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Bit Error Ratio concept and 3D Eye diagram to Analysis of M state digitally modulated signals

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ABSTRACT

When designing digital systems and incorporating a high-speed digital device with the need of quick transfer of large data amounts between chips and peripherals, jitter will be a key parameter to measure. In this paper, we are able to determine the initial phase of a carrier sine wave by performing carrier recovery loop in Digital communication systems of M-ary quadrature amplitude modulation (M-QAM) schemes. It is important for the M-ary QAM carrier recovery circuits to have low phase jitter as well as only four stable phase points as we see below. We examined the effect of channel noise on carrier recovery. More specifically, we examined what behaviour can occur when channel noise is significant enough to prevent carrier locking. We saw the symbols on the 3D Eye Diagram and constellation plot begin to jitter at first, and then settle closer to the ideal symbol locations after a short period of time. Authors of this article present real results, which illustrate the link between number of symbols in M-state QAM modulation, SNR and BER. Constellation diagrams of transmitted and received symbols (with superposition of noise) were presented in the article. Simple picture is transmitted through simulated radio channel to show the result of signal impairments. Modular PXI HW platform was used in connection with graphically oriented development environment. This combination of modular HW and flexible SW components allows changing the communication protocol, modulation scheme, frequency bandwidth and other parameters in a very simple way by changing the software part of the system.

KEYWORDS

M-QAM, Jitter, carrier recovery system, 3D Eye Diagram, BER, SNR, synthetic instrumentation, PLL (phase-locked loop), LabVIEW.

1 Introduction

Software Defined Radio is a radio communications transceiver system in which all the typical components of a communication system such as mixers, modulators/demodulators, detectors, amplifiers are implemented through software rather than hardware. This approach is helpful because there is a scope of developing a system which is compatible with more than one mobile communication standard [1]. This can be achieved by using reconfigurable hardware and swapping the software for different technologies. In a digital communication system, digital information can be sent and received by subtly changing characteristics of a carrier sine wave. In this case, determining changes in amplitude (ASK) is quite simple. However, detecting changes in phase (PSK and QAM) is much more difficult and requires a process known as carrier recovery [2] and synthetic instrumentation for analysis of the signals. A functional transmission system based on software defined radio concept was implemented on PXI modular HW platform using LabVIEW development environment. By performing carrier recovery, we are able to determine the initial phase of a carrier sine wave. Thus, it is possible to detect shifts in the phase of this signal.

2 System Model

We investigate one of the more widespread in digital TV broadcasting family of modulation schemes, QAM works by using M different combinations of voltage magnitude and phase to represent N bits, as described by the relationship M = 2N. When N is an even integer, the constellation is regular with I and Q each representing 2N-1 bits. When N is an odd integer, the constellation is not necessarily symmetrical, and finding an optimal distribution of sample points is not straightforward, for which the signal can be generally given by [3]:

$$s(t) = \sqrt{2E_s/T}\left[I(t)\cos\omega_0 t - Q(t)\sin\omega_0 t\right] \qquad (1)$$

Where I (t) and Q(t) are the baseband I and Q waveforms, respectively [3].

$$I(t) = C_0 \sum_n a_n^I \sqrt{T}\sigma(t-nT), \qquad (2)$$

$$Q(t) = C_0 \sum_n a_n^Q \sqrt{T}\sigma(t-nT), \qquad (3)$$

Here σ(t) has unit energy and C_0 is chosen so that the normalizing condition is satisfied. This requires averaging over all the pairs (a_n^I, a_n^Q), weighting each by 1/M, the integral in is simply T, so [3]:

$$1/C_0 = \left[(1/M)\sum_{a^I,a^Q}\left[(a^I)^2 + (a^Q)^2\right]\right]^{1/2}. \qquad (4)$$

The probability of error in symbol transmission is in M-QAM modulated transmission channel with AWGN noise and coherent demodulation, determined by the equation below:

$$P_{EMQAM} \cong 2\left(1 - \frac{1}{\sqrt{M}}\right) erfc\left(\sqrt{\frac{E_{min}}{N_0}}\right), \qquad (5)$$

The basic structure of designed communication system comes from the general chain of digital communication system and was implemented using functions from LabVIEW Modulation Toolkit additional library. Our Experiment Model represents the use of LabVIEW Modulation Toolkit. This Experiment demonstrates continuous acquisition and demodulation of a QAM signal see figure 1 below [4].

