate 1st received QPSK signal(with noise) at Receiver 1
        % remodulate and send it to Receiver 2 as reference signal.
        % repeats at the rest of the receivers
        Rx_proced = zeros(4,length(Rx_received)); %Buffer
        % Begin with SIC, then perform demodulation
        for rcv_count = 1 : 4  % 4: FOUR receivers
            % Interference cancellation
            if rcv_count == 1 % At Receiver One, no SIC and detection
               Rx_proced(1,:)= Rx_received(1,:); % save ref signal 1
            elseif rcv_count == 2 % Perform RSIC at Receiver Two
               Rx_proced(2,:)=Rx_received(2,:)-(beta12*Rx_proced(1,:));
            elseif rcv_count == 3 % At Receiver Three
             Rx_proced(3,:)=Rx_received(3,:)-(beta23*Rx_proced(2,:))...
                    - (beta13 * Rx_proced(1,:));
            elseif rcv_count == 4 % At Receiver Four
             Rx_proced(4,:)=Rx_received(4,:)-(beta34*Rx_proced(3,:))...
                    -(beta24*Rx_proced(2,:))-(beta14*Rx_proced(1,:));
            end

            if ch == 2 % OFDM simulation
               % OFDM Demodulation
               for n = 1 : n_symbols;
               r_ofdm_cyc = Rx_proced(:,(n-1)*(n_fft+n_cyc)+1 :...
                   n*(n_fft+n_cyc));  % retrieve each ofdm symbol
               r_ofdm = r_ofdm_cyc(:,n_cyc+1:n_fft+n_cyc)'; %Remove CP
               r_qpsk=fft(r_ofdm,n_fft)/sqrt(n_fft);    %Normalized FFT
               QPSK_ref(:,(n-1)*n_fft+1:n*n_fft) = r_qpsk';
               end
               Rx_proced = QPSK_ref;
            end
```

```
            % QPSK detection on received signal
            % Need to flip I and Q here to have correct sequence!
            Q(rcv_count,:) = (real(Rx_proced(rcv_count,:))<0);
            I(rcv_count,:) = (imag(Rx_proced(rcv_count,:))<0);

            % Remodulate for transmition (as referecnce signal)
            Rx_proced(rcv_count,:)=...
((I(rcv_count,:)==0).*(Q(rcv_count,:)==0)*(exp(1i*pi/4))...
+(I(rcv_count,:)==0).*(Q(rcv_count,:)==1)*(exp(3*1i*pi/4))...
+(I(rcv_count,:)==1).*(Q(rcv_count,:)==1)*(exp(5*1i*pi/4))...
+(I(rcv_count,:)==1).*(Q(rcv_count,:)==0)*(exp(7*1i*pi/4)));

            if ch ==2 % OFDM simulation
               % OFDM re-Modulation
               for n = 1 : n_symbols;
                 s_ofdm=sqrt(n_fft)*ifft(Rx_proced(:,(n-1)*n_fft+1:...
                 n*n_fft)',n_fft);
                 s_ofdm_cyc = sqrt(n_fft/(n_fft+n_cyc))*...
                [s_ofdm(n_fft-n_cyc+1:n_fft,:);s_ofdm];
                 OFDM_ref(:,(n-1)*(n_fft+n_cyc)+1:n*(n_fft+n_cyc))=...
                     s_ofdm_cyc';
               end
               Rx_proced = OFDM_ref;
            end % End of OFDM simulation
        end % End of Demodulated-RSIC
        end % End of three RSIC techniques loop
%% -----------------------------------------------------
        %% Final demodulation at receiver for BER calculation
        if ch == 2 % OFDM simulation
         % OFDM Demodulation
         for n = 1 : n_symbols;
         r_ofdm_cyc=Rx_proced(:,(n-1)*(n_fft+n_cyc)+1:n*(n_fft+n_cyc));
         r_ofdm = r_ofdm_cyc(:,n_cyc+1:n_fft+n_cyc)'; %Remove CP
         r_qpsk=fft(r_ofdm,n_fft)/sqrt(n_fft);    %Normalized FFT
         QPSK_Rcv(:,(n-1)*n_fft+1:n*n_fft) = r_qpsk';
         end
         Rx_proced = QPSK_Rcv;
        end
        % QPSK Demodulation
        I_rx = (real(Rx_proced)<0); %Detection
        Q_rx = (imag(Rx_proced)<0);
        uncoded_bits_rx = zeros(4,2*length(Rx_proced));
        uncoded_bits_rx(:,1:2:end) = Q_rx;     %converge split streams
        uncoded_bits_rx(:,2:2:end) = I_rx;     %converge split streams
        %% Sum up bit errors
        diff = uncoded_bits - uncoded_bits_rx;     % find the errors
        Tx_Errors = Tx_Errors + sum(abs(diff),2); % 2 : sum columns
        Tx_bits = Tx_bits + length(uncoded_bits);
    end % end of while loop(keep running until # of errors)
    %% Calculate Bit Error Rate of each SNR
    BER(:,snr_count) = Tx_Errors./Tx_bits;  %Calculate BER for each SNR
 end  % end of each SNR calculation loop
%------------------------------------------------------------
 %% save BERs of each SNR
```

