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Robust interference cancellation for differential quadrature phase-shift keying modulation with band limiting and adaptive filter

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ABSTRACT

Differential quadrature phase-shift keying (DQPSK) modulation techniques and their variants are widely applied in digital communication, such as for high-speed optical fiber, bluetooth, or satellite communication. In its implementation, DQPSK cannot be separated from the potential harmful interference. In this research, a system model has been made for observation and analysis of the interference cancellation process. Discrete finite-duration impulse response (FIR) filters for band limiting and adaptive filter are the key components of the supporting block for this system model. Robust Simulink results have shown a significant increase in system performance in the existence of these key components. The indication has been shown by the best bit error rate (BER) of 3.3e-05. Constellation and eye pattern diagrams have supported the BER.

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1. INTRODUCTION

In its development, there are two types of quadrature phase-shift keying (QPSK) modulation techniques, namely, offset quadrature phase-shift keying (OQPSK) and π/4-QPSK or differential quadrature phase-shift keying (DQPSK). In terms of minimizing step discontinuities, OQPSK is superior, but DQPSK is useful because it is consistent with differential encoding. The DQPSK modulation is used for example in long-haul optical or bluetooth transmission systems [1]. Due to the modulation process, there are always potential impairments due to attenuation, noise, multipath fading, and interference in the process of transmitting the information. It is possible that there is interference from one device to another. For example, wireless fidelity (Wi-Fi) and bluetooth systems can be interferer with a wireless sensor network system, and vice versa [2]-[4]. The problem is how to maintain the presentation of the DQPSK system that gets interference attacks by constructing a better system configuration. The purpose of this research is to propose a DQPSK system configuration that is equipped with an adaptive filter and discrete finite-duration impulse response (FIR) as a band-limiting filter and to evaluate the performance of the end-to-end DQPSK system in conducting interference cancellation. Observations were made on the main data in the formula of an eye pattern diagram, constellation diagram, and bit error rates (BERs).

It is also useful in communication to quantify the deterioration of a transmitting signal. A commonly used graphical example of this decay is a diagram of eye-pattern, so-called because, in shape, they are eye-like. A variety of factors can change the received signal in the message transmission, such as noise or interference. In assessing the effect of inter-symbol interference (ISI), eye pattern diagrams are also useful. A calculation used to calculate the output of a radio transmitter or receiver is the error vector magnitude or EVM (sometimes also called relative constellation error or RCE). A signal transmitted or received by an ideal sender by a receiver will have all points perfectly at the ideal positions, but different implementation imperfections allow the specific point of the constellation to diverge from the ideal places [5]. As a hypothesis, the DQPSK system configuration proposed in this study can be simulated to suppress and cancel interference by observing the bit error rate, constellations, and eye pattern diagrams. The simulation is powerfully prejudiced by the adjustment of the value of each parameter to get the best BER.

Research on interference can be done by looking at the performance of the device through the BER meter, eye pattern, and constellation diagram. Wirastuti *et al.* [4], reduction of inter-carrier interference (ICI) is done by simulating the circuit formed by the orthogonal frequency-division multiplexing (OFDM) pulse shaping system. The result of the simulation in terms of BER vs. Eb/No suggested that rectangular (REC) improved sinc-power (ISP) pulse shaping and ISP pulse shaping are more efficient in minimizing intercarrier interference (ICI) no-implemented pulse forming relative to the OFDM system. Another way is to do a relative analysis. Comparison of the performance of various types of basic modulation techniques is carried out in various studies to see the performance of BER, Eye diagram, and constellation diagram respectively on additive white Gaussian noise (AWGN), Rayleigh and Rician channels using MATLAB Simulink, graphical user interface (GUI), and BER tool on OFDM systems, code division multiple access (CDMA) to optical systems. The goal is to see the efforts to suppress inter symbol interference (ISI) and/or multipath fading with the simulation [6]-[13]. Performance comparison of optical fiber is found in [14], [15]. One thing that is also important from the existing comparison is that the AWGN channel is better than Rayleigh and Rician channel on the OFDM system. [16]-[20]. Meanwhile [21] observed BER in orthogonal frequency division multiplexing interleave division multiple access (OFDM-IDMA) of 5G system. Kadhum and Haitham [22], the best BER result is 1.0e-3.

