# Performance Improvements of FQPSK Modulated Signals in the Presence of Co-Channel Interference

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This article evaulates the performance of Feher's quadrature phase shift keying (FQPSK) modulated signals in the presence of the co-channel interference (CCI) and additive white Gaussian noise (AWGN) and shows how it can be improved using a hard-limited amplifier.

A non-linearly amplified (NLA) FQPSK modulated signal with the data rate of 1 megabit per second (Mb/s) and carrier frequency of 70 MHz is interfered by a sinusoidal signal at different frequencies. As the relative distance of the center frequency of the CCI changes, different bit error rate (BER) result.

In order to improve the BER in the presence of the CCI, a hard-limited filter is added at the receiver input. The hard-limited filter has a different amplification factor for different signal strengths. As a result, amplification of the CCI, which is normally a weaker signal, is smaller than the desired signal. This means that the amplification of the signal is greater than the interference, suppressing the CCI and improving the BER. The improvements are verified in both hardware and software simulations for different center frequencies.

## Introduction

In recent years, variations of FQPSK have been recommended by the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the American Institute of Aeronautics and Astronautics (AIAA), the International Consultative Committee for Space Data Systems (CCSDS) and various organizations as spectrally efficient modulation schemes with non-linear amplifiers.

Because of wide adoption of FQPSK, it is important to understand it effects and possible solutions when CCI is present. Due to the spectral efficiency of the FQPSK, a good BER performance even in the presence of CCI is expected. This article is mainly concerned with BER analysis and improvement of FQPSK-B in a channel, based on both computer simulations and hardware measurements.

The BER is one of the most important parameters in the performance analysis of communication systems. In general, the BER is inversely proportional to the C/I. The higher the C/I, the lower the BER. Both the power of the interfering signal and the frequency of the interferer in relation to the signal spectrum has an impact on the BER.

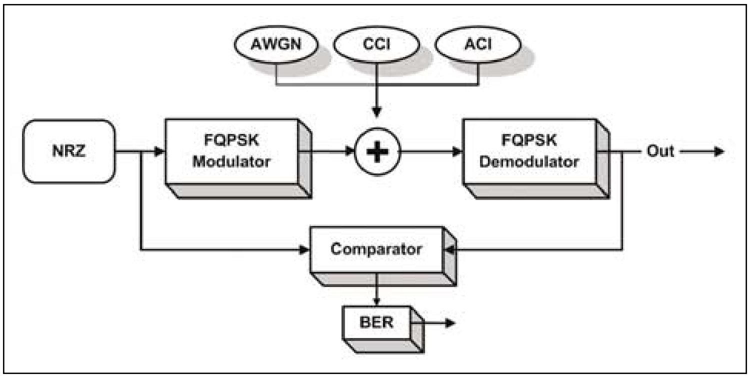
The spectrum of the CCI can have any arbitrary shape, however this article studies the effects of an unwanted sinusoid on the BER. The reasons for adopting a simple harmonic as an interferer are:

- The simplicity of studying the behavior of the system.
- Any complex CCI can be broken down to a collection of simple harmonics.

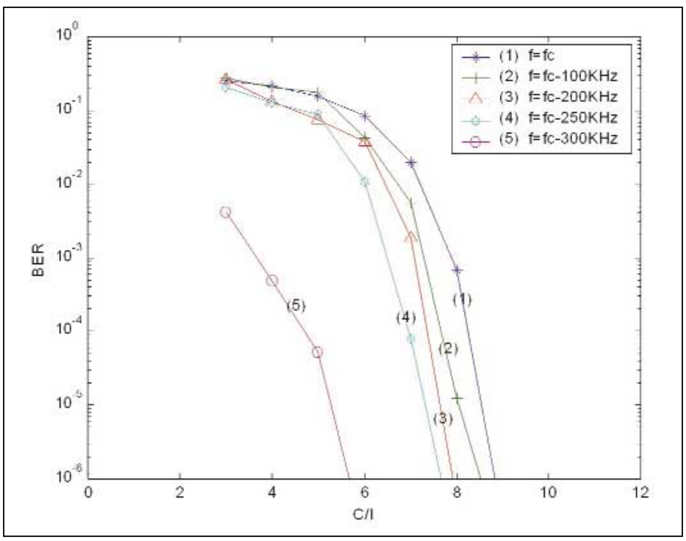
Depending on the CCI's center frequency relative to the FQPSK modulated signal's center frequency, the impact of the CCI varies. Consequently, both the simulation and measurement results are studied for CCI with different relative center frequencies.