```
% save BER (all four channels) of ND-RSIC and D-RSIC separately.
   if RSIC_count == 1      % Non-RSIC
       BER_Non_RISC = BER; % Save BER of all 4 signals (Non-RSIC)
   elseif RSIC_count == 2  % Non-Demodulated RSIC
       BER_ND_RSIC = BER; %save BER of all 4 signals (ND-RSIC)
   elseif RSIC_count == 3  % Demodulated RSIC
       BER_D_RSIC = BER;   % save BER of all 4 signals (D-RSIC)
   end % end of saving BER of all four signals in three RSIC
%-------------------------------------------------------------
end % end of three RSIC techniques loop

 %% save Receiver 2 BER of each alpha12
 BER_ND_RSIC_Rcv2_alpha(alpha_count,:) = BER_ND_RSIC(2,:); %ND_RSIC
 BER_D_RSIC_Rcv2_alpha(alpha_count,:) = BER_D_RSIC(2,:);   %D_RSIC

%% Comparison of three RSIC, Show Receiver 2(same as two receivers)
figure(1)
subplot(2,2,alpha_count)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results
semilogy(SNR,BER_Non_RISC(2,:),'m-o','LineWidth',2)
semilogy(SNR,BER_ND_RSIC(2,:),'b-d','LineWidth',2)
semilogy(SNR,BER_D_RSIC(2,:),'r-^','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
legend('QPSK Theory', 'Non-RSIC', 'ND-RSIC', 'D-RSIC');
if ch == 1 % QPSK simulation
   title(['Three RSICs in a two QPSK receiver system',...
   sprintf('\n'),'\alpha_{12} = ', num2str(alpha12(alpha_count)),...
    ';  \gamma_{12} = ', num2str(gamma12)]);
elseif ch == 2 % OFDM simulation
    title(['Three RSICs in a two OFDM receiver system',...
    sprintf('\n'),'Alpha_{12} = ', num2str(alpha12(alpha_count)),...
    ';  \gamma_{12} = ', num2str(gamma12)]);
end
grid on;

%% plot ND-RSIC all four signals (in one given alpha value)
figure(2)
subplot(2,2,alpha_count)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2)
hold on
% Simulation results (Non-Demudulated RSIC)
semilogy(SNR,BER_ND_RSIC(1,:),'-or','LineWidth',2)
semilogy(SNR,BER_ND_RSIC(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_ND_RSIC(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_ND_RSIC(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
legend('QPSK Theory','Rx Signal 1','Rx Signal 2','Rx Signal 3',...
```

```
    'Rx Signal 4');
if ch == 1 % QPSK simulation
  title(['Four ND-RSIC QPSK receivers demodulating signals',...
  sprintf('\n'),'\alpha_{12} = ', num2str(alpha12(alpha_count)),...
  ';  \gamma_{12} = ', num2str(gamma12)]);
elseif ch == 2 % OFDM simulation
  title(['Four ND-RSIC OFDM receivers demodulating signals',...
  sprintf('\n'),'\alpha_{12} = ', num2str(alpha12(alpha_count)),...
  ';  \gamma_{12} = ', num2str(gamma12)]);
end
grid on
hold off