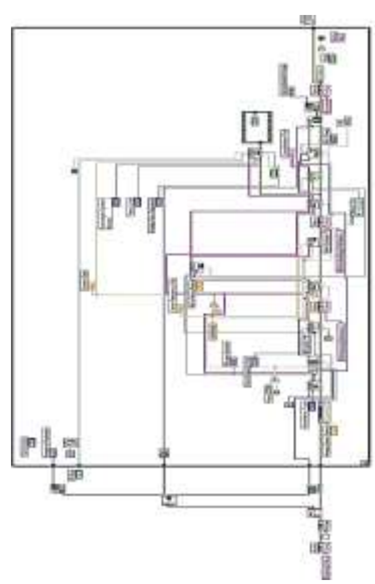

Figure 1. Block diagram of implemented Experiment

3 Multistate M-QAM Modulation

This modulation is used primarily in systems where high spectral efficiency is required. Quadrature amplitude modulation (QAM) requires changing the phase and amplitude of a carrier sine wave.

Quadrature Amplitude Modulation, QAM, has fast become the dominant modulation mechanism for high speed digital signals. From the wireless 802.11 protocols to ADSL modems to personal communicators for the military, QAM has become a necessary part of our daily lives. With increases in processing power, QAM as a part of software defined radio (SDR) schema is now easily achievable.

QAM is a modulation scheme which is carried out by changing (modulating) the amplitude of two carrier waves. The carrier waves are out of phase by 90 degrees, and are called quadrature carriers - hence the name of the scheme. QAM can be viewed as a combination of ASK and PSK. That means the digital information is carried in both the phase and the amplitude of the carrier signal [5].

Quadrature amplitude modulation, or QAM, extends the idea of PSK to modulating the pulse amplitudes as well as the phases. If forms the basis of TCM coded modulation, and so we will set down some analytical tools. As a generic communication term, QAM implies linear I and Q modulation and carrier, in contrast to PAM, which implies single-channel linear baseband modulation. A general from for a QAM signal is once again Eq, with the data mapped to M two-tuples (a_n^I,a_n^Q), but this time the resulting constellation is more than just the PSK circle. Some QAM signal space constellations are shown in figure 2, see [2].

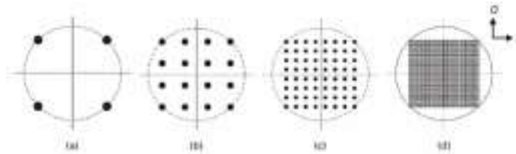

Figure 2. Square QAM constellations: a) 4-QAM (QPSK), b) 16-QAM, c) 64 –QAM, d) 1024-QAM

A common convention is to take the a_n^I anda_n^Q, as whole integers, as in the figure, but this requires an extra step to normalize I and Q.

4 Vector Signal Generator - NI PXI 5670

Along with the development environment LabVIEW, complemented by extended Modulation Toolkit library, the PXI module could be used to generate the required test signals for verifying the possibilities of digital transmission systems which use the new standards. The whole test system can be easily adapted to new requirements, while the focal point of functionality of such a system is located in the software part.

RF vector signal generator, the NI PXI-5670, as shown in figure 3, represents the generator of user-defined waveform (arbitrary waveform generator) working a resolution of 16 bits and sampling rate of 100MS / s (400MS/s in the interleaved mode) with a depth of memory up to 512 MB and the real bandwidth of 20 MHz Using a digital upconvertor along with this module can generate signal in the range of 250 kHz to 2.7 GHz with random modulation scheme such as: AM, FM, PM, ASK, FSK, MSK, GMSK, PSK, QPSK, PAM, and QAM [6].

