COMPUTER-BASED STUDY OF THE EFFECT OF PHASE NOISE IN 256-QUADRATURE AMPLITUDE MODULATION USING SCATTER PLOT SCOPES

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Abstract.

This work is aimed at studying the effect of phase noise on 256-quadrature amplitude modulation using Scatter Plot Scopes. It also proffers a technical solution on how such effect can be reduced. Values of the Phase Noise Level Density (PNLD) were varied from -20dBc/Hz to -120dBc/Hz; in a model that is capable of simulating the effect of phase noise in 256-QAM, contained in a MATLAB 7.1 version, which was installed in Compaq desktop. A few adjustments (such as increasing the value of signal to noise ratio in AGWN to 100dB, etc) were made on the model before using it. The results obtained indicate that as the values of the phase noise level density decrease, the negative effect of the phase noise on the transmitted signal reduces, as seen from the display of the Scatter Plot Scopes. This work is of benefit to communication companies, in that it will enable them to be aware of the pronounce effect phase noise could have on the modulation scheme under consideration. And by this they can guard against it.

Keywords: *Phase noise, quadrature amplitude modulation, simulink and MATLAB*

1. Introduction

Communication has become an indispensable means of interaction in the society. Without communication, human beings could not have understood themselves, even now. There are different means of communication. These can be on one-on-one interaction; by means of newsprint; radio transmission or telephone.

Our study here is related to communication through telephones and satellites. Before communication is achieved through telephones and satellites, the information to be communicated may have to be "modulated". Modulation is a way of adding information on to a carrier to enhance communication between distant persons.

Various modulation schemes have evolved. Some of these include: amplitude modulation, frequency modulation, phase modulation, and pulse modulation. Complex forms of modulation such as: quadrature amplitude modulation and phase shift keying, are presently in use. These two are mainly used in radio applications, such as: satellite communication systems. Most often, quadrature amplitude modulation is used along with pulse code modulation in such digital systems. In this study, the 256-QAM with attendant effects of "phase noise" is expressly considered.

2. Quadrature Amplitude Modulation (QAM)

Quadrature amplitude modulation is a relatively simple technique. Here, two carrier waves are one quarter of a cycle out of phase with each other. The two carrier waves are usually sinusoidal or cisoidal. These two signals may be transmitted independently both carrying the same information at the same frequency band. The major advantage of the QAM is that it can enable data transmission at twice the rate of a standard pulse amplitude modulation (PAM) without any degradation in the bit error rate (BER). In addition, it has the advantage of reducing intermodulation interference caused by a continuous carrier wave near the modulating sideband.

Quadrature amplitude modulation is a modulation scheme that combines both amplitude modulation and phase shift keying. Data is usually conveyed by changing some aspects of the carrier signal (usually the amplitude) in response to the imputed data signal. When the amplitude of the carrier signal is kept constant and only the frequency is varied, this is termed: *frequency shift keying modulation.* It is a special case of QAM. When two signals are transmitted by modulating them with QAM, the transmitted signal will be of the form:

$$S(t) = I(t)\cos(2\pi f_0 t) + Q(t)\sin(2\pi f_0 t) \quad (1)$$

where I (t) and Q (t) are the modulating signals. I (t) is the in-phase component of the signal while Q (t) is the quadrature component of the signal. f_o is the carrier frequency. At the receiver, these two modulating signals can be demodulated using appropriate demodulator. The receiver multiplies the received signal separately with both the sine and cosine signals, to produce received estimates of Q (t) and I (t), as the case may be. It is possible to detect the modulating signals independently because of the orthogonality property of the carrier signals. Thus:

$R_{si}(t) = S(t)\cos(2\pi f_o t)$ (where $R_{si}(t)$ is the received estimate of I (t) information)

$$R_{si}(t) = I(t)\cos(2\pi f_o t)\cos(2\pi f_o t) + Q(t)\sin(2\pi f_o t)\cos(2\pi f_o t) \quad (2)$$

Using trigonometric identities:

$\cos A \cos A = ½[\cos 2A + 1]$ and $\sin A \cos A = ½ \sin 2A$

Equation (2) results in:

$$R_{si}(t) = I(t)/2\,[\cos 4\pi f_o t + 1] + Q(t)/2 \sin 4\pi f_o t$$

That is:

$$R_{si}(t) = ½ I(t) + ½ I(t)\cos 4\pi f_o t + 1/2\, Q(t)\sin 4\pi f_o t \quad (3)$$