## FQPSK-B

FQPSK-B is one of the modulation schemes in the FQPSK family. It is a constant envelope modulation scheme with the baseband wave-




▲ **Figure 1. Simulation scheme without the hard-limited filter.**




▲ **Figure 2. Simulation results for different CCI center frequencies without the hard-limited filter.**

form-shaped with cross-correlation between the in-phase and quadrature (I and Q) channels. Simulation and measurements are performed for FQPSK-B at 1 Mb/s with a carrier frequency of 70 MHz.

## Simulation scheme

The simulation is accomplished using MatLab. Figure 1 shows the simulation scheme without the hard-limited filter. A NRZ sequence is generated and modulated using a FQPSK-B scheme. The modulated signal is then exposed to AWGN and a sinusoidal signal.

$$S = S + AWGN + A\cos(2*\pi*CciCenterFrequency*t)$$

Next, the exposed signal is attenuated. The combination of the AWGN, the sinusoidal signal and the attenuation simulates the channel. The resulting signal is demodulated and detected. The result is an array of non-return to zero (NRZ) sequence. We compare this sequence and the original NRZ sequence and count the number of differences between the two sequences. This number represents the BER. The same simulation is repeated for different CCI strengths and different CCI center frequencies.

## Simulation results

In most practical systems, either the CCI or the AWGN is the dominant factor. The AWGN in this simulation is chosen to be low and the CCI is the dominant interference. Figure 2 shows the simulation results for different CCI strengths and different CCI center frequencies. According to the simulation results, the effect of the CCI decreases as the CCI center frequency moves away from the center of the modulated signal. It also shows that if AWGN is low, the BER decreases rapidly as the strength of the CCI decreases.

## Hardware scheme

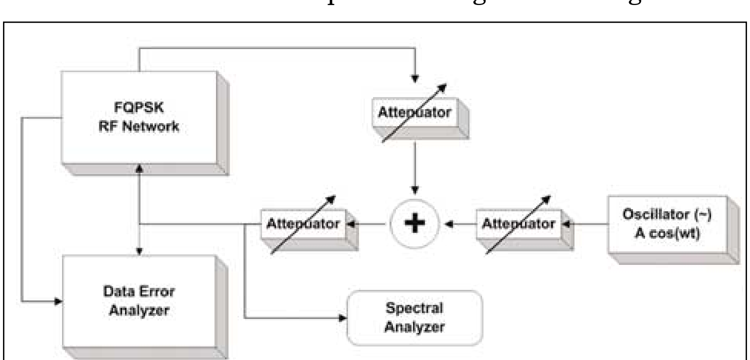
Figure 3 shows the measurement scheme without the hard-limited filter. A NRZ signal sequence is generated and sent to a FQPSK modulator with $f_c$ = 70 MHz and then attenuated. The signal is then exposed to AWGN and an interfering sinusoidal signal. The resulting signal is again passed through an attenuator and sent to an FQPSK demodulator.

The attenuators, AWGN and the sinusoidal signal simulate a channel with interference. The demodulated and detected signal is compared with the original data and the differences are counted. The number of differences represents the BER.

Using this hardware scheme, we are able to add the single tone to the original transmitted signal at different frequencies. Figure 4 shows the actual measured spectrum after adding the CCI to the FQPSK modulated signal.

## Hardware results

Using the hardware scheme described in the previous section, different BER results are obtained for CCI at different center frequencies. The same measurements as simulated are repeated for different




▲ **Figure 3. Measurement scheme without the hard-limited filter.**

CCI strengths and different CCI center frequencies. The AWGN level in these measurements is chosen to be low and the CCI is the most dominant interference. Figure 5 shows the measurement results for different CCI strengths and different CCI center frequencies.

As the measurement results show, the effect of the CCI decreases as the CCI center frequency moves away from the center of the modulated signal. If the AWGN is low, the BER decreases rapidly as the strength of the CCI decreases.

### Comparing simulation and hardware results

The BER results obtained from measurements and simulations are very close. They confirm that the effect of the CCI decreases as the CCI center frequency moves away from the center of the modulated signal. The results also show that if AWGN is low, the BER decreases rapidly as the strength of the CCI decreases.