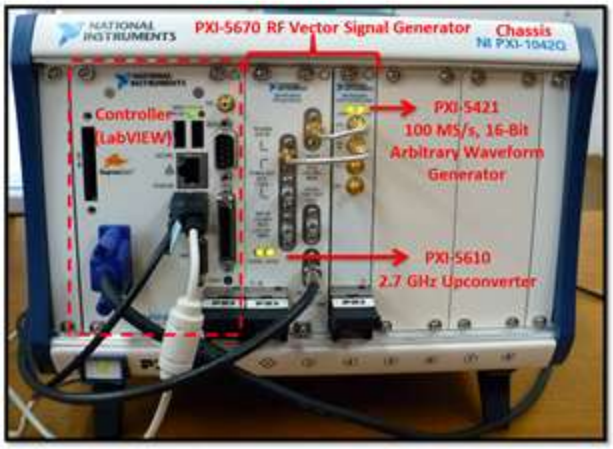

Figure 3. Vector Signal Generator (NI PXI-5610 – RF Upconverter, NI PXI-5421 -100MS/s AWG)

5 Vector Signal Analyzer – NI PXI 5661

For the analysis of digitally modulated signals a NI PXI-5660 module, as shown in figure 4, was used. This module is a very compact solution (30% of normal weight and cubature of separate devices in this class), allowing very rapid measurement of digitally modulated signals in the range from 9 kHz to 2.7 GHz. With the real bandwidth of 20 MHz, but with possible flow of data 132 Mb/s over the PCI bus, this solution represents tremendous progress in the contrast of 1 MB throughput via GPIB interface for connection of single vector signal analyzers [7].

Along with the development environment of LabVIEW with Modulation Toolkit extension libraries and Spectral Measurement Toolkit, this module represents very flexible platform for the automation of usual parameters measurement such as: in-band power, adjacent channel power, power and frequency-peak-search. Visualization of measurement results is possible in traditional forms such as 3D spectrograms and constellation diagrams for analysis of digitally modulated signals (I/Q Modulation for Data Analysis).A complete communication system has two parts: a receiver and a transmitter. Simple configuration of transmitter's and receiver's digitally modulated signal parameters allows these devices demonstration of basic principles of different transmission systems without changing the hardware of these devices. The function of designed and implemented communication system was verified by transmission of simple picture.

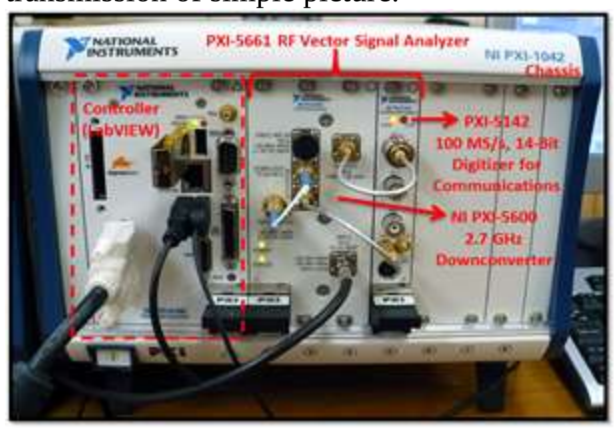

Figure 4. Vector Signal Analyzer (NI PXI-5600 – RF Downconvertor, NI PXI-5142 - 100MS/s OSP Digitizer)

6 Synthetic Instrumentation

The US Department of Defense, as the largest single purchaser of test equipment in the world, is a key adopter of next-generation instrumentation technology. The DoD has created a standards body called the Synthetic Instrument Working Group (SIWG), the role of which is to define standards for interoperability of synthetic instrument systems. The SIWG defines synthetic instruments (SI) as: A reconfigurable system that links a series of elemental hardware and software components with standardized interfaces to generate signals or make measurements using numeric processing techniques [8].

The philosophy of synthetic measurement instruments is very progressive, since it allows creating of a device, whose functions match the requirements of end-users. The performance parameters of this device are the same like performance parameters of conventional instruments, while the functions are implemented in software [9].

The firmware as the key component of synthetic instruments is user defined. The difference between traditional and synthetic instrument is shown on Figure 5.