Now this signal has to pass through the low-pass filter, which removes the high frequency components, leaving only I (t) term. That is,

$$R_{si}(t) = ½\ I(t) \quad (4)$$

On the other hand, Q (t) information can be retrieved by multiplying sin(2f$_o$t) to the received signal S(t). That is:

$R_{sq}(t) = S(t)\sin(2\pi f_o t)$ (where $R_{sq}(t)$ is the received estimate of Q (t) information)

$$R_{sq}(t) = I(t)\cos(2\pi f_o t)\sin(2\pi f_o t) + Q(t)\sin(2\pi f_o t)\sin(2\pi f_o t) \quad (5)$$

Again using trigonometric identities such as: $\sin A \sin A = ½[1 \cos 2A]$ and

$\sin A \cos A = ½ \sin 2A$

Equation (5) results in:

$R_{sq}(t) = ½ I(t) \sin(4\pi f_0 t) + ½ Q(t) - ½ Q(t) \cos(4\pi f_0 t)$ (6)

Low-passfiltering the signal we obtain:

$R_{sq}(t) = ½ Q(t)$ (7)

The schematic diagram of the receiver shown in Fig.1 and that for the transmitter in Fig.2.

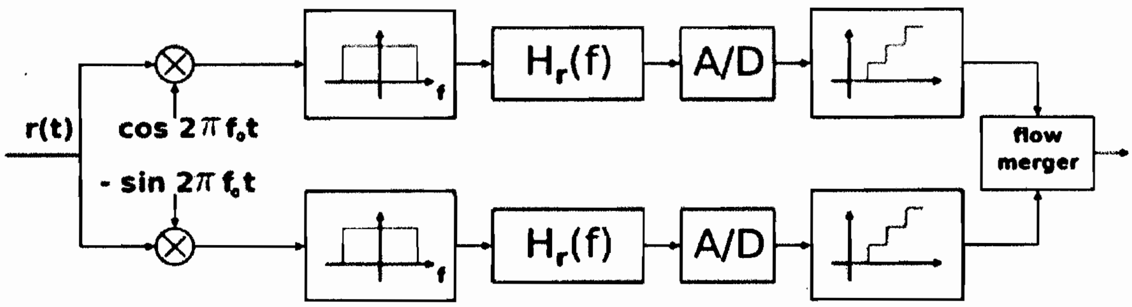

Fig.1: A schematic diagram of the receiver subsystem

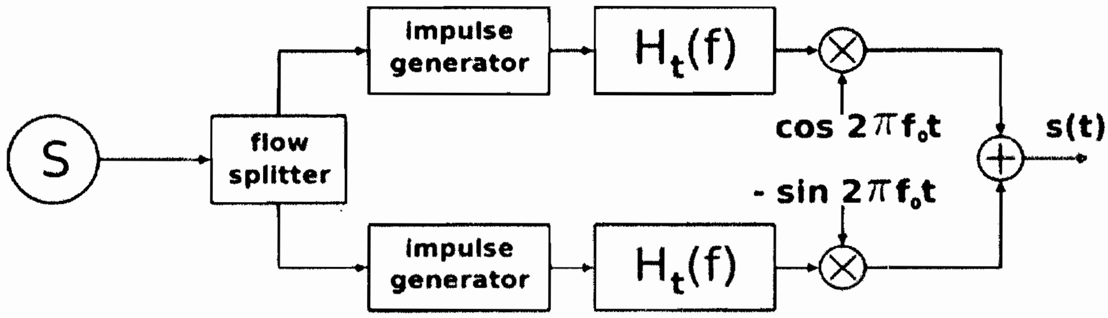

Fig.2: The schematic diagram of a QAM transmitter

The quadrature amplitude modulation above is the analogue type. It is used in NTSC and PAL television systems, where I- and Q- signals carry the components of chroma (colour) information. The digital QAM is represented using constellation points. Here, the constellation points are usually arranged in square grid with equal horizontal and vertical spacings (see Fig. 6); though other configurations are possible.Since in telecommunication the data is usually binary, the number of points in the grid is usually a power of 2. The advantage of moving to higher ordered constellation is that it allows for transmission of more bits per symbol.

