

AMPLITUDE AND PHASE MODULATION FOR ULTRASONIC WIRELESS COMMUNICATION

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ABSTRACT

Short range wireless communications have been used more and more frequently in our life. But the electromagnetic fields waves also have some disadvantages. One of these disadvantages is health problems. Many studies shows the electromagnetic field waves using for communication may damage our health. And in most hospitals, they also have bans on the use of mobile phones and wide area networks because of Electromagnetic Interference. So this paper studied the use of ultrasound for wireless communication in air, instead of using electromagnetic field wave. In order to find an advisable modulation method for ultrasound wireless communication, Amplitude modulation method and Phased modulation method has been test.

KEYWORDS

wireless communication; electromagnetic pollution; ultrasound, modulation

1. INTRODUCTION

In recent years, short range wireless communications have been used more and more frequently in our life. Just like RF systems[1] which using various kinds of technologies, including many popular commercial protocols. Other wireless communications like cell phones or wireless local area networks are also used very often today. Almost all of these communication systems link to each other by electromagnetic field waves, otherwise referred to electromagnetic radiation. But the electromagnetic fields waves also have some disadvantages. One of these disadvantages is health problems. Now several research work have already been taken out to study the adverse health effect of electromagnetic field waves. The earliest scientific study in this area was following the work of epidemiologist Nancy Wertheimer in 1979[2]. Her research showed there was a high incidence of leukemia among the children who lived near high tension power lines, where electromagnetic fields were stronger. After that, more research has broadened in the biophysical field of electromagnetic field waves and health. In May 2011, the WHO's International Agency for Research on Cancer published a review of the evidence on health risks of electromagnetic fields wave. This review concluded limited evidence that cell phone users might be at increased risk of glioma and acoustic neuroma, and there was inadequate evidence of any other health risks posed by electromagnetic fields wave [3].

Also in most hospitals, they have bans on the use of mobile phones and wide area networks for different reason. Because these wireless communications may be dangerous. In hospitals, there are many electronic devices which keep watch on patient's heartbeats and other things when they are getting surgery. But if we use mobile phone near these devices, the electromagnetic waves may cause them stop working. This will cause bad accidents when the doctors and nurses are

trying to save lives. So any communications system within the hospital should not generate significant EMI and have no EMC problems.

So we consider using ultrasound wave for wireless communication instead of using electromagnetic field wave here. The ultrasound wave has already been used for communication in the past time. For example, through-wall communication[4] and underwater communication[5]. Now with the development of technology, it is possible to send ultrasound wave through air within a certain distance. This means that ultrasound wave can be used for short-range wireless communication in air. Some studies of ultrasound communication system have also been published, just like a wireless keyboard using ultrasound[6]. Ultrasound wave can provide a better environment for our health, or a safer wireless communication environment in hospital. Using ultrasound will also offer other advantages over position and security. Because the propagation speed of acoustic wave is much slower than electromagnetic field wave and it is effectively blocked by most barriers.

2. APPARATUS AND EXPERIMENT

Today wireless communication network is envisioned to provide a wide range in our life. More and more applications of wireless network have been developed. Just like wireless sensor network using in monitoring[7,8], or mobile ad hoc network[9]. At the same time, wireless communication network is also used in medical area. For example, wireless body area network to capture continuous data from patients in real time [10,11]. Or wireless sensor network used in healthcare applications for vital sign collection from medical devices[12,13]. Even a wireless sensor network for air pollution monitoring[14]. Some other technology just like ZigBee is also used widely[15]. However, all of these wireless communication systems may cost EMS problems. So in most hospitals, they have bans on the use of common wireless communication systems, just like cell phone or wireless location area network. Because EMS problems may be dangerous in hospital. As we know, there are many electronic devices which keep watch on patient's heartbeats and other things when they are getting surgery. But if we use mobile phone near these devices, the electromagnetic waves may cause them stop working. This will cause bad accidents when the doctors and nurses are trying to save lives.

Any communications system within the hospital should not generate significant EMI and have no EMC problems. Some new wireless systems have been proposed, just like optical wireless network[16]. Here we consider using ultrasound wave for wireless communication system in hospital.