2. KEY COMPONENTS

2.1 Differential QPSK

The DQPSK together with OQPSK is a type of differential modulation that is widely used in digital communications [22]. In DQPSK, information is carried by the establishment of a certain step of a single symbol comparative to the preceding symbol. The phase variation between neighboring symbols is used by DQPSK to prevent issues associated with the absence of phase synchronization between transmitter and receiver. The DQPSK constellation expresses four dissimilar symbols (M=4) so that 2 bits are organized per symbol. The bit error probability of DQPSK is expressed in (1).

$$P_b = \frac{1}{log_2 M} . \frac{sin\frac{\pi}{M}}{2\pi} \int_{-\pi/2}^{\pi/2} \frac{\exp((\Upsilon_b.log_2 M).(1-cos\,\pi/M.cos\theta))}{(1-cos\,\pi/M.cos\theta)}\, \mathrm{d}\theta \tag{1}$$

With ϒb = Eb/No. Eb denotes the energy per transmitted bit and No is the noise added by the channel [1].

2.2. Discrete FIR filter

A finite-duration impulse response or FIR filter takes a system function of the form:

$$H(z) = b_0 + b_1 z^{-1} + b_2 z^{-2} + \quad \dots\dots\dots\dots\dots + \ b_{M-1} z^{1-M} \tag{2}$$

where M is the number of coefficients and M-1 is the order of the filter. FIR filter structures are often stable and compared to infinite-duration impulse response (IIR) structures, they are relatively simple [23]. The FIR filter is broadly used including in the communications field. An example of its use is for a band-limiting filter. To reach the idealism of the transmitted spectrum signal, the discrete FIR filter is used for this band restricting [5].

2.3. Adaptive filter

Using adaptive filter algorithms, the filter coefficient can be modified. The adaptive filter has x(n) input, weight w(n) and output y(n). The output y(n) is produced as a linear mixture of the delayed input sequence samples x(n) according to the equation. The equation is according to [24]:

$$y(n) = \sum_{i=0}^{N-1} w_i(n)x(n-1) \qquad (3)$$

The least mean square (LMS) algorithm is incredibly basic, reducing the instantaneous square error rather than the mean square error. As the learning parameter μ increases the convergence rate, LMS has a downside, but the error is greater. In LMS, then, there is a balance between these two. The algorithm of the normalized least mean square (NLMS) can be considered to be a special case of LMS recursion, which takes into account the change in the signal level at the filter output. Recursive least square (RLS) is an adaptive filter algorithm that recursively finds filter coefficients that decrease the cost function of input signals belonging to weighted linear least squares. This is in contrast to other algorithms that, such as the LMS, aim to reduce the mean square error. The input signals are called deterministic for the derivation of the RLS, although they are considered stochastic for the LMS and related algorithms [24].

Adaptive filtering is widely used in both identification, prediction, and interference cancellation systems. Included in the interference cancellation is an adaptive beamforming system [25]. Adaptive filtering with LMS and NLMS algorithms is also used for interference canceling on the smart antenna system in the study [26]. The comparison of LMS, NLMS, and RLS for noise cancellation is carried out in [24]. Meanwhile, the RLS algorithm is used, for example, for the interference mitigation process to global positioning system (GPS) operation by setting its forgetting factor to value ≤1 [27].

3. SYSTEM MODEL AND OBSERVATION PROPOSED

This study uses the Simulink block that we propose in Figure 1, where the complete parameters are as shown in Table 1. The main block starts with a random integer generator, DQPSK modulator, channel, DQPSK demodulator and sink in the form of an eye diagram, constellation diagram, and BER meter. Meanwhile, the source of interference (interferer) is added to the system before entering the channel. The channel type we chose was AWGN. Especially for the study of the constellation of this DQPSK signal, we add checking the shape of the constellation with pseudocode after Table 1. The simulation of error rate, eye pattern, and constellation diagram is done by observing the results and comparing them without a discrete FIR filter against a complete block with a discrete FIR filter. For further observations and comparisons, the positions of the three sink types were placed both before and after the adaptive filter. Meanwhile, for adaptive filters, a comparison was also made between the three types used, namely LMS, NLMS, and RLS. We take the Eb/No range in this simulation from 2-10 dB and display the full error simulation results in Table 2. We added Scope3 to complete the observation of the modulator output and the shape of the adaptive filter signal.

In Figure 1, as a sub-block, we add two terminators each to the unobserved RLS and LMS adaptive filters. These terminators are temporary where when we observe, we move these terminators to the position of the NLMS that has been observed. For the observation of the source of interference, just for the record, we added a periodogram to compare it to the spectrum analyzer display.