3. Noise

Noise, in electrical terms is defined as any unwanted energy tending to interfere with the proper reception and reproduction of transmitted signals (George and Bernard, 1999). According to Onuu and Inyang (2004), environmental noise is any undesired sound that constitutes a menace to the environment. Although this definition is given from the point of view of acoustics, it is still relevant to the subject of study. Noise according to Menkiti (2000) is defined as any signal that was not sent from the node. It can come from electronic component; from radio aerial, microwave dishes, electronic devices or even from humans who handle the equipment. Therefore, noise can either be natural or artificial.

In digital communication systems, noise may produce unwanted pulses or perhaps cancel out the desired ones (George and Bernard, 1999). Noise may introduce serious mathematical errors in signal analysis and limit the range of systems for a given transmitted power. It can also affect the sensitivity of receivers by placing restrictions on the weakest signals to be amplified. All these are some of the effects of noise on signals and communication systems at large.

3.1 Phase noise

Phase noise affects the phase of carrier signals. Here, the noise (whose phase is random) causes the phase of the carrier signal to be random. When phase noise is introduced into a carrier signal, it causes angular displacement of the carrier signal as can be seen in Fig. 8. Such noise is usually associated with oscillators. In the digital 256-QAM, phase noise is generated when the constellation points oscillate at a very high frequency (about 10MHz). It is a very important parameter to be consider when designing devices such as satellite repeaters, sensitive communication receivers and the mobile stations (Baruch, 2006).

Phase noise like other types of noise can only be described statistically, because of its random nature and is expressed in dBc/Hz at various offsets from the carrier frequency. This is usually referred to as phase noise level density (PNLD) and it can be expressed as:

$$PNLD = -10 \log I/I_o \qquad (8)$$

where, I = noise intensity level in dB

and $I_o = 10^{-12}$ is a reference noise intensity level

For example, if the noise intensity level is 10^{-4}dB at a frequency offset of 1000Hz then,

$$PNLD = -10 \log (10^{-4}/10^{-12}) = -80 \text{ dBc/Hz}$$

4. Materials

Materials used for this work include: a dedicated high-speed and large capacity (40 Gbit hard disk size) personal computer, with a Pentium 3 microprocessor and RAM memory size of 512 Mbit. The computer has a clock frequency of 547 MHz and the operating system working in the computer is Microsoft window XP professional, windows 2000. Accessories to the computer include: a 16 inch Acer monitor, a 19.0 Gbit hard disk drive, a 2.0 Gbit removable hard drive, a Microsoft mouse and a Touch mate keyboard.

The software package used in this work is MATLAB 7.1 Version. This software contains, "similink", which is a tool (sub-software) that helps to simulate models after varying desired parameters in the models. Similink turns our computer into a laboratory for performing experiments. For example, one can build a model from the scratch using simulink. One can also take up existing models in the similink environment and improve on it. These and more are what similink can offer.

5. Methodology

The experiments were performed using a similink model (contained in MATLAB 7.1) that is capable of simulating the Effect of Phase Noise in Quadrature Amplitude Modulation. The model is shown in Fig.3.

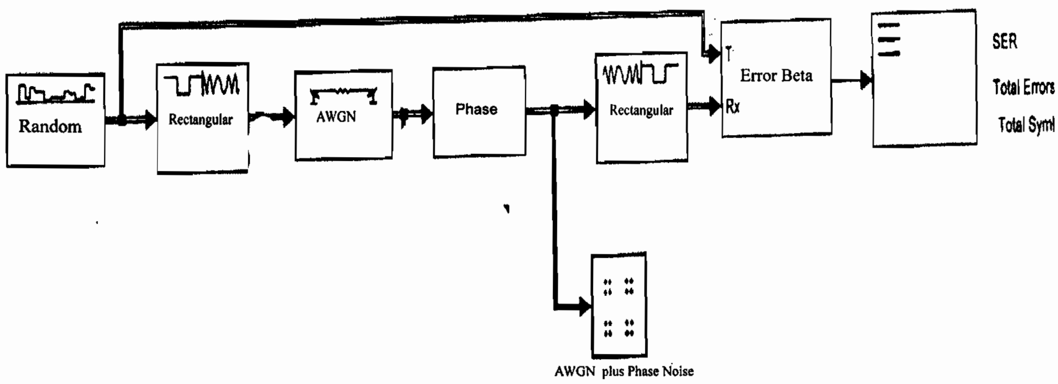

Fig. 3: A similink model capable of simulating the effect of phase noise in 256-QAM.