%% plot Demodulated RSIC all four signals (in one given alpha value)
figure(3)
subplot(2,2,alpha_count)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results (Demodulated RSIC)
semilogy(SNR,BER_D_RSIC(1,:),'-or','LineWidth',2)
semilogy(SNR,BER_D_RSIC(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_D_RSIC(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_D_RSIC(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
legend('QPSK Theory','Rx Signal 1','Rx Signal 2','Rx Signal 3',...
    'Rx Signal 4');
%axis([8 13 10^(-6) 1.0])
 if ch == 1 % QPSK simulation
  title(['Four ND-RSIC QPSK receivers demodulating signals',...
  sprintf('\n'),'\alpha_{12} = ', num2str(alpha12(alpha_count)),...
  ';  \gamma_{12} = ', num2str(gamma12)]);
elseif ch == 2 % OFDM simulation
  title(['Four ND-RSIC OFDM receivers demodulating signals',...
  sprintf('\n'),'\alpha_{12} = ', num2str(alpha12(alpha_count)),...
  ';  \gamma_{12} = ', num2str(gamma12)]);
end
grid on
hold off

end  % end of various Alpha12 loop

%% Plot BER Vs. SNR(dB) Curve on logarithmic scale
%% Non-Demodulated RSIC Receiver 2 in various alpha
%% Non-Demodulated RSIC Receiver 2 in various alpha
figure(4)
subplot(1,2,1)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results (Non-Demudulated RSIC)
semilogy(SNR,BER_ND_RSIC_Rcv2_alpha(1,:),'-or','LineWidth',2)
```

```
semilogy(SNR,BER_ND_RSIC_Rcv2_alpha(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_ND_RSIC_Rcv2_alpha(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_ND_RSIC_Rcv2_alpha(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
if ch == 1 % QPSK simulation
title(['ND-RSIC QPSK Receiver 2 demodulation with various alpha',...
    sprintf('\n'),'( \alpha_{12} = 0.5 to 2 and \gamma_{12} = ',...
    num2str(gamma12),')']);
elseif ch == 2 % OFDM simulation
    title(['ND-RSIC OFDM Receiver 2 demodulation with various alpha',...
    sprintf('\n'),'( \alpha_{12} = 0.5 to 2 and \gamma_{12} = ',...
    num2str(gamma12),')']);
end
legend('QPSK Theory', '\alpha_{12} = 0.5', '\alpha_{12} = 1.0',...
    '\alpha_{12} = 1.5', '\alpha_{12} = 2')
axis([6 13 10^(-6) 1.0])
grid on;

%% Demodulated RSIC Receiver 2 in various alpha
figure(4)
subplot(1,2,2)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results (Demudulated RSIC)
semilogy(SNR,BER_D_RSIC_Rcv2_alpha(1,:),'-or','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_alpha(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_alpha(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_alpha(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
if ch == 1 % QPSK simulation
title(['D-RSIC QPSK Receiver 2 demodulation with various alpha',...
    sprintf('\n'),'( \alpha_{12} = 0.5 to 2 and \gamma_{12} = ',...
    num2str(gamma12),')']);
elseif ch == 2 % OFDM simulation
    title(['D-RSIC OFDM Receiver 2 demodulation with various alpha',...
    sprintf('\n'),'( \alpha_{12} = 0.5 to 2 and \gamma_{12} = ',...
    num2str(gamma12),')']);
end
legend('QPSK Theory', '\alpha_{12} = 0.5', '\alpha_{12} = 1.0',...
    '\alpha_{12} = 1.5', '\alpha_{12} = 2')
axis([6 13 10^(-6) 10^(0)])
grid on;
toc
% *******************END of Simulation***********************
```

Figures 9 to 13 (QPSK simulation with various γ) and Figures 18 to 22 (OFDM simulation with various γ) are generated by the following Matlab codes:

```
%***************************************************************
% Description:
% 1. Four QPSK/OFDM emitters and receivers
% 2. Three techniques: non-RSIC, Non-Demodulated and Demodulated RSIC
% 3. At Receiver 2, alpha12 varies and Gamma12 = -0.05(fixed)
%**********************************************************************
clc; clear all; close all
format long;
% choose simulation model: (1)QPSK; (2)OFDM
disp('RSIC simulation with fixed alpha and various gamma value')
ch = input('Choose (1)QPSK Simulation or (2)OFDM Simulation : ');
ch_gamma = input('Choose (1)Positive or (2)Negative Gamma Value: ');
tic % start clock to measure performance
% Bit length
if ch == 1 % QPSK simulaiton
    bit_length = 1e6;
elseif ch == 2 % OFDM simulation
    % Bit Length
    M=4;                % Number of symbols in the constellation
    k=log2(M);          % Bits per symbol
    n_fft=64;           % Size of FFT(number of OFDM carriers)
    n_cyc=16;           % Length of cyclic prefix (OFDM)
    n_symbols = 1e4; % Number of symbols;n_symbols=(bit_count/k)/n_fft
    bit_length=k*n_fft*n_symbols; %bl=(bits/symbol)*(FFTsize)*(symbols)
end
% Range of SNR(dB) to simulate
EbNo = -3: 1: 10;
% Convert Eb/No values to channel SNR
SNR = EbNo + 10*log10(2);

%% Define variables - interference amplitude gain factor
% Alpha
alpha12 = .5; % Signal 1 leaks to Receiver 2
alpha13 = .9; % Signal 1 leaks into Receiver 3
alpha23 = .9; % Signal 2 leaks into Receiver 3
alpha14 = .8; % Signal 1 leaks into Receiver 4
alpha24 = .8; % Signal 2 leaks into Receiver 4
alpha34 = .7; % Signal 3 leaks into Receiver 4
% Beta: Reference signal amplitude received at subsequent receiver
beta13 = .95; %Receiver 1 pass reference signal to receiver 3
beta14 = .95; %Receiver 1 pass reference signal to receiver 4
beta23 = .9;  %Receiver 2 pass reference signal to receiver 3
beta24 = .9;  %Receiver 2 pass reference signal to receiver 4
beta34 = .65; %Receiver 3 pass reference signal to receiver 4

% Various gamma12 (Gamma = Alpha - Beta)
if ch_gamma == 1     % positive gamma value
    gamma12 = [0.01 0.05 0.1 0.15];
elseif ch_gamma == 2 % negative gamma value
    gamma12 = -0.1: 0.025: -0.025;
```

```
end
%% create BER buffers (to increase Matlab speed, not necessary)
BER = zeros(4,length(SNR));  % 4: FOUR receivers
%save Rcvr2 SNR of various gamma12
BER_ND_RSIC_Rcv2_gamma= zeros(length(gamma12),length(SNR));
BER_D_RSIC_Rcv2_gamma = zeros(length(gamma12),length(SNR));

%% Start various Gamma12 calculation loop
for gamma_count = 1: 1: length(gamma12)  % Calculate each gamma12
    beta12 = alpha12 - gamma12(gamma_count); % various gamma12
 for RSIC_count = 1 : 1 :3 % Do three RSIC techniques one at a time
     % 1: Non-RSIC; 2: Non-demodulated RSIC; 3: Demodulated RSIC
%% Start the main calculation loop for each SNR
 for snr_count = 1: 1: length(SNR)
    % Initiate values for error buffer
    Tx_Errors = [0; 0; 0; 0]; % FOUR rows = FOUR receivers
    Tx_bits   = [0; 0; 0; 0]; % FOUR rows = FOUR receivers

    % Keep running until we get 100 errors in Signal 1
    while Tx_Errors(1,:) < 100