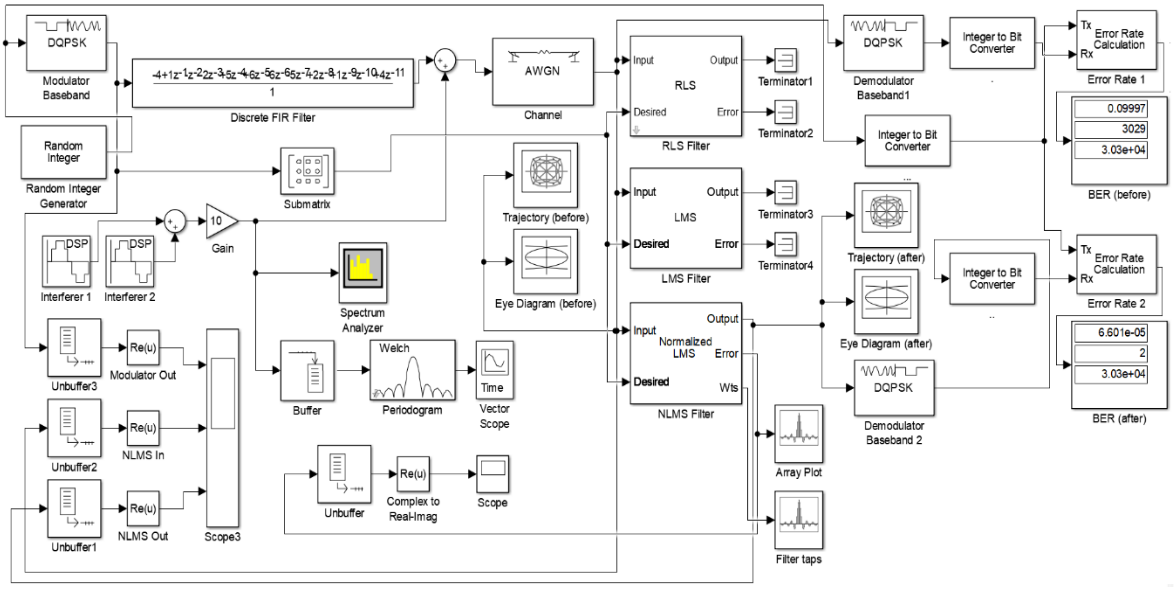


Figure 1. Proposed interference cancellation Simulink block

Table 1. Parameter settings of the Simulink

Block	Parameter	Setting
Random Integer Generator	Set size	1
	Initial seed	37
	Sample time	0.001 s
	Sample per frame	100
	Output data type	double
DQPSK Modulator Baseband	Constellation ordering	Gray
	Phase rotation	pi/4 rad
Discrete FIR Filter	Filter structure	Direct form transposed
	Coefficients	[-4 1 -1 -2 5 6 -6 -5 2 1 -1 4]
	Input processing	Columns as channels (frame-based)
	Initial states	0
Submatrix	Ending row	Index
	Ending row index	100
DSP Sinewave (interferer 1)	Frequency	100 Hz
	Amplitude	1 volt
	Phase offset	0 rad
DSP Sinewave (interferer 2)	Frequency	300 Hz
	Amplitude	1 volt
	Phase offset	0 rad
Gain	gain	10
AWGN Channel	Eb/No	2-10 dB
	Number bits per symbol	2 bits
RLS Filter	Filter length	32
	Forgetting factor (λ)	0.98; 1.0
NLMS and LMS Filter	Filter length	32
	Step size (μ)	0.01; 0.1
DQPSK Demodulator Baseband	Constellation ordering	Gray
	Phase rotation	pi/4 rad
Spectrum Analyzer	Sample/update	1536
Constellation/Trajectory Diagram	Symbol to display	400
Periodogram	FFT length	256
Error Rate Calculation	Receive delay	0
	Computation delay	0
Display	Decimation	1