This model was then used to study how phase noise affects quadrature amplitude modulation. Before proceeding to the experiments, the value of the signal to noise ratio in the Add white Gaussian noise (AWGN) channel was first raised to 100dB, such that the channel itself would not have any effect on the modulated signal. This was confirmed by attaching two scatter plot scopes before and after the AWGN channel (Fig. 6 and 7 respectively). These two scopes enabled the signal to be viewed before and after passing

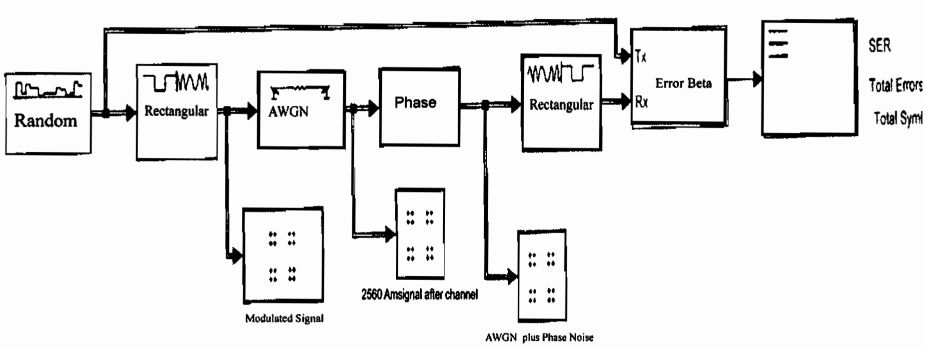

Fig.4: Two scatter plot scopes attached to the original simulink model

through the channel (Fig.4).

The experiment was performed taking values of PNLD from 20 dBc/Hz to 120dBc/Hz, in step of 20dBc/Hz; for frequency offset of 200Hz. For each variation, the model was simulated. Results were displayed by the scatter plot scopes.

5.1 Parameters used for simulation

The following parameters were used in each block for the simulation:

For the random integer generator block:

M-ary number is 256, initial seed is 12345, sample time is 0.001s, output status is to frame-based, number of samples per frame is 500, and output data type used is unit 8.

For the Rectangular QAM Block:

M-ary number is 256, input data type is integer, constellation ordering is set to 'binary', normalization method is set to 'average power', average power used is 1 watt, phase offset is set to 0 rad, and output data type set to 'single'.

For the rectangular qam demodulation baseband block:

M-ary number is 256, output data type is Integer, constellation ordering is set to 'binary', normalization method is set to 'average power', average power is 1 watt, phase offset is set 0 rad, output data type set to 'Unit 8'.

For the AWGN channel:

Initial seed is 54321, signal-to-noise ratio (Es/No) mode is used, value of signal to noise ratio used is 100 dB, input signal power used is 1 watt, and the symbol period is 0.001s

For the error rate calculation block:

Receive delay is zero, computation delay also zero, computation mode is set to 'entire frame', and the output data set to 'port'.

For the discrete-time scatter plot scope we have:

Minimum x-axis value was set to 1.5, maximum x-axis value was set to 1.5, minimum y-axis value set to 1.5, maximum y-axis value set to 1.5, In-phase x-axis label was tagged in-phase amplitude, quadrature y-axis label was tagged quadrature amplitude, the scope position is set to [32 306 240 240], and the scope was titled: 'scatter plot'.

The same parameters were set for the three scatter plot scopes in the model presented They were all set to "open scope at start of simulation". In this case, the scopes open on their own immediately simulation starts.

For the configuration parameters:

Simulation time was set to start from 0.0 and stop at 10.0; the solver type used is Ode 45; relative tolerance was set to ie-3 = 0.001; absolute tolerance was set to 'auto'

Solver options

Type = variable step

Max step size = auto

Min step size = auto

Initial step size = auto

Zero crossing control = use local settings.

6. Results of the Scatter Plot Scopes

The results of the scatter plot scopes gave visual analyses of the effects of the phase noise in the quadrature amplitude modulated signal for each substituted phase noise density value. The results of the scatter plots were shown on the scopes in Fig. 8, 9, 10, 11, 12, and 13.