        %% Generate information bits; 4 rows for 4 signals(emitters)
        uncoded_bits  = round(rand(4,bit_length));
        %% Split each signal into two streams, for Quadrature Carriers
        I = uncoded_bits(:,1:2:end);    % get odd bits
        Q = uncoded_bits(:,2:2:end);    % get even bits
        % QPSK modulator set to pi/4 radians constellation(emitter)
        Tx_sig =...
            ((I==0).*(Q==0)*(exp(1i*pi/4))...
            +(I==0).*(Q==1)*(exp(3*1i*pi/4))...
            +(I==1).*(Q==1)*(exp(5*1i*pi/4))...
            +(I==1).*(Q==0)*(exp(7*1i*pi/4)));
        if ch == 2 % OFDM simulation
            %% OFDM Modulation
            for n = 1 : n_symbols;
              s_ofdm = sqrt(n_fft)*ifft(Tx_sig(:,(n-1)*n_fft+1:...
                  n*n_fft)',n_fft);   %Normalized IFFT operation
              s_ofdm_cyc = sqrt(n_fft/(n_fft+n_cyc)) * [s_ofdm(n_fft...
                 -n_cyc+1 : n_fft,:); s_ofdm]; %Appending cyclic prefix
              OFDM_tx(:,(n-1)*(n_fft+n_cyc)+1 : n*(n_fft+n_cyc))...
                  = s_ofdm_cyc'; % Combine subcarriers into one to tx
            end
            Tx_sig = OFDM_tx;
        end

        %% Gaussian Link Noise
        No = 1/10^(SNR(snr_count)/10); % Noise variance
        Noise = sqrt(No/2)*... % 4 ramdom noises for four channels
                (randn(4,length(Tx_sig))+1i*randn(4,length(Tx_sig)));
        %% Receiver intercepted signals
        % including target SOI and interferences from adjacent emitters
        Rx_received = zeros(4,length(Tx_sig)); % Create buffer
        % Receiver 1: Signal 1 + Noise 1
        Rx_received(1,:) = Tx_sig(1,:)+ Noise(1,:);
        % Receiver 2: Signal 2 + (alpha12 * S1) + Noise 2
```

```
        Rx_received(2,:) = Tx_sig(2,:)+...
          (alpha12 * Tx_sig(1,:))+ Noise(2,:);
        % Receiver 3: Signal 3 +(alpha23 * S2)+(alpha13 * S1)+Noise 3
        Rx_received(3,:) = Tx_sig(3,:)+ (alpha23 * Tx_sig(2,:))+...
          (alpha13 * Tx_sig(1,:))+ Noise(3,:);
        % Receiver 4: S4 +(a34 * S3) +(a24 * S2) +(a14 * S1) +Noise 4
        Rx_received(4,:) = Tx_sig(4,:)+ (alpha34 * Tx_sig(3,:))+...
          (alpha24 * Tx_sig(2,:))+ (alpha14 * Tx_sig(1,:))+ Noise(4,:);
%%------------------------------------------------------------------
        %% Reference-based successive interference cancellation
        %  run one RSIC technique at a time
        %% Non-RSIC
        if RSIC_count == 1
        Rx_proced = Rx_received; % no cancellation applied

        %% Non-Demodulated RSIC
        elseif RSIC_count == 2
        % Signal 1 is used as reference directly; Intercepted signals
        % will be subtract by reference signal with a factor Beta
        Rx_proced = Rx_received;  % Create buffer and save Signal 1
        Rx_proced(2,:)=Rx_received(2,:)-(beta12 * Rx_proced(1,:)); %S2
        Rx_proced(3,:)=Rx_received(3,:)-(beta23 * Rx_proced(2,:))...
            - (beta13 * Rx_proced(1,:));  % get Signal 3 only
        Rx_proced(4,:) = Rx_received(4,:) - (beta34*Rx_proced(3,:))...
            - (beta24 * Rx_proced(2,:)) - (beta14*Rx_proced(1,:)); % S4

        %% Demodulated RSIC
        elseif RSIC_count == 3
        % Demodulate 1st received signal at Receiver One,
        % remodulate and send it to Receiver Two as reference signal.
        % repeats at the rest of the receivers
        Rx_proced = zeros(4,length(Rx_received)); %Buffer; 4 signals

