PERFORMANCE OF FQPSK TRANSCEIVERS IN A COMPLEX REAL-LIFE INTERFERENCE ENVIRONMENT

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ABSTRACT

The Bit Error Rate (BER) performance of FQPSK modulated signals in the presence of the Co-Channel Interference (CCI) and Additive White Gaussian Noise (AWGN) is evaluated and improved. A Non-Linearly Amplified (NLA) FQPSK modulated signal with the data rate of 1Mb/s and carrier frequency of 70 MHz is interfered with a sinusoidal signal at different frequencies. As the relative distance of the center frequency of the Co-channel interference (CCI) changes, different BER are obtained. The effect of the CCI decreases as the CCI center frequency moves away from the center of the modulated signal.

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 strength. As a result, the amplification factor for the CCI, which is normally a weaker signal, 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. The results of both simulations and measurements are obtained for different CCI center frequencies, before and after the improvements.

* Significant parts of this material are based on the authors' reports and remain the property of the authors

KEY WORDS

Modulation, FQPSK, Co-Channel Interference (CCI), Bit Error Rate (BER), AWGN

INTRODUCTION

Due to the spectral efficiency of the FQPSK, one can expect a good BER performance even in the presence of CCI. This paper is mainly concerned with BER analysis of the FQPSK-B in the presence of CCI, using computer simulations and actual life measurements.

The BER is one of the most important parameters in the performance analysis of communication systems. In general, the BER is a function of C/I, and it is inversely proportional to the C/I. The higher the C/I, the lower the BER.

The interference can be Adjacent Channel Interference (ACI), Co-Channel Interference (CCI), Additive White Gaussian Noise (AWGN) or a combination of all of the above. In most practical systems Noise, ACI and ACI are all present, however in most these cases, just one of these factors is dominant.

The spectrum of the CCI can have an arbitrary shape, however this paper studies the effects of an unwanted sinusoidal on the BER. Depending on the location of the CCI's center frequency relative to the FQPSK modulated signal's center frequency, the magnitude of the CCI varies. Consequently we get different BER result depending on the relative location of the CCI's center frequency. Both the simulation and measurement results are obtain for CCI with different relative center frequencies.

In the followings, first the simulation methodology and simulation result for different CCI as the sinusoidal signals center frequency changes will be discussed. Next measurement methodology and the measurement results will be presented. An improvement methodology for the improvement of the BER is introduced. Finally a comparison of both simulation and measurement results before and after the improvement is presented.

FQPSK-B MODULATION SCHEME

There are a number of publications describing FQPSK systems (references [1] and [2]). It has been successfully demonstrated that the FQPSK-B modulated signals have a great spectral efficiency and bit error performance (references [3], [4], [5] and [6]).

The FQPSK-B is one of the modulation schemes in the FQPSK family. It is a constant modulation scheme with baseband waveform-shaped with cross correlation between the I and Q channels. Figure(1) illustrate the measured spectrum for FQPSK-B at 1Mb/s with carrier frequency of 70MHz.

SIMULATIONS WITHOUT THE HARD LIMITED FILTER

The simulation is done in MatLab and Figure(4) illustrates the simulation scheme without the hard limited filter. A NRZ sequence is generated and modulated using a FQPSK-B modulation scheme. The FQPSK's K factor is chosen as K=0.707. The cut off frequencies for the BW filter are chosen as BTb=0.5 and BiTb=0.55. The modulated signal is then exposed to an AWGN and a sinusoidal signal.

S = S + AWGN + A cos(2*p*CciCenterFrequency*t)

The exposed signal is then attenuated. The combination of the AWGN, the sinusoidal signal and the attenuation simulates the channel. The resulting signal is demodulated and detected and the result is an array of NRZ sequence. A comparison of this sequence and the original NRZ sequence is made 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 and different CCI center frequencies.

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 (5) illustrates the simulation results for different CCI strengths and different CCI center frequencies.

As the simulation results show, 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 the AWGN is low, then the BER decreases rapidly as the strength of the CCI decreases.

MEASUREMENTS WITHOUT THE HARD LIMITED FILTER

Figure (6) illustrates the Measurement scheme without the hard limited filter. A NRZ signal sequence is generated and sent to a FQPSK modulator with fc = 70MHz and then attenuated. The signal is then exposed to an 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 then 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 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 (7) illustrates 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. It also shows that if the AWGN is low, then the BER decreases rapidly as the strength of the CCI decreases.

MEASUREMENT VERSES SIMULATIONS WITHOUT THE HARD LIMITED FILTER

The BER results obtained from the measurements and the 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. It also shows that if AWGN is low, then the BER decreases rapidly as the strength of the CCI decreases.