Table 2. BER result

Adaptive Filter (AF)	Step size (μ) / Forgetting factor (λ)	Eb/No of AWGN (dB)	ERROR without Discrete FIR filter after AF (BER)	ERROR with Discrete FIR filter		
				Before AF (BER)	After AF (BER)	After AF (bit)
RLS	λ = 1.0	2	0.19830	0.19160	0.000363	11
		4	0.18480	0.16140	0.000429	13
		6	0.17180	0.13490	0.000429	13
		8	0.16140	0.11470	0.000396	12
		10	0.15120	0.09997	0.000396	12
	λ = 0.98	2	0.19900	0.19160	0.000330	10
		4	0.18460	0.16140	0.000396	12
		6	0.17290	0.13490	0.000429	13
		8	0.16260	0.11470	0.000363	11
		10	0.15280	0.09997	0.000330	10
LMS	μ = 0.01	2	0.00634	0.19160	0.005281	160
		4	0.00634	0.16140	0.005347	162
		6	0.00634	0.13490	0.005248	159
		8	0.00634	0.11470	0.005314	161
		10	0.00634	0.09997	0.005248	159
	μ = 0.1	2	0.00396	0.19160	0.003498	106
		4	0.00396	0.16140	0.003498	106
		6	0.00396	0.13490	0.003465	105
		8	0.00396	0.11470	0.003531	107
		10	0.00396	0.09997	0.003531	107
NLMS	μ = 0.01	2	0.19890	0.19160	6.601e-05	2
		4	0.18530	0.16140	6.601e-05	2
		6	0.17300	0.13490	3.300e-05	1
		8	0.16200	0.11470	3.300e-05	1
		10	0.15150	0.09997	6.601e-05	2
	μ = 0.1	2	0.19860	0.19160	6.601e-05	2
		4	0.18520	0.16140	6.601e-05	2
		6	0.17200	0.13490	3.300e-05	1
		8	0.16120	0.11470	3.300e-05	1
		10	0.15160	0.09997	6.601e-05	2

For DQPSK constellation checking, we include the following pseudocode:

```
data = zeros(1,bit);
I = zeros(1,S); Q = zeros(1,S);
II = zeros(1,S); QQ = zeros(1,S);
theta = zeros(1,S);
thetaout = zeros(1,NT*S);
data=round(rand(1,bit));
II=data(1:2:bit-1); QQ=data(2:2:bit);
theta(1)=iph;
thetaout(1:NT)=theta(1)*ones(1,NT);
for k=2:S
if II(k)==1
phi_k=(2*QQ(k)-1)*pi/4;
else
phi_k=(2*QQ(k)-1)*3*pi/4;
end
theta(k)=phi_k+theta(k-1);
for i=1:NT
j=(k-1)*NT+i;
thetaout(j)=theta(k);
end
end
I=cos(thetaout);Q=sin(thetaout);
[b,a]=butter(fo,nb);
If=filter(b,a,I);
Qf=filter(b,a,Q);
kk=0;
figure
constel(If,Qf)
plot(If,Qf)
axis('equal')
xlabel('In-phase')
ylabel('Quadrature')
```

4. RESULTS AND ANALYSIS

The stability of the selected discrete FIR filter is shown by all the poles inside the unit circle in Figure 2. The spectrum analyzer displays the shape of the interference source at the 100 Hz and 300 Hz positions in Figure 3. The results obtained from the BER-meter correspond to the constellation plot and eye pattern diagram. Figure 4 shows the form of an eye diagram with an optimum eye-opening with an error rate of 6.601e-05 or 2 errors. This happened at the step size setting (μ) 0.01 of the adaptive NLMS filter; Eb/No of 10 dB and 2 bits per symbol on the AWGN channel. It can be clearly compared with the appearance of the eye diagram after the NLMS filter and before the NLMS filter. Likewise, the constellation display after the NLMS filter against before the NLMS filter in Figure 5. The constellation shown here is a signal trajectory from DQPSK. The trajectory appearance after NLMS bears a resemblance to the octagon shape of the theory. And this is evidenced by the MATLAB simulation results in Figure 6. Meanwhile, Figure 7 shows the taps of the adaptive filter according to the filter length settings that have been done.

The results of the filter adaptation process used are shown in Figure 8 where the error was observed to decrease after 1 second, indicating the stability of the system that occurred. This stability can also be seen from Figure 9 where the results showed that the NLMS filter was able to adapt to changes in frequency and response accordingly. The error rate results in Table 2 clearly illustrate the comparison between before and after the adaptive filter. The smallest number of bit errors is in the NLMS filter, and the most error (up to 162 bits error) of the three are in the LMS filter. RLS forgetting factor setting is taken for the commonly used value (0.98) up to a maximum value of 1.0. If the configuration is without a discrete FIR filter, it is clear that the error rate is worse than having a discrete FIR filter as a band-limiting filter. This applies to the three types of adaptive filters used. When compared with research [22] with the best BER value of 1.0e-3, overall in this study there is an improvement. In this case, by taking the same filter length of 32, the best adaptive filter among the three types tested is the filter with the NLMS algorithm with BER 3.3e-05; meanwhile BER 3.3e-04 for RLS and 3.4e-03 for LMS.