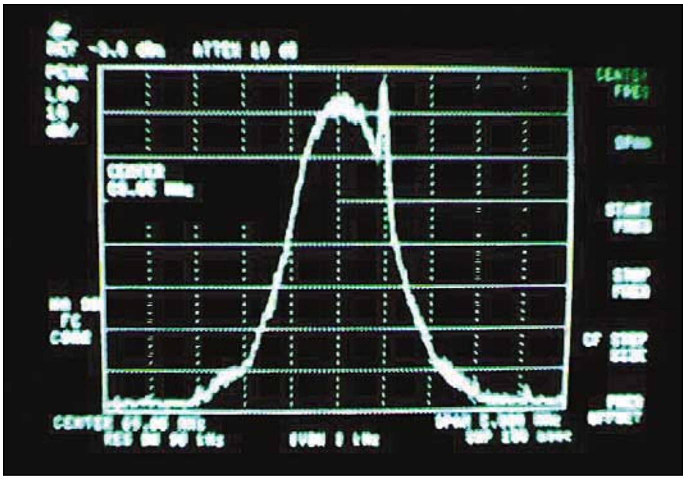
Slight discrepancies in the results obtained from measurements and simulations exist due to noise in the instruments. The AWGN level was chosen to be very low to make the CCI the most dominated interfering factor.

While lowering AWGN in simulations is trivial, the elimination of AWGN in the real instruments is difficult. This is especially evident for the higher C/I because higher C/I means lower CCI. When the CCI level is low it requires a low AWGN and the total elimination of AWGN in the instruments is nearly impossible. But in general, the results obtained from simulations and measurements are supportive.

Figure 6 shows a comparison of the simulation and measurement results for the CCI center frequency ($f = f_c$ – 250 kHz).

### Improvements

So far, we have only examined the impact of the CCI on the BER of a FQPSK modulated signal. In the next sections, an improvement scheme is presented. By introducing a hard-limited filter before the demodulator, the BER performance of the FQPSK signal is improved. This is verified in both MatLab simulation and by laboratory measurements.

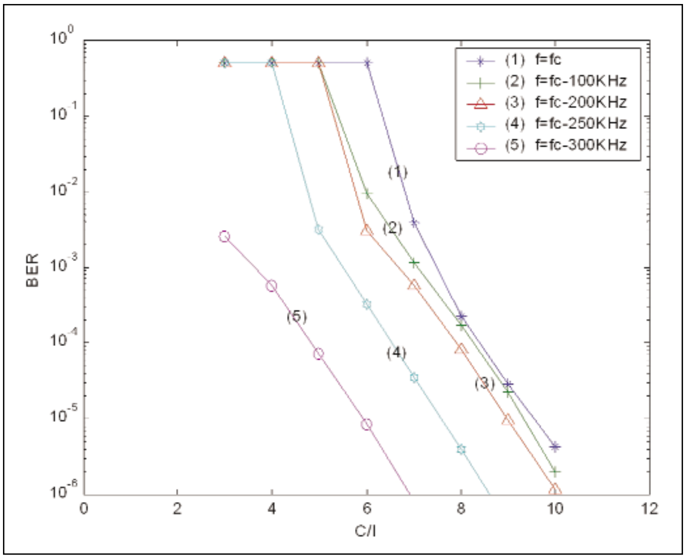


▲ **Figure 4. FQPSK-B spectrum with CCI at $f = f_c$ + 450 kHz, 1 Mb/s and fc = 70 MHz.**