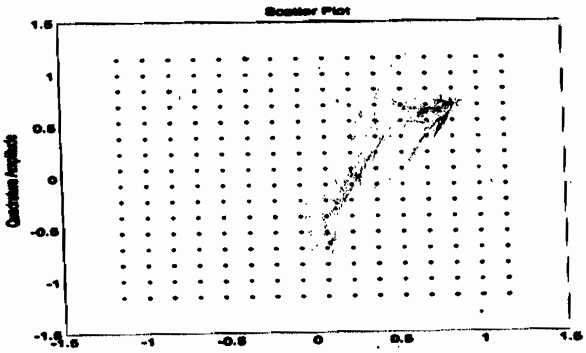

Fig.6: Original quadrature amplitude modulated signal

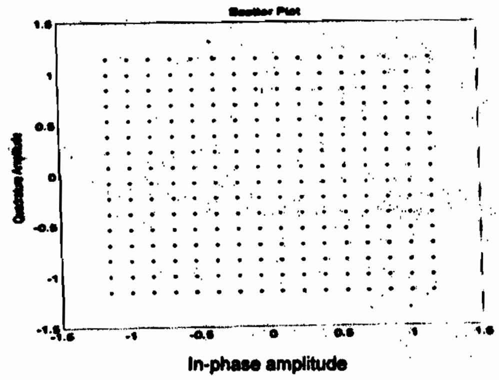

Fig.7: Signal after passing through the channel

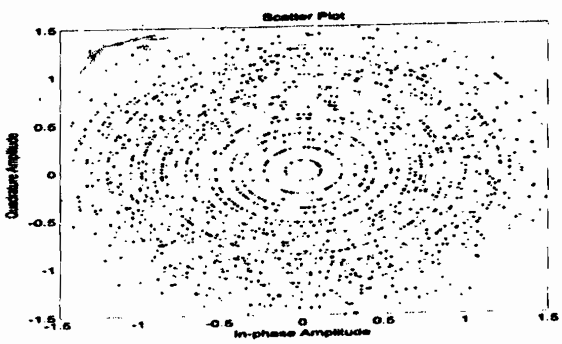

Fig.8: Scatter plot display for 20dBc/Hz

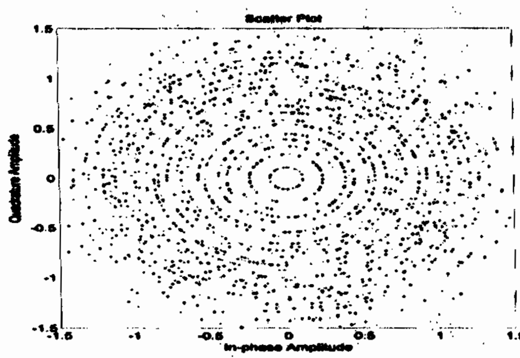

Fig. 9: Scatter plot display for - 40dBc/Hz

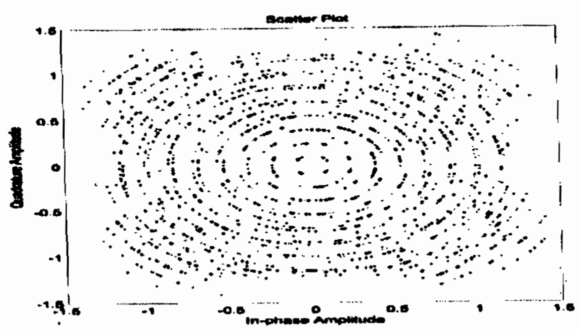

Fig. 10: Scatter plot display for 60dBc/Hz

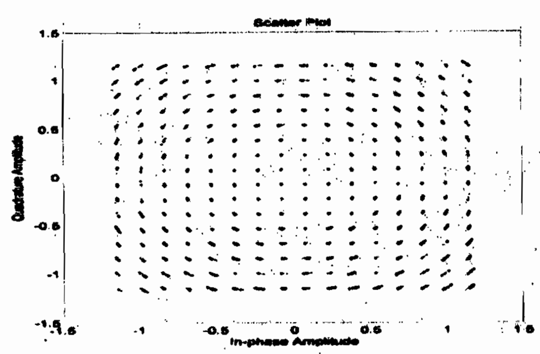

Fig. 11: Scatter plot display for 80dBc/Hz

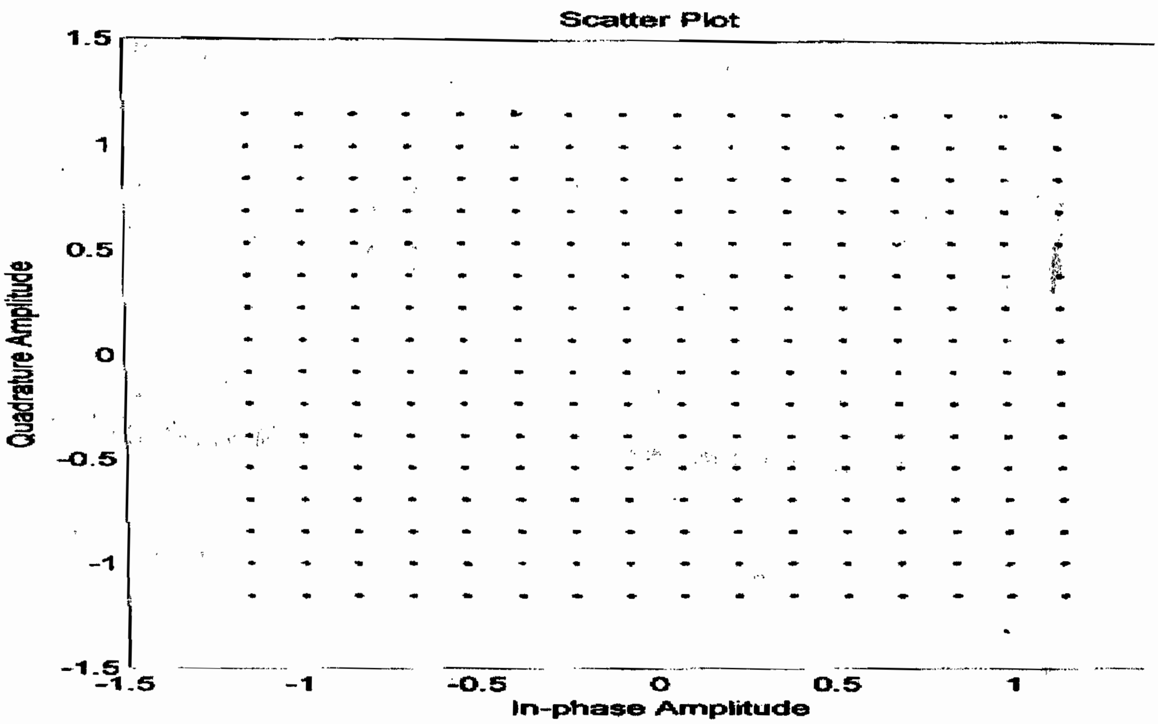

Fig. 12: Scatter plot display for – 100dBc/Hz

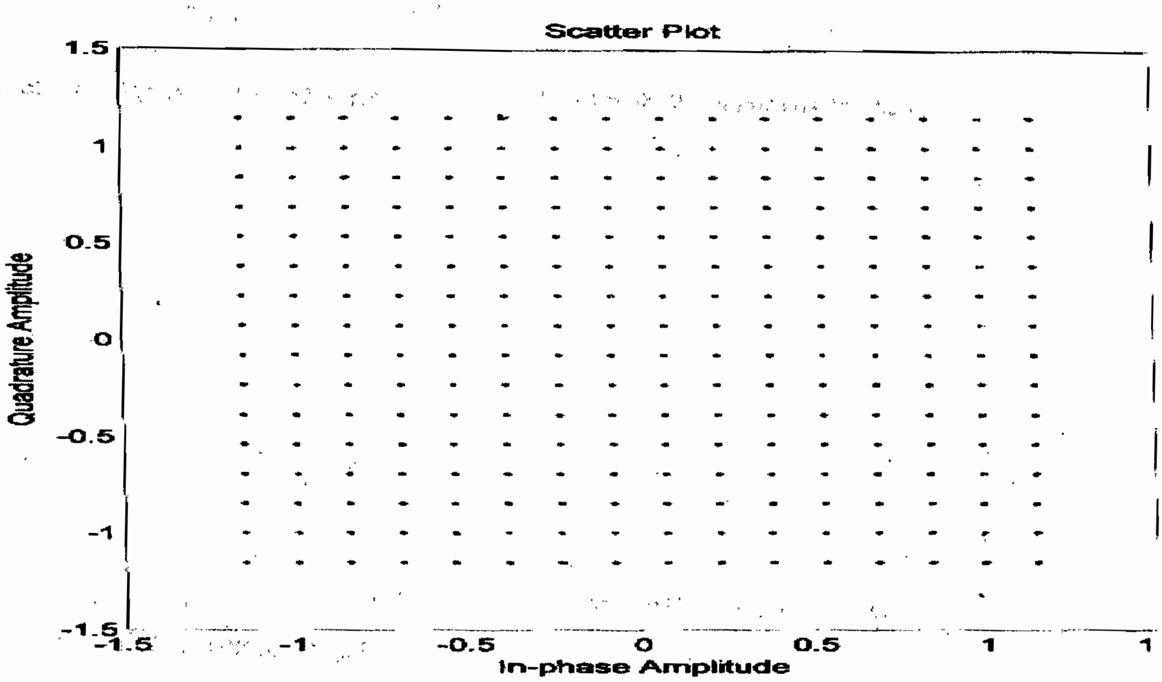

Fig.2: Signal after passing through the channel

The Scatter Plot Scope before the AGWN channel displayed the form of the original signal that was transmitted (see Fig. 6). The second Scatter Plot Scope (Fig.7) displayed signal similar to the original signal; signifying that the channel did not affect the transmitted signal. This was because the signal-to-noise ratio in the channel was raised to 100dB. The Scatter Plot Scope placed after the Phase Noise Block gave different result for each PNLD value, varied from -20dBc/Hz to -120dBc/Hz.

Figure. 8 shows a great deal of angular displacement/distortion of the quadrature amplitude modulated signal. A slight reduction in the angular displacement is shown in Fig.9. Figure10 show a significant reduction in the angular displacement. The reduction in the angular displacement was actually obvious in Fig.11. In Fig.12, we obtain a signal that was an exact replica of the original modulated signal (see Fig.6). Fig.13 did not show any difference from Fig.12.