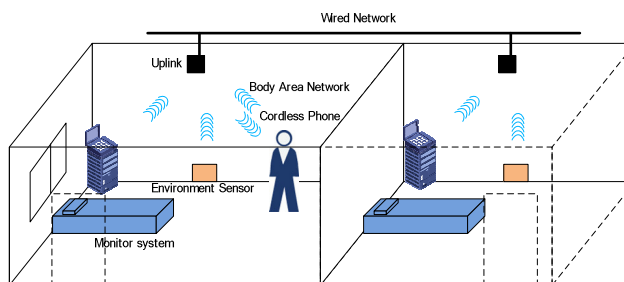


Figure 1. Ultrasound wave communication system

Figure 1 is a diagram of ultrasound wireless communication system. We set one main ultrasound transceiver in every room. This transceiver is used to receive ultrasound signals sending by other devices and communicate with other room through wired network. In this system, all the wireless communications use ultrasound wave. Therefore, a modulation method using for ultrasound

communication is needed. And the main objective of this paper is finding a suitable modulation method for this communication system.

2.1. Basic Testing

In order to test different modulation method, a transport model for ultrasound wireless communication is studied. Figure 2 shows the typical experimental arrangement. In this experimental, the source was driven by a signal generator. This signal generator can supply the required digital signal for experimental. A linear power amplifier with a gain of 32dB was used to boost the output of the signal generator. The received signal was fed into signal analyzer for offline signal processing.

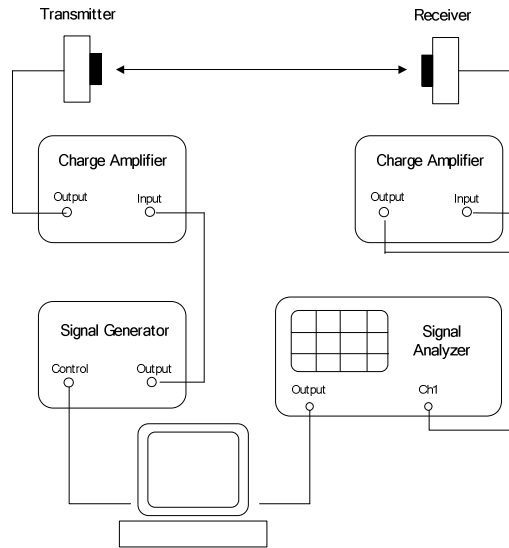


Figure 2. Schematic diagram of the experimental arrangement

In this experiment, the first important parameter is operating frequency of the ultrasound transducer. Figure 3 shows the test result of operating frequency. In this test, two transducer was set face to face, and the distance between them was 1 meter. It can be seen that optimum frequency is 40kHz, while 60kHz is also can be used.

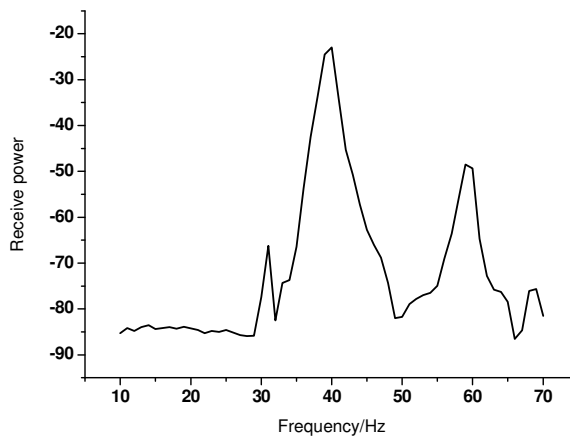


Figure 3. Experiment result of frequency response

As known to all, transfer rate may become higher when the 60kHz operating frequency is used for transmission. But high frequency will also cause high air absorption. Air absorption is one of the major factors which will significantly affect ultrasound attenuation. This absorption will be affected by many things, for example air temperature, air compression, relative humidity and so on. Weather condition will also affect it, just like wind and rain. In general the air absorption can be defined by the following equation, when air temperature is 20 degree centigrade:

$$A_e = 7.4 \frac{f^2 r}{\phi} \times 10^{-8} \quad (1)$$

Where f is frequency of ultrasound wave, and ϕ is relative humidity.