Slight discrepancies in the results obtained from measurements and simulations, depend on the existence of noise in the instruments. As mentioned the AWGN level was chosen to be very low. The choice was made in order to make the CCI the most dominated interfering factor.
While lowering AWGN in simulations is trivial, the elimination of the AWGN in the real instruments is a big problem. This is especially obvious for the higher C/I because higher C/I means lower CCI. When the CCI level is low it requires a very low AWGN and the total elimination of the AWGN in the instruments is difficult and nearly impossible. But in general the results obtained from both simulations and real life measurements are very close and support each other.

Figure (8) shows a comparison of the simulation and measurement results for CCI center frequency f = fc-250KHz.

SIMULATIONS WITH THE HARD LIMITED FILTER

The simulation scheme with the hard limited filter is similar to the simulation scheme that was previously introduced. The main difference here is the introduction of a hard limited filter before the demodulator. This filter improves the BER for the CCI for certain C/I ratios. As in the previous case the simulation is done in MatLab and Figure (9) illustrates the simulation scheme with the hard limited filter. A NRZ sequence is generated and modulated using a FQPSK-B modulation scheme. The FQPSK's K factor is chosen as K=0.707. The cut off frequencies for the BW filter are chosen as BTb=0.5 and BiTb=0.55.

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

S = S + AWGN + A cos(2*p*CciCenterFrequency*t)

The exposed signal is then attenuated. The combination of the AWGN, the sinusoidal signal and the attenuation simulates the channel. The resulting signal, after the channel is passed through a hard limited filter. The signal is then demodulated and detected and the result is an array of NRZ sequence. A comparison of this sequence and the original NRZ sequence is made 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 in the previous case the AWGN is chosen to be low, and the CCI is the most dominant interference. Figure(10) illustrates the simulation results with and without the hard limited for different CCI strengths and with the CCI center frequency f = fc-250KHz

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

MEASUREMENTS WITH THE HARD LIMITED FILTER

The measurement scheme with the hard limited filter is similar to the measurement scheme that was previously introduced. The main difference here is the introduction of a hard limited filter before the demodulator. The hard limited filter is implemented by cascading several amplifiers, operating in the saturated mode followed by attenuators. This filtration improves the BER for certain C/I ratios. Figure(11) illustrates the Measurement scheme without the hard limited filter. A NRZ signal sequence is generated and sent to a FQPSK modulator and then attenuated. Then the signal is exposed to an 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 then 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.

As in the previous case the AWGN is chosen to be low and the CCI is the dominant interference. Figure(12) illustrates the measurement results for different CCI strengths, with and without the hard limited and with the CCI center frequency f = fc-250KHz

As the measurement results show, there are some BER improvements for certain C/I ratios.

THE BER IMPROVEMENTS

As both the simulation and the measurement results (figure 10 and 12) show the introduction of the hard limited filter at the receiver side improves the BER in the presence of the CCI. The improvement varies for different C/I ratios. In order to explain the improvement variations for different C/I we must look at the characteristics of the hard limited filter. The hard limited filter has a different amplification factor for different signal strengths. As a result, the amplification factor for the CCI, which is normally a weaker signal, 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.

As mentioned in these measurements the AWGN level is chosen to be low, and the CCI is the most dominant interference. Again simulating the BER without the noise is feasible but eliminating the noise level in the measurement is not practical. Almost all practical components contribute to the noise level. This has effected the measurement results for small C/I ratios. However in general the results of both measurements and simulation show BER improvements for certain C/I ratios.

CONCLUSION

As both the simulated and measured results illustrate, the BER performance of the FQPSK-B in the presence of CCI depends heavily on the relative distance of the CCI’s center frequency from the signal’s center frequency. The BER decreases rapidly as the CCI center frequency is away from the center by more than 2/5 of the bandwidth. If the AWGN is low in the channel and the CCI is the dominant interfering factor, then 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, the amplification factor for the CCI, which is normally a weaker signal, 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 real life measurements show different level of BER improvements for different C/I ratios.