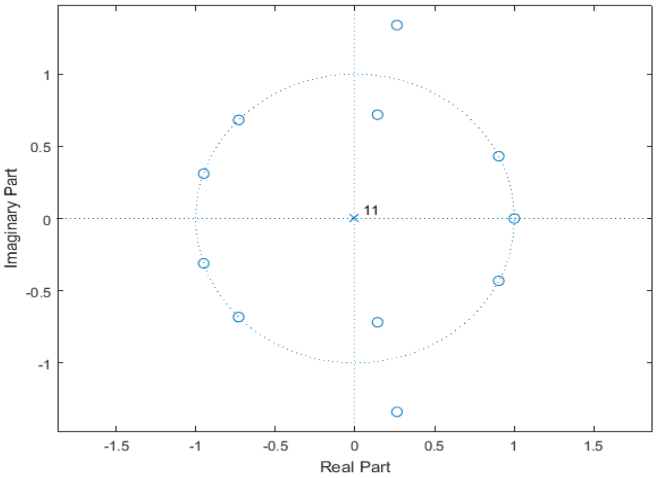


Figure 2. Pole-zero of discrete FIR filter proposed

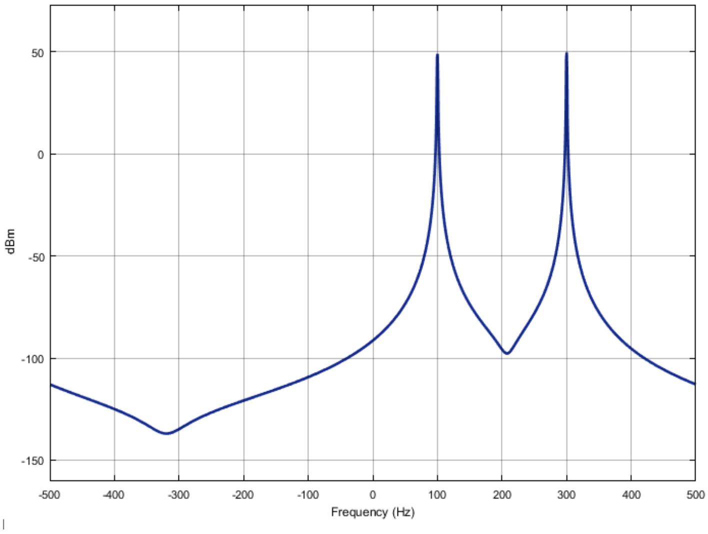
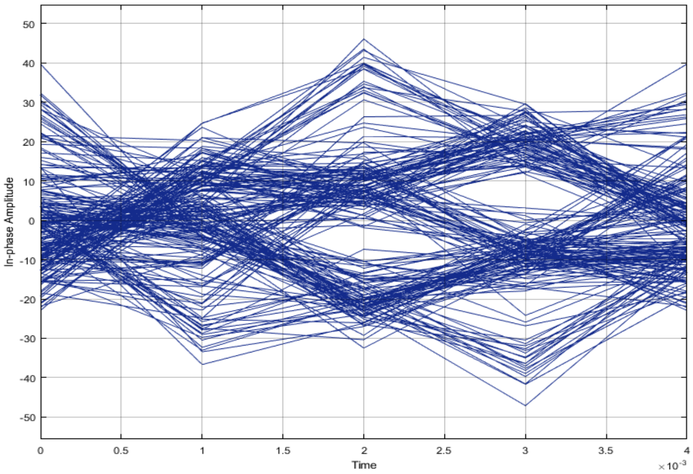
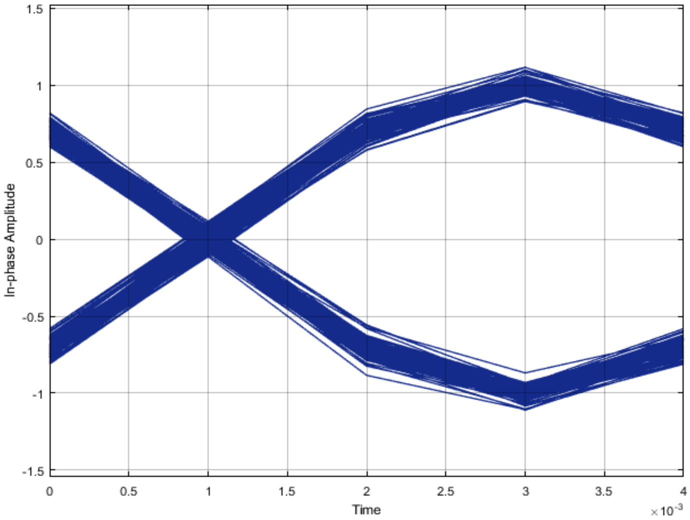