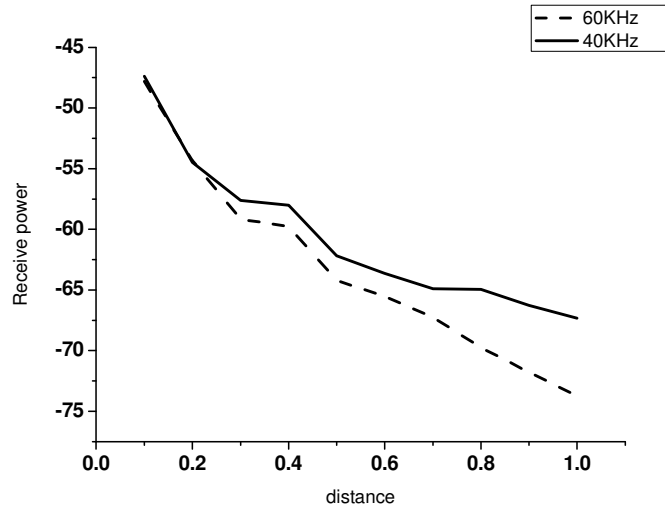


Figure 4. Transmission attenuation for different frequency

Figure 4 shows the different ultrasound attenuation between two frequency. Obviously, the attenuation is much higher when the operating frequency is 60kHz. Because the transmission distance is very important for one indoor communication system, so this paper choose 40kHz as the operating frequency.

Because the final goal of this paper is building an ultrasound wireless communication system, so the next part will study the modulation method using for ultrasound wave. Modulation is the addition of information to a signal. Mainly, modulation method can be divided into three types. They are Amplitude Modulation, Frequency Modulation and Phase modulation. But as showing in figure 3, the bandwidth of ultrasound transducer is very narrow, and the attenuation will change with frequency. So the Frequency Modulation method is not suit for ultrasound wireless communication in air.

2.2. Amplitude Modulation for Ultrasound Communication

Amplitude modulation(AM) was the earliest modulation method used to transmit voice by radio. It is a modulation technique used in electronic communication, most commonly for transmitting information via a radio carrier wave. AM works by varying the strength of the carrier in

proportion to the waveform being sent. Because it is very easy to vary the amplitude of ultrasound, Am is the first modulation method which is studied in this paper.

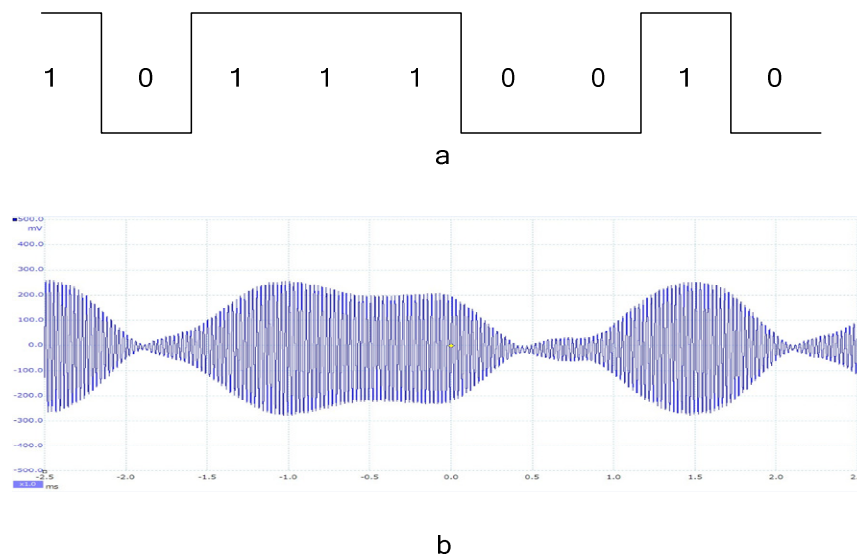


Figure 5. Transmission experiment using amplitude modulation

The experiment result is showing in figure 5. Figure 5(a) is the digital data used for modulation and figure 5(b) is the received ultrasound signal. The experiment system just as showing in figure 1 while the distance between two transmitter is 1 meters. On the receive side, a PC oscilloscope has been used to measure the received signal. As showing in this result, AM modulated signal can be sent and received by a pair of ultrasound transmitters. But there are also many disadvantage of AM modulation.

One of the disadvantage is amplitude of received signal is not steady. Both of transmission distance and environment will significantly affected the received amplitude. Other disadvantage of all amplitude modulation techniques is that the receiver amplifies and detects noise and electromagnetic interference in equal proportion to the signal. Another disadvantage of AM is that it is inefficient in power usage; at least two-thirds of the power is concentrated in the carrier signal. The carrier signal contains none of the original information being transmitted. So the amplitude modulation method is not very suit for ultrasound wireless communication. In the next experiment, this paper will test phase modulation method.