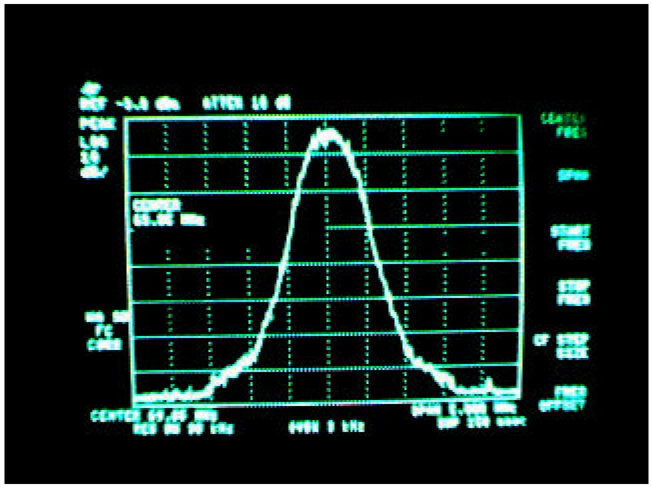


Figure (1) FQPSK-B spectrum, 1Mb/s and fc = 70MHz

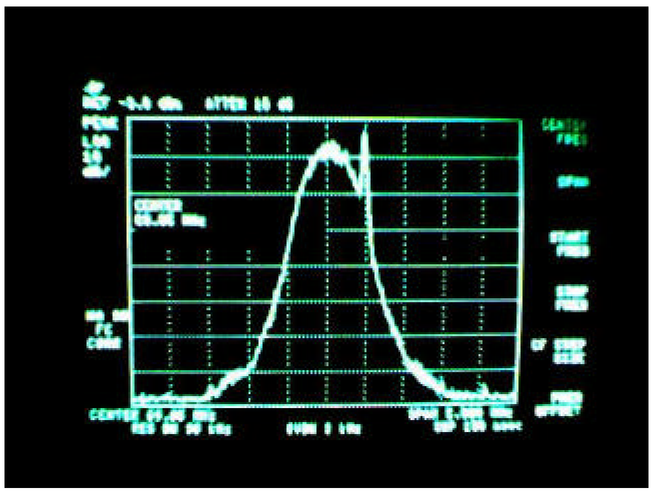


Figure (2) FQPSK-B spectrum with CCI at f = fc +450KHz, 1Mb/s and fc = 70MHz

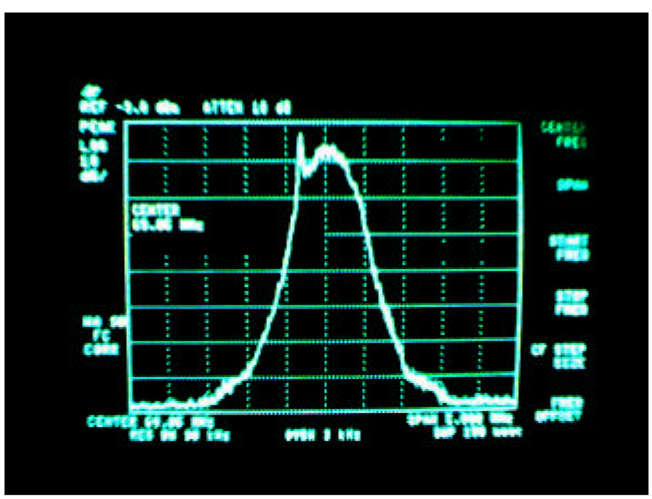


Figure (3) FQPSK-B spectrum with CCI at f = fc –450KHz, 1Mb/s and fc = 70MHz

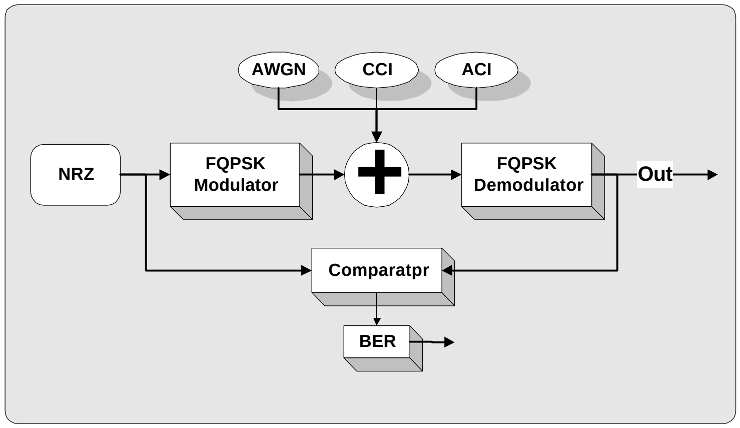


Figure (4) Simulation scheme without the hard limited filter

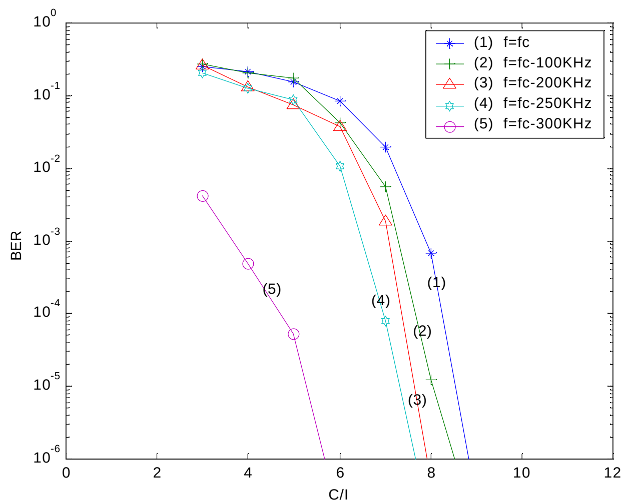