Figure 3. A spectrum of interference sources

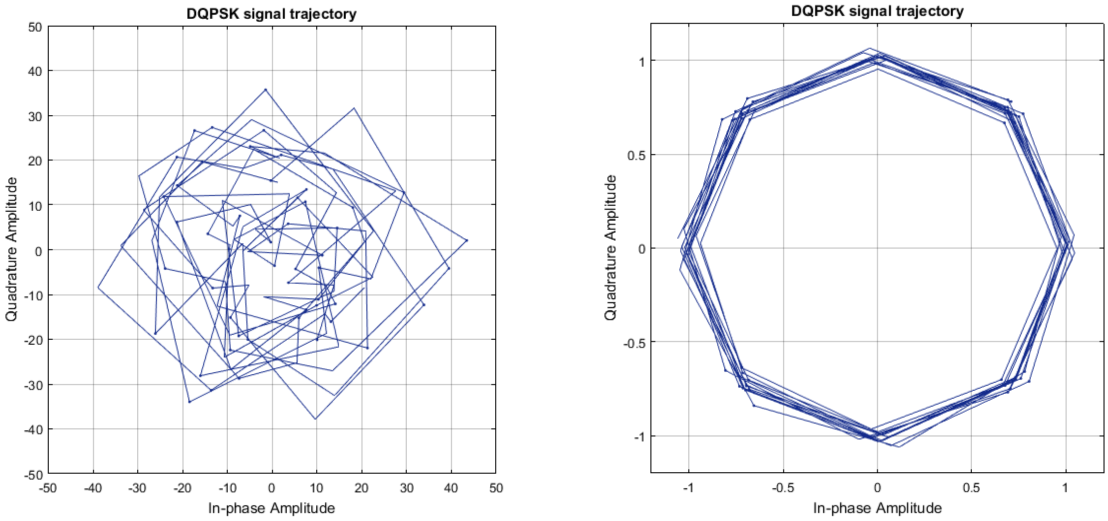


(a)



(b)

Figure 4. Eye diagram (μ=0.01; Eb/No=10 dB): (a) before NLMS filter and (b) after NLMS filter



(a) (b)

Figure 5. Signal trajectory of DQPSK (NLMS: μ=0.01; Eb/No=10 dB): (a) before NLMS filter and (b) after NLMS filter