        % Begin with SIC, then perform demodulation
        for rcv_count = 1 : 4  % 4: FOUR receivers
            % Interference cancellation
          if rcv_count == 1 % At Receiver One, no SIC and detection
            Rx_proced(1,:)= Rx_received(1,:); % save RS1(+Noise1)
          elseif rcv_count == 2 % Perform RSIC at Receiver Two
            Rx_proced(2,:)=Rx_received(2,:)-(beta12*Rx_proced(1,:));
          elseif rcv_count == 3 % At Receiver Three
            Rx_proced(3,:)= Rx_received(3,:)-(beta23*Rx_proced(2,:))...
                - (beta13 * Rx_proced(1,:));
            elseif rcv_count == 4 % At Receiver Four
             Rx_proced(4,:)=Rx_received(4,:)-(beta34*Rx_proced(3,:))...
                -(beta24*Rx_proced(2,:))-(beta14*Rx_proced(1,:));
            end

          if ch == 2 % OFDM simulation
             % OFDM Demodulation
             for n = 1 : n_symbols;
             r_ofdm_cyc = Rx_proced(:,(n-1)*(n_fft+n_cyc)+1 :...
                 n*(n_fft+n_cyc));  % retrieve each ofdm symbol
             r_ofdm = r_ofdm_cyc(:,n_cyc+1:n_fft+n_cyc)'; %Remove CP
             r_qpsk=fft(r_ofdm,n_fft)/sqrt(n_fft);   %Normalized FFT
```

```
            QPSK_ref(:,(n-1)*n_fft+1:n*n_fft) = r_qpsk';
            end
            Rx_proced = QPSK_ref;
         end

         % QPSK detection on received signal
           % Need to flip I and Q here to have correct sequence!!
           Q(rcv_count,:) = (real(Rx_proced(rcv_count,:))<0);
           I(rcv_count,:) = (imag(Rx_proced(rcv_count,:))<0);

           % Remodulate for transmition (as referecnce signal)
           Rx_proced(rcv_count,:)=...

((I(rcv_count,:)==0).*(Q(rcv_count,:)==0)*(exp(1i*pi/4))...

+(I(rcv_count,:)==0).*(Q(rcv_count,:)==1)*(exp(3*1i*pi/4))...

+(I(rcv_count,:)==1).*(Q(rcv_count,:)==1)*(exp(5*1i*pi/4))...

+(I(rcv_count,:)==1).*(Q(rcv_count,:)==0)*(exp(7*1i*pi/4)));

           if ch ==2 % OFDM simulation
              % OFDM re-Modulation
              for n = 1 : n_symbols;
                s_ofdm  =  sqrt(n_fft)*ifft(Rx_proced(:,(n-1)*n_fft+1:...
                    n*n_fft)',n_fft);
                s_ofdm_cyc = sqrt(n_fft/(n_fft+n_cyc))*...
                    [s_ofdm(n_fft-n_cyc+1:n_fft,:);s_ofdm];
                OFDM_ref(:,(n-1)*(n_fft+n_cyc)+1:n*(n_fft + n_cyc))=...
                    s_ofdm_cyc';
              end
              Rx_proced = OFDM_ref;
           end % End of OFDM simulation
       end % End of Demodulated-RSIC
       end % End of three RSIC techniques loop
%% -----------------------------------------------------
       %% Final demodulation at receiver for BER calculation

       if ch == 2 % OFDM simulation
           % OFDM Demodulation
           for n = 1 : n_symbols;
        r_ofdm_cyc=Rx_proced(:,(n-1)*(n_fft+n_cyc)+1:n*(n_fft+n_cyc));
           r_ofdm = r_ofdm_cyc(:,n_cyc+1:n_fft+n_cyc)'; %Remove CP
           r_qpsk=fft(r_ofdm,n_fft)/sqrt(n_fft);    %Normalized FFT
           QPSK_Rcv(:,(n-1)*n_fft+1:n*n_fft) = r_qpsk';
           end
           Rx_proced = QPSK_Rcv;
       end
       % QPSK Demodulation
       I_rx = (real(Rx_proced)<0); %Detection
       Q_rx = (imag(Rx_proced)<0);
       uncoded_bits_rx = zeros(4,2*length(Rx_proced));
       uncoded_bits_rx(:,1:2:end) = Q_rx;     %converge split streams
       uncoded_bits_rx(:,2:2:end) = I_rx;     %converge split streams
       %% Sum up bit errors
```