Figure (5) Simulation results for different CCI center frequencies without the hard limited filter

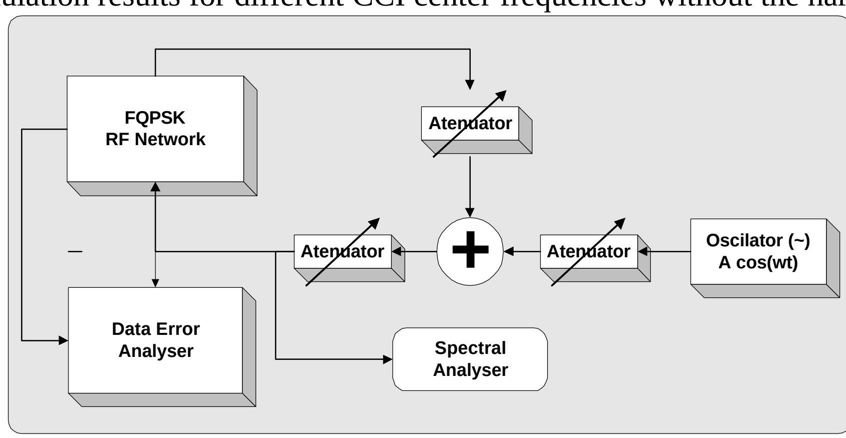


Figure (6) Measurement scheme without the hard limited filter

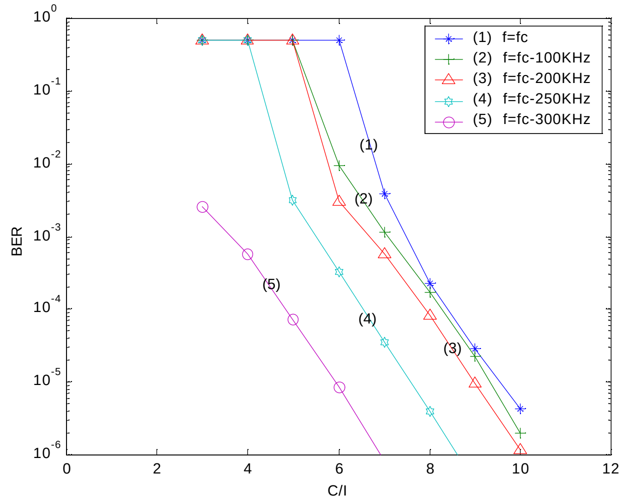


Figure (7) Measurement results for different CCI center frequencies without the hard limited filter

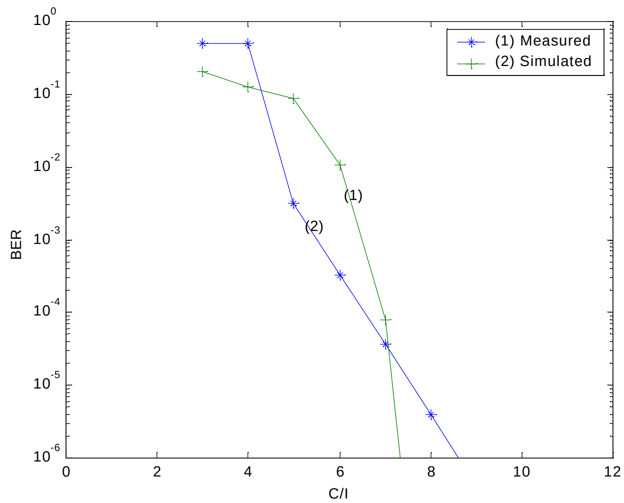


Figure (8) Simulated and measured without the hard limited filter, CCI center frequency=fc-250KHz