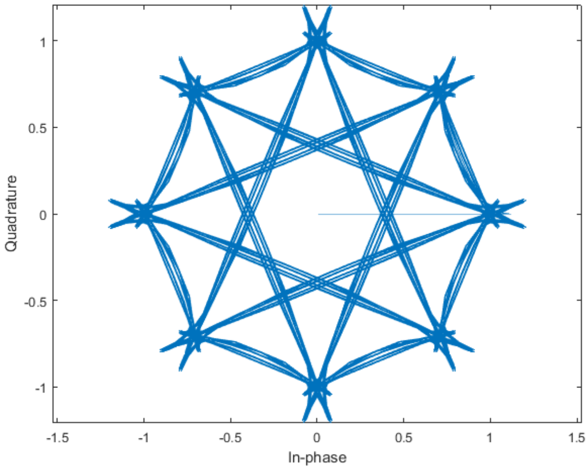


Figure 6. Error signal of the filter

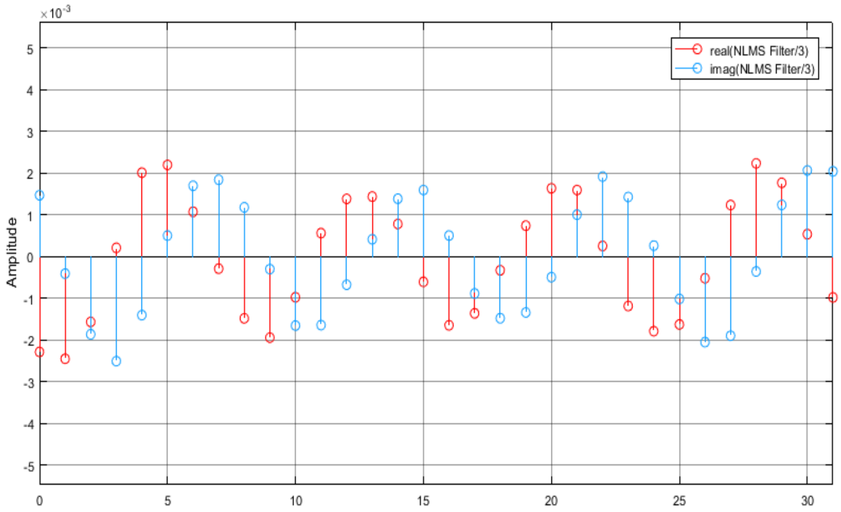


Figure 7. Modulator and adaptive filter signal

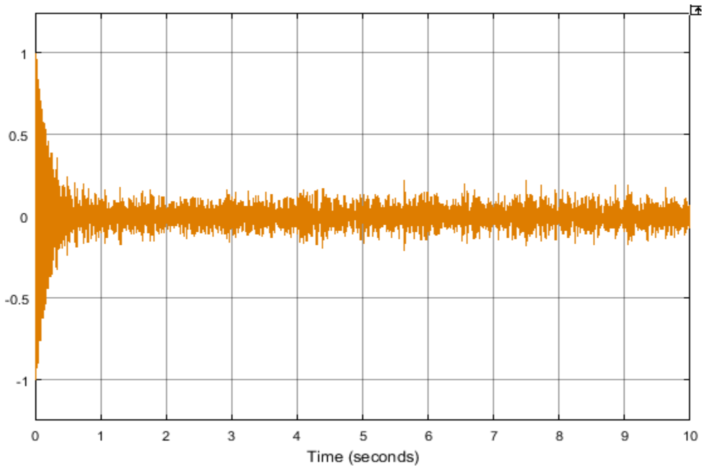


Figure 8. Adaptive filter taps

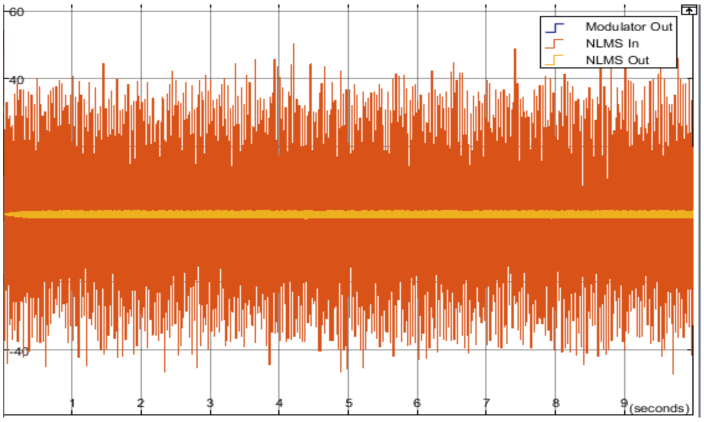


Figure 9. Constellation check

5. CONCLUSION

Observation and analysis of the DQPSK communication system have been carried out through adjustments of each parameter in order to obtain the best BER performance, constellation, and eye pattern diagrams of the harmful interference cancellation process in the proposed block. The quantitative value of all parameters is represented by BER. The results show that the performance of this system configuration is greatly helped by the presence of the discrete FIR filter being tested. The selected discrete FIR filter coefficient performs the band-limiting function well. Likewise, the adaptive filter can improve the quality of digital communication in interference cancellation. As with the results and analysis above, a comparative study has been conducted in which the BER value is better, which is 3.3e-05 in this research. And the best adaptive filter among the three types tested is the filter with the NLMS algorithm. For future work, the configuration will be equipped with sub-blocks to further explore the use of other types of discrete FIR filters against the possibility of ICI in the channel segment of the existing DQPSK system.

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