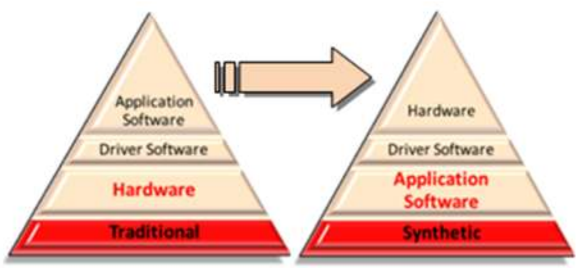

Figure 5. The difference between traditional and synthetic instrument

7 Jitter and Eye Diagram

Jitter is time-base error. It is caused by varying time delays in the circuit paths from component to component in the signal path. The two most common causes of jitter are poorly-designed Phase Locked Loops (PLL's) and waveform distortion due to mismatched impedances and/or reflections in the signal path. An eye diagram provides the most fundamental intuitive view of jitter [10], as shown in Figure 6. It is a composite view of all the bit periods of a captured waveform superimposed upon each other.

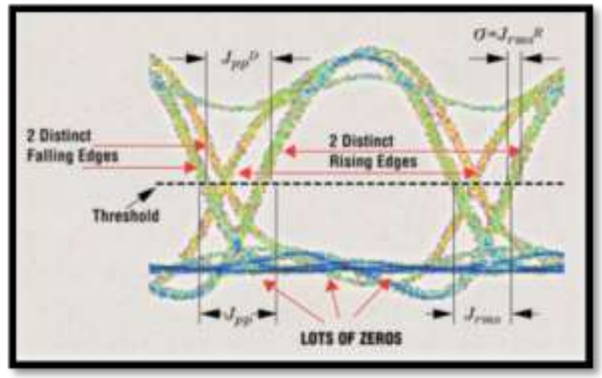

Figure 6. An eye diagram with an irregular shape provides a wealth of information

8 Fundamentals of jitter analysis

Jitter is fundamentally an expression of phase noise. Mathematically, jitter is the undesired variation in the phase of a signal given by the term, ϕ (t), in the expression:

$$S(t) = P(2\pi f_d\, t + \varphi(t)) \qquad (6)$$

Where S is the received signal, P represents the sequence of signal pulses as a function of time, and f_d is the data rate. Jitter isn't measured simply to create statistics; it is measured because jitter can cause transmission errors. For example if jitter results in a signal being on the "wrong side" of the transition threshold at the sampling point, the receiving circuit will interpret that bit differently than the transmitter intended, causing a bit error. See figure 7, from experiment.

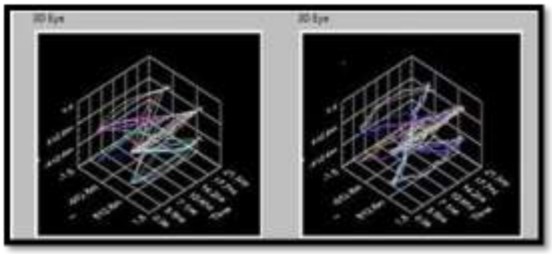

Figure 7. 3D Eye diagram for 4-QAM respectively with Bit to Noise Ratio (100) & (30)

9 Constellation diagrams

A constellation diagram is the representation of a digital modulation scheme on the complex plane. The diagram is formed by choosing a set of complex numbers to represent modulation symbols. These points are usually ordered by the gray code sequence. Gray codes are binary sequences where two successive values differ in only one digit. The use of gray codes helps reduce the bit errors. The real and imaginary axes are often called the in-phase and the quadrature. These points are usually arranged in a rectangular grid in QAM, though other arrangements are possible. The number of points in the grid is usually a power of two because in digital communications the data is binary, when start the process to convert the file to a single binary bistream, modulate it using the QAM modulation scheme, and then do the reverse process to reconstruct the original image. The channel to noise ratio is set to a maximum value, so the constellation plot shows the symbols mapped almost perfectly to their ideal positions, and then for both of the phase and the frequency of the carrier are able to be determined correctly. We will also see that the "Image to Modulate" and the "Demodulated Image" match very closely to one another. By decrease the "Bit to Noise Ratio" do 30 then observe the affect in the constellation plot, this means as the Bit to Noise Ratio decreases, the noise floor increases, see Figure 8.