```
        diff = uncoded_bits - uncoded_bits_rx;  % find the errors
        Tx_Errors = Tx_Errors + sum(abs(diff),2); % 2 : sum columns
        Tx_bits = Tx_bits + length(uncoded_bits);
    end % end of while loop
    %% Calculate Bit Error Rate of each SNR
    BER(:,snr_count) = Tx_Errors./Tx_bits;  %Calculate BER for each SNR
 end  % end of each SNR calculation loop
%-------------------------------------------------------------
 %% save BERs of each SNR
 % save BER (all four channels) of ND-RSIC and D-RSIC separately.
    if RSIC_count == 1       % Non-RSIC
        BER_Non_RISC = BER; % Save BER of all 4 signals (Non-RSIC)
    elseif RSIC_count == 2  % Non-Demodulated RSIC
        BER_ND_RSIC = BER;% save BER of all 4 signals(ND-RSIC)
    elseif RSIC_count == 3  % Demodulated RSIC
        BER_D_RSIC = BER;    % save BER of all 4 signals (D-RSIC)
    end % end of saving BER of all four signals in three RSIC.
%-------------------------------------------------------------
 end % end of three RSIC techniques loop

  %% save Receiver 2 BER of each alpha12
  BER_ND_RSIC_Rcv2_gamma(gamma_count,:) = BER_ND_RSIC(2,:); %ND_RSIC
  BER_D_RSIC_Rcv2_gamma(gamma_count,:) = BER_D_RSIC(2,:);   %D_RSIC

 % Plot Figures
%% Comparison of three RSIC, show Receiver 2
figure(1)
 subplot(2,2,gamma_count)
 % Theoretical BER
 theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
 semilogy(SNR,theoryBer,'-k','LineWidth',2);
 hold on
 % Simulation results
 semilogy(SNR,BER_Non_RISC(2,:),'m-o','LineWidth',2)
 semilogy(SNR,BER_ND_RSIC(2,:),'b-d','LineWidth',2)
 semilogy(SNR,BER_D_RSIC(2,:),'r-^','LineWidth',2)
 xlabel('SNR (dB)');
 ylabel('BER');
 legend('QPSK Theory', 'Non-RSIC', 'ND-RSIC', 'D-RSIC');
 if ch == 1 % QPSK simulation
    title(['Three RSICs in a two QPSK receiver system',...
    sprintf('\n'),'\alpha_{12} = ', num2str(alpha12),...
     ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 elseif ch == 2 % OFDM simulation
     title(['Three RSICs in a two OFDM receiver system',...
     sprintf('\n'),'Alpha_{12} = ', num2str(alpha12),...
     ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 end
 grid on;

 %% plot Non-Demodulated RSIC all four signals (in one given alpha
value)
 figure(2);
 subplot(2,2,gamma_count)
 % Theoretical BER
```

```
 theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
 semilogy(SNR,theoryBer,'-k','LineWidth',2)
 hold on
 % Simulation results (Non-Demudulated RSIC)
 semilogy(SNR,BER_ND_RSIC(1,:),'-or','LineWidth',2)
 semilogy(SNR,BER_ND_RSIC(2,:),'-db','LineWidth',2)
 semilogy(SNR,BER_ND_RSIC(3,:),'-^g','LineWidth',2)
 semilogy(SNR,BER_ND_RSIC(4,:),'-*m','LineWidth',2)
 xlabel('SNR (dB)');
 ylabel('BER');
 legend('QPSK Theory','Rx Signal 1','Rx Signal 2','Rx Signal 3',...
     'Rx Signal 4');
 if ch == 1 % QPSK simulation
   title(['Four ND-RSIC QPSK receivers demodulating signals',...
   sprintf('\n'),'\alpha_{12} = ', num2str(alpha12),...
   ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 elseif ch == 2 % OFDM simulation
   title(['Four ND-RSIC OFDM receivers demodulating signals',...
   sprintf('\n'),'\alpha_{12} = ', num2str(alpha12),...
   ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 end
 grid on
 hold off