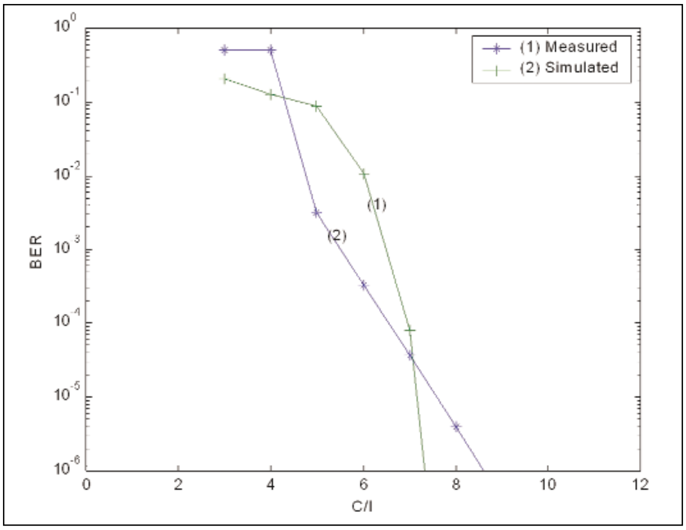
### Simulation scheme with improvements

The simulation scheme with a hard-limited filter is similar to the simulation scheme that was previously introduced. This filter improves the BER for the CCI for certain C/I ratios. The simulation is again performed in MatLab. Figure 7 shows the simulation scheme with the hard limited filter. A NRZ sequence is generated and modulated using a FQPSK-B scheme.

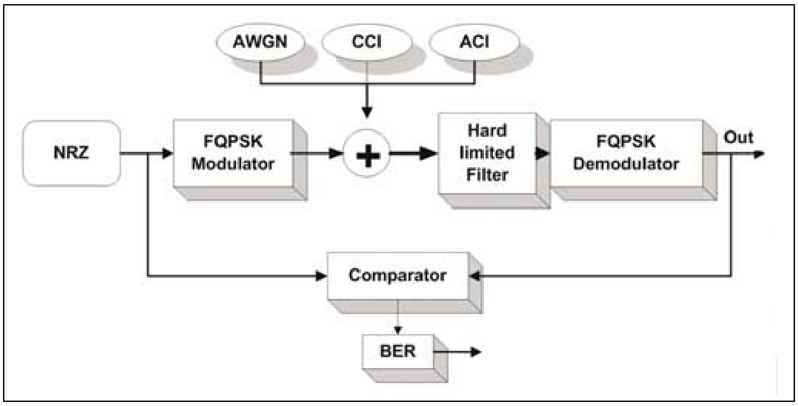
The modulated signal is then exposed to AWGN and a sinusoidal signal.



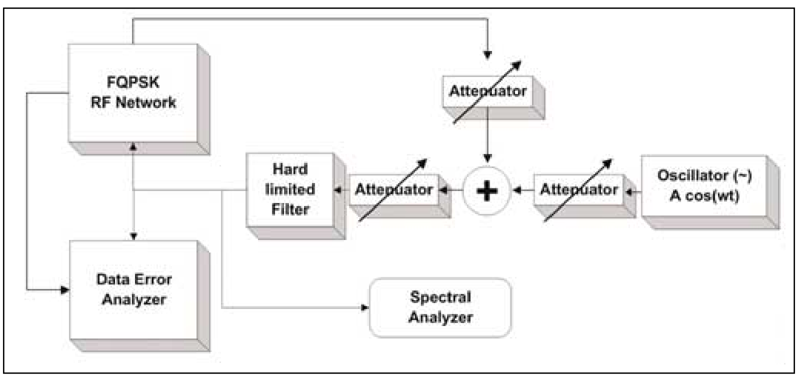

▲ **Figure 5. Measurement results for different CCI center frequencies without the hard-limited filter.**




▲ **Figure 6. Comparison of the simulated and measured results for CCI center frequency = $f_c$ – 250 kHz without the hard-limited filter.**




▲ **Figure 7. Simulation scheme with the hard-limited filter.**




▲ **Figure 8. Measurement scheme with the hard-limited filter.**

$$S = S + AWGN + A\ cos(2*\pi*CciCenterFrequency*t)$$

The exposed signal is then attenuated. The combination of AWGN, the sinusoidal signal and the attenuation simulates the channel. The signal is then demodulated and detected and the result is an array of NRZ sequence. This sequence and the original NRZ sequence are compared and the number of differences between the two sequences is counted. This number represents the BER. The same simulation is repeated for different CCI strengths.

As the simulation results in Figure 9 show, there are BER improvements for certain C/I ratios.