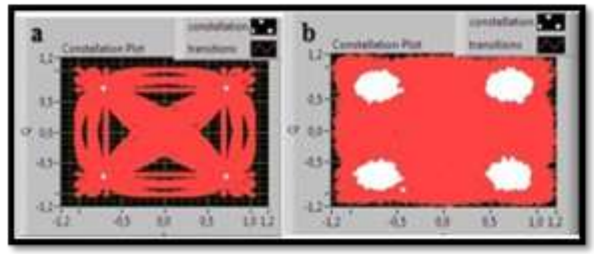

Figure 8. Constellation diagram with Bit to Noise Ratio for 4-QAM a) with 100 b) with 30

Upon reception of the signal, the demodulator examines the received symbol and chooses the closest constellation point based on Euclidean distance. It is possible to transmit more bits per symbols by using a higher-order [9].

10 Carrier Recovery Fundamentals

A carrier recovery system is a circuit used to estimate and compensate for frequency and phase differences between a received signal's carrier wave and the receiver's local oscillator for the purpose of coherent demodulation.

When coherent detection is used, the receiver must exploit knowledge of both carrier frequency and phase to detect the signals. Carrier recovery typically entails two subsequent steps: in the first step carrier synchronization parameters are estimated, and in the second the receiving carrier signal is corrected according to the estimates made. These steps must be performed quickly and accurately in burst-mode [11].

A QAM transmitter fundamentally modulates a bit pattern onto a carrier signal with a specific phase and amplitude. On the receiver side, it is absolutely imperative that the receiver is able to detect both the phase and amplitude of that signal. Otherwise, the receiver will not be able to correctly demodulate the incoming signal into the appropriate symbols.

11 Results and Discussion

There are two main ways to solving this problem of carrier recovery. The first approach to carrier recovery is to implement a pilot signal. The receiver is able to extract this signal and lock its local oscillator to both the phase and frequency of this signal. The receiver thus uses a phase-locked loop (PLL) to track the pilot signal. The second approach, which is more commonly implemented, is to derive the carrier phase directly from the modulated signal. We used this approach by using the QAM demodulation VI's in LabVIEW, this shown in Figure 9.

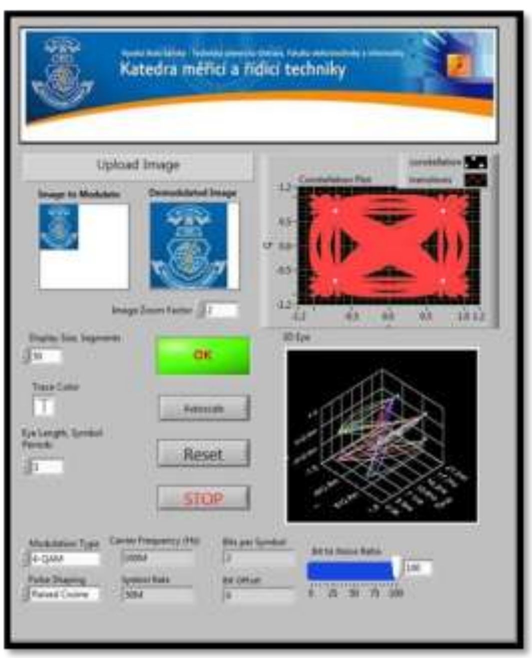

Figure 9. Front-panel: 4-QAM Screenshot with maximum Bit to Noise Ratio

We will examine what behaviour can occur when noise channel noise is significant enough to prevent carrier locking. We work with QAM modulation scheme of (8, 16, 32, 64, 128, and 256) QAM, we use here a prompted file as image (recommended .jpg.).

When start the process to convert the file to a single binary bistream, modulate it using the QAM modulation scheme, and then do the reverse process to reconstruct the original image. Run the QAM modulation scheme of M-QAM, the channel to noise ratio is set to a maximum value, so the constellation plot and 3D eye diagram in Figure 10 shown respectively (8, 16, 32, 64, 128 and 256) M-QAM, the symbols mapped almost perfectly to their ideal positions and an 3D eye diagram of a waveform that is even less ideal. But the characteristic of its irregular shape enables the viewer to learn much about it, and then for both of the phases and the frequency of the carrier are able to be determined correctly.