 %% plot Demudulated RSIC all four signals (in one given alpha value)
 figure(3);
 subplot(2,2,gamma_count)
 % Theoretical BER
 theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
 semilogy(SNR,theoryBer,'-k','LineWidth',2);
 hold on
 % Simulation results (Demudulated RSIC)
 semilogy(SNR,BER_D_RSIC(1,:),'-or','LineWidth',2)
 semilogy(SNR,BER_D_RSIC(2,:),'-db','LineWidth',2)
 semilogy(SNR,BER_D_RSIC(3,:),'-^g','LineWidth',2)
 semilogy(SNR,BER_D_RSIC(4,:),'-*m','LineWidth',2)
 xlabel('SNR (dB)');
 ylabel('BER');
 legend('QPSK Theory','Rx Signal 1','Rx Signal 2','Rx Signal 3',...
     'Rx Signal 4');
  if ch == 1 % QPSK simulation
     title(['Four D-RSIC QPSK receivers demodulating signals',...
     sprintf('\n'),'\alpha_{12} = ', num2str(alpha12),...
     ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 elseif ch == 2 % OFDM simulation
     title(['Four D-RSIC OFDM receivers demodulating signals',...
     sprintf('\n'),'\alpha_{12} = ', num2str(alpha12),...
   ';  \gamma_{12} = ', num2str(gamma12(gamma_count))]);
 end
 grid on
 hold off

end  % end of various Gamma12 loop

%% Plot BER Vs. SNR(dB) Curve on logarithmic scale
```

```
%% Non-Demodulated RSIC Receiver 2 with various gamma
figure(4)
subplot(1,2,1)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results (Non-Demudulated RSIC)
semilogy(SNR,BER_ND_RSIC_Rcv2_gamma(1,:),'-or','LineWidth',2)
semilogy(SNR,BER_ND_RSIC_Rcv2_gamma(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_ND_RSIC_Rcv2_gamma(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_ND_RSIC_Rcv2_gamma(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
if ch == 1 % QPSK simulation
    title(['ND-RSIC QPSK Receiver 2 BER with various \gamma_{12} ',...
    '(\alpha_{12}=',num2str(alpha12),')']);
elseif ch == 2 % OFDM simulation
    title(['ND-RSIC OFDM Receiver 2 BER with various \gamma_{12} ',...
    '(\alpha_{12}=',num2str(alpha12),')']);
end
if ch_gamma == 1 % positive gamma value
    legend('QPSK Theory','\gamma_{12} = 0.01', '\gamma_{12} = 0.05',...
           '\gamma_{12} = 0.1', '\gamma_{12} = 0.15')
elseif ch_gamma == 2 % negative gamma value
    legend('QPSK Theory','\gamma_{12} = -0.1', '\gamma_{12} = -
0.075',...
           '\gamma_{12} = -0.05', '\gamma_{12} = -0.025')
end
axis([6 13 10^(-6) 10^(-1)])
grid on;

%% Demodulated RSIC Receiver 2 in various alpha
figure(4)
subplot(1,2,2)
% Theoretical BER
theoryBer = 0.5*erfc(sqrt(10.^(EbNo/10)));
semilogy(SNR,theoryBer,'-k','LineWidth',2);
hold on
% Simulation results (Demudulated RSIC)
semilogy(SNR,BER_D_RSIC_Rcv2_gamma(1,:),'-or','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_gamma(2,:),'-db','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_gamma(3,:),'-^g','LineWidth',2)
semilogy(SNR,BER_D_RSIC_Rcv2_gamma(4,:),'-*m','LineWidth',2)
xlabel('SNR (dB)');
ylabel('BER');
if ch == 1 % QPSK simulation
    title(['D-RSIC QPSK Receiver 2 BER with various \gamma_{12} ',...
    '(\alpha_{12}=',num2str(alpha12),')']);
elseif ch == 2 % OFDM simulation
    title(['D-RSIC OFDM Receiver 2 BER with various \gamma_{12} ',...
    '(\alpha_{12}=',num2str(alpha12),')']);
end
if ch_gamma == 1 % positive gamma value
    legend('QPSK Theory','\gamma_{12} = 0.01', '\gamma_{12} = 0.05',...
```

```
           '\gamma_{12} = 0.1', '\gamma_{12} = 0.15')
elseif ch_gamma == 2 % negative gamma value
    legend('QPSK Theory','\gamma_{12} = -0.1', '\gamma_{12} = -
0.075',...
           '\gamma_{12} = -0.05', '\gamma_{12} = -0.025')
end
axis([6 13 10^(-6) 10^(-1)])
grid on;
toc
%*************************************************************
```

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