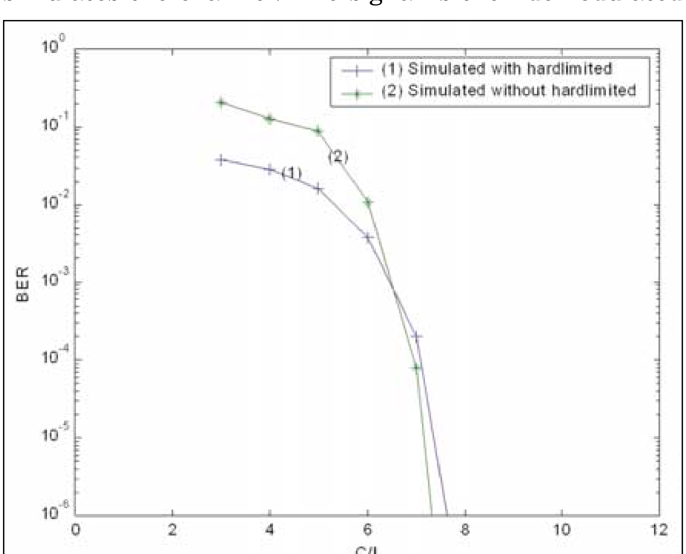
## Hardware scheme with improvements

The measurement scheme with a hard-limited filter is similar to the measurement scheme that was previously introduced. The hard-limited filter is implemented by cascading several amplifiers, operating saturated, followed by attenuators. This filtration improves the BER for certain C/I ratios.

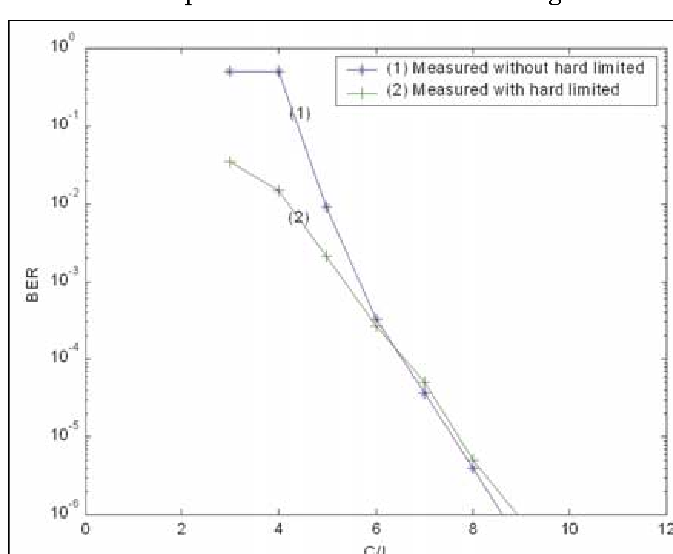
Figure 8 shows the measurement scheme with the hard-limited filter. A NRZ signal sequence is generated and sent to a FQPSK modulator and then attenuated.

The signal is then exposed to AWGN and an interfering sinusoidal signal. The resulting signal is again passed through an attenuator. The signal is sent through a cascade of amplifiers operating in saturated mode followed by an attenuator.

The signal is then sent to an FQPSK demodulator. The attenuators, AWGN and the sinusoidal signal simulate a channel with interference. The demodulated and detected signal is compared with the original data and the differences are counted. The number of differences represents the BER. The same measurement is repeated for different CCI strengths.




▲ **Figure 9. Simulated BER with and without the hard-limited for CCI center frequency of $f_c$ – 250 kHz.**




▲ **Figure 10. Measured BER with and without the hard limited for CCI center frequency of $f_c$ – 250 kHz.**

As in the previous case, the AWGN is chosen to be low, and the CCI is the dominant interference. Figure 10 shows the measurement results for different CCI strengths, with and without the hard limiting and with the CCI center frequency ($f = f_c$ – 250 kHz). The measurement results show that there are BER improvements for certain C/I ratios.

## Conclusion

As both the simulated and measured results show, the BER performance of the FQPSK-B in the presence of CCI depends heavily on the relative distance of the CCI center frequency from the signal center frequency. The BER decreases rapidly as the CCI center frequency moves away from the center by more than 2/5 of the bandwidth. If AWGN is low in the channel and the CCI is the dominant interfering factor, the BER decreases rapidly as the C/I ratio increases.

Introduction of the hard-limited filter improves the BER in the presence of the CCI. The hard-limited filter has different amplification factors for different signal strengths. As a result, amplification of the weaker CCI is smaller than the actual signal. This means that the signal is amplified more than the interference, and as a result, the CCI is suppressed and the BER rate improves. Since the amplification of the hard-limited filter is heavily related to the signal strength, the CCI suppression is also heavily dependent on the C/I ratio. As expected, the results from both simulations and measurements show different level of BER improvements for different C/I ratios. ■

## Author information

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