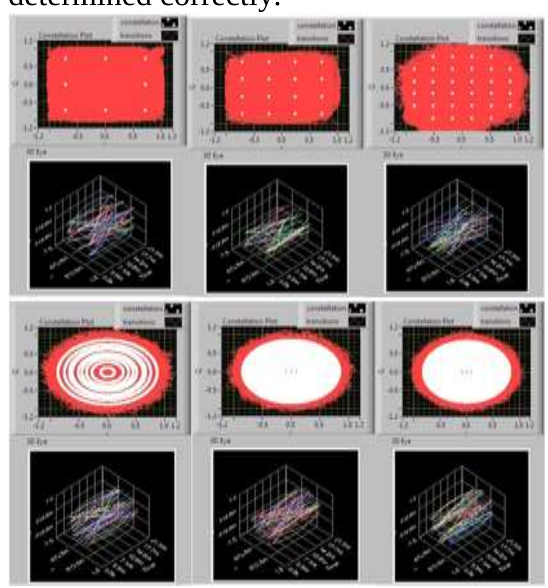

Figure10. Constellation and 3D Eye diagram for M-QAM with Bit to Noise Ratio (100) respectively for (8, 16, 32, 64, 128 and 256)

To observe the PLL performing carrier recovery by adding enough noise such that the phase and frequency information of the carrier signal can no longer be determined, by slowly decrease the value of Bit to Noise Ratio (current value 30) even more until the constellation plot begins to spin. This gives us two key characteristics. First, while the Demodulated Image is not exactly recovered, it does unclear like the image to modulate. This illustrates that at least some of the symbols are mapped to bits that are close to their expected location. Second and more importantly, notice that the constellation plot is now appears to have a ringed or unclear , that is mean the constellation plot is now spinning and that the carrier's frequency cannot be properly determined. In Figure 11 below have the constellation plot and 3D eye diagram for the results respectively of all the M-ary QAM (8, 16, 32, 64, 128 and 256) with Bit to Noise Ratio (30).

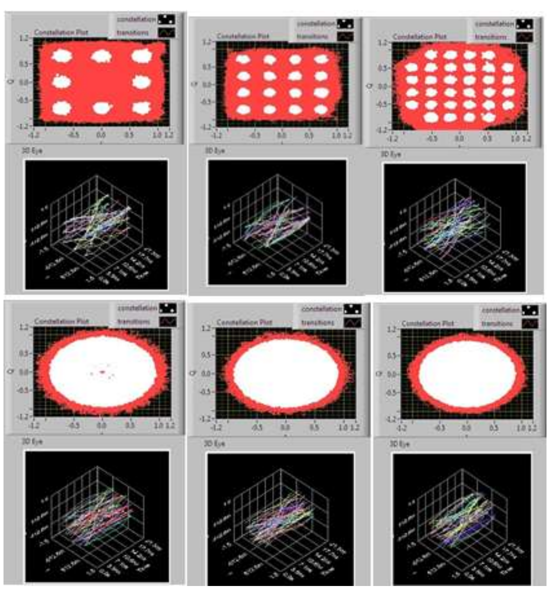

Figure11. Constellation and 3D Eye diagram for M-QAM with Bit to Noise Ratio (30) respectively for (8, 16, 32, 64, 128 and 256)

We will also see that the "Image to Modulate" in Figure 12 and the "Demodulated Image" in Figure 13 match very closely to one another. By decrease the "Bit to Noise Ratio" do 30 then observe the affect in the constellation plot, this means as the Bit to Noise Ratio decreases, the noise floor increases. As a result, the recovered symbols begin to show jitter from the ideal symbol locations. However, each of these symbols can still be mapped to the correct bit values, and the image is to be recovered correctly.