In all of these, it is observed that, as the phase noise level density was reduced, the effect of the phase noise in 256-QAM also reduced.

8. Recommendation and Conclusion

Having looked at the study so far, it is recommended that since the amount of phase noise generated, during the oscillation of the constellation points, depends on the diameters of these points (for a real life situation) and having seen that reducing this noise in density also reduces its effect in 256-QAM then, effort must be made by communication companies to ensure that the diameters of these points are kept as small as possible. This is because the wider points, the more the phase noise level density introduced, this owing to the wider oscillation the points. This cannot enable transmission of pure signals with little or no effect of phase noise.

References

Akpan, A.O, Onuu, M.U, Menkiti, A.I., and Asuquo, U.E. (2003):Measurements and Analysis of Industrial Noise and its impact on Workers in Akwa Ibom State,South-Eastern Nigeria, Nigerian Journal of Physics, 15 (2), 41-45

Asiegbu, A.D (2005): Computer-Aided Studies of Telephone Traffic in hia-, South East Nigeria.Unpublished PhD Dissertation, Michael Okpara University of Agriculture, Umudike, 90.

Bello, K. (1999): Telecommunication, NITELJournal, .26. 38-42.

Bernard, D. and George, K. (1999) Electronic Communication System, 4th ed. McGraw Hill Company ltd, Delhi, 2-60

Froehlich, F. (1999):Encyclopedia of Telecommunication, Marcel Dekker Publishers, Vol.11, 512.

Onugbolu, N.B (2003): Modern Telecommunication Network in Nigeria.A paper presented to the Nigeria Society of Engineers Ibadan Branch,Unpublished, 1-26pp.

Onuu, M.U (1999): Environmental Noise Control: Review and Assessment of Theories and Model, Nigerian Journal of Physics, 11, 91-96

Onuu, M.U. (2000):Road Traffic Noise in Nigeria. Measurement, Analysis and Evaluation of Nuisance, Journal of Sound and Vibration, 233 (3), 391-405

Onuu, M.U and Akpan A.O. (2006): Industrial Noise in Nigeria: Measurements, Analysis, Dose and Effects Journal of Building Acoustics, 13 (1),41-45

Onuu, M.U. and Inyang, A. (2004): Environmental Noise Pollution in Nigeria Universities. A CaseStudy of the University of Calabar, Calabar, Nigeria, Journal of Nigerian Environmental Society, 2 (1), 100-109.

Sheldon, T. (2001). Encyclopedia of Networking & Telecommunications, McGraw Hill Inc., 87.

http://www.intel.com accessed in January, 2007.

http://enwiktionary.org/wiki/crosstalk accessed in February, 2007.

http://www.mathworks.com accessed in June, 2007.

http://www.enwikipedia.org/wiki/Quadrature-amplitude modulation accessed in July, 2007.

Http://www.searchnetworking.techtarget.com accessed in August, 2007.