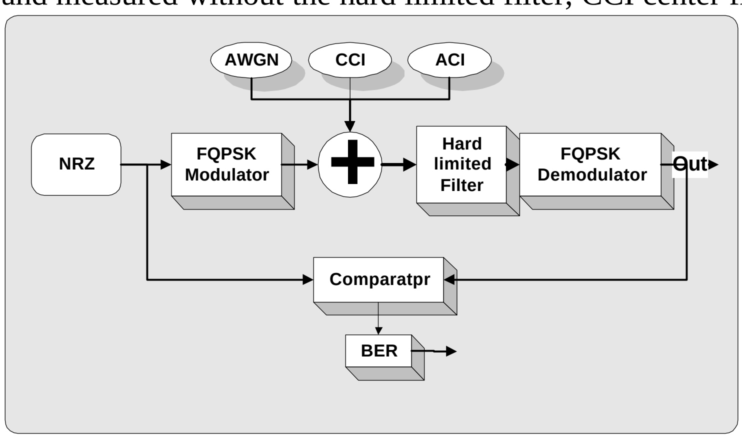
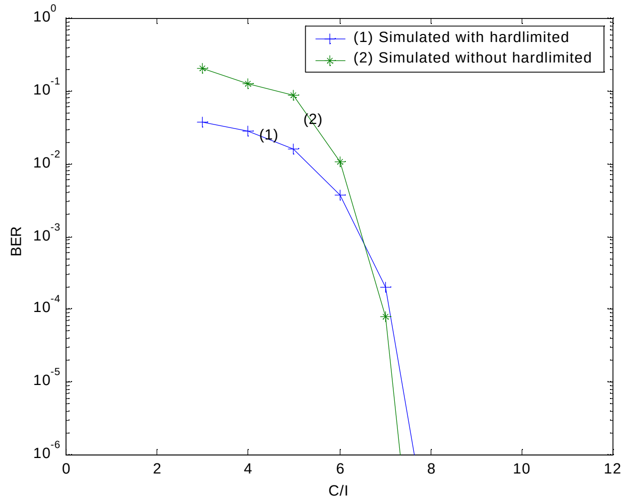
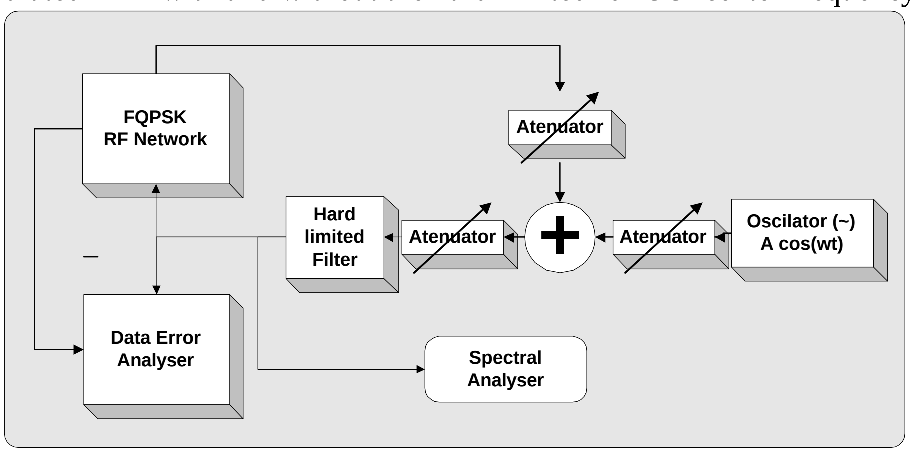


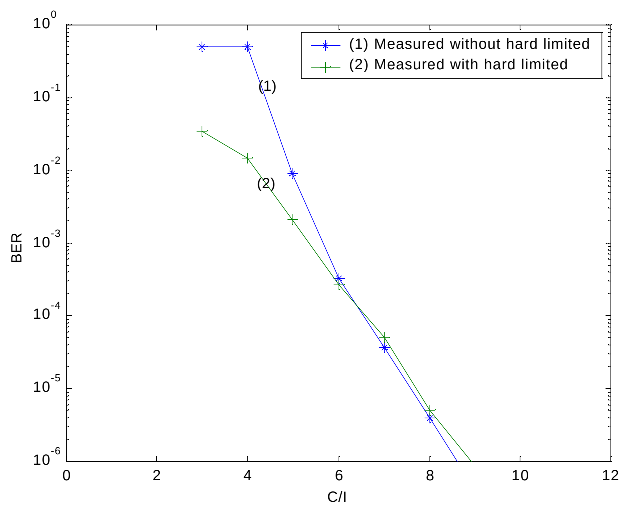
Figure (9) Simulation scheme with the hard limited filter



Figure(10) Simulated BER with and without the hard limited for CCI center frequency of fc-250KHz



Figure(11) Measurement scheme with the hard limited filter



Figure(12) Measured BER with and without the hard limited for CCI center frequency of fc-250KHz

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