Figure12. Demodulated Image with Bit to Noise Ratio 100 respectively for M-ary QAM (8, 16, 32, 64, 128 and 256)

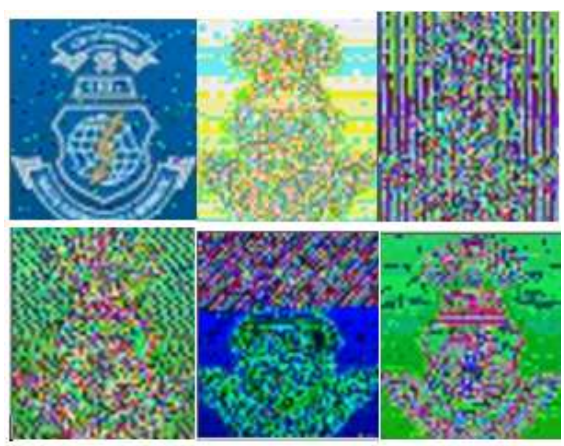

Figure13. Demodulated Image with Bit to Noise Ratio 30 respectively for M-ary QAM (8, 16, 32, 64, 128 and 256)

The simulation of different M-QAM modulation shows that increasing of the state number, leads to an increase of transfer rate (transfer more bits per symbol). The downside however is that with the growing number of states BER increases at the same transmission power as a result of worse distribution of symbols in constellation diagram, as shown in table 1 and figure 14.

Table 1. Measured BER dependency on SNR

SNR [dB]	BER			
	4-QAM	*8-QAM*	*16-QAM*	*32-QAM*
0	0,07619	0,20548	0,25817	0,31779
2	0,03885	0,14895	0,21275	0,28123
4	0,01340	0,09589	0,15531	0,24034
6	0,00235	0,05170	0,10306	0,18916
8	0,00025	0,02040	0,05729	0,13475
10	0	0,00550	0,02302	0,08237
12	0	0,00083	0,00630	0,04066
14	0	0	0,00072	0,01392
16	0	0	0	0,00232
18	0	0	0	0,00026
20	0	0	0	0

SNR [dB]	BER		
	64-QAM	*128-QAM*	*256-QAM*
0	0,33487	0,36892	0,37226
2	0,30724	0,34759	0,35701
4	0,27879	0,31427	0,33408
6	0,24236	0,28459	0,31021
8	0,20290	0,25156	0,28401
10	0,14695	0,20976	0,25270
12	0,09932	0,16677	0,21929
14	0,05529	0,11732	0,18249
16	0,02435	0,07168	0,13336
18	0,00733	0,03634	0,09004
20	0,00103	0,01323	0,05140
22	0,00012	0,00284	0,02156
24	0	0,00023	0,00662
26	0	0	0,00097
28	0	0	0,00006
30	0	0	0

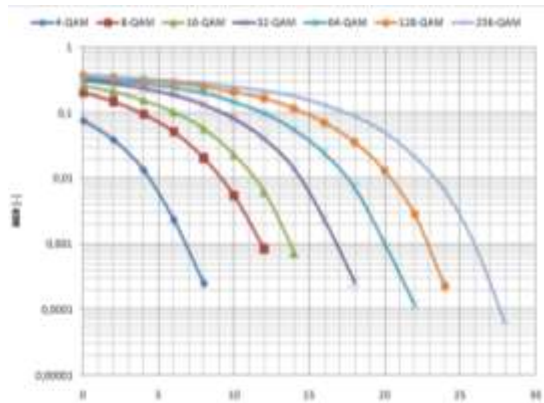

Figure14. Measured BER dependence on SNR

11 Conclusion

It was clearly observed that the PLL (phase-locked loop) spent at maximum noise, with the number of iterations, before eliminating it from the physical channel; it was also noticed in some instances that the constellation plot seems to show significant PLL jitter at first, but then settles onto the appropriate phase and amplitude. As this demonstration illustrates that carrier recovery is a significant aspect of digital communications systems. We have created 3D eye diagrams to show the relationship among time, in-phase, and quadrature signals. Moreover, the phase-lock loop performs a significant role in allowing the receiver to accurately determine both the phase and frequency of the carrier signal. Here, we observed that channel noise is one of the largest impairments to carrier recovery and that significant noise can even “break” the carrier locking ability of a PLL.

The synthetic instrument for analysis of digitally M-QAM modulated signal was implemented on National Instruments PXI modular HW platform using graphically oriented development environment LabVIEW.

The main contribution of the work is in the creation of a virtual instrument designed for real measurement, applicable in wireless transmission systems. The idea of functionality of such systems comes from the definition of the software radio, which regards the hardware of the transmission system as a universal, generally conceived device.

ACKNOWLEDGEMENT

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