2.3. Phase Modulation for Ultrasound Communication

The same to the amplitude modulation, phase modulation also uses a finite number of distinct signals to represent data. When the data is binary digits, phase shift keying (PSK) can be used for digital modulation. Usually, each phase in the signal encodes an equal number of bits.

One of the most widely used phase modulation method is Binary Phase shift keying (BPSK). It is particularly well suited to the growing area of data communications. It use two phases which are separated by 180 degree and so can also be termed 2-PSK. This modulation method in the most robust of all phase shift keying method. BPSK has the highest level of noise and distortion. So the demodulator can reach an incorrect decision. However, the transmit speed is only able to 1 bit per symbol and not suitable for high speed applications.

The general form for BPSK can be described by the following equation:

$$s_n(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + (1-n)\pi), n = 0,1 \quad (2)$$

where E_b is the energy per bit, T_b is the bit duration, and f_c is the frequency of carry wave.

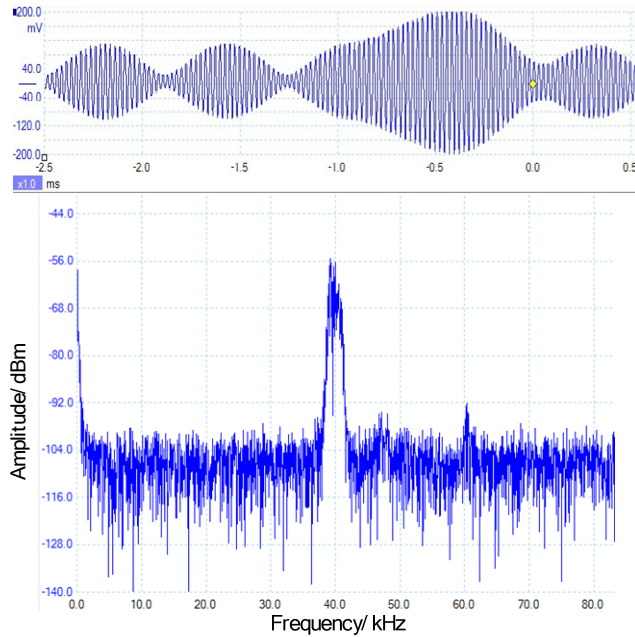


Figure 6. Transmission experiment using BPSK modulation

The first experiment is about BPSK method. The experiment system is the same to previous one. Figure 6 shows the received signal and spectrum. From this result , it can be seen that phase modulated 40kHz signal has been successfully received by the receive side. Because BPSK modulation signal is different from amplitude modulation, we choose to measure constellation diagram and error vector magnitude(EVM) of this signal.

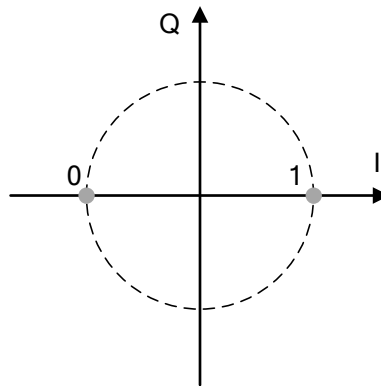


Figure 7. Example of constellation diagram for BPSK

Constellation diagram is a representation of a signal modulated by a digital modulation scheme such as quadrature amplitude modulation or phase shift keying. It displays the signal as a two-dimensional scatter diagram in the complex plane at symbol sampling instants. Measured constellation diagrams can be used to recognize the type of interference and distortion in a signal. The example of constellation diagram for BPSK is showing in figure 7.

While the error vector magnitude is a measure used to quantify the performance of a digital radio transmitter or receiver. Under the ideal conditions, one signal sent by a transmitter and received by a receiver would have all constellation points at the ideal locations. However, in actual cases the constellation points will deviate from the ideal locations. Then error vector magnitude is a measure of how far the points are from the ideal area. Many things can affect the error vector magnitude, just like noise, spurious signals, distortion, noise and phase noise. Therefore, error vector magnitude can provide a comprehensive measure of the quality of a communication system.

The error vector magnitude can be described by the following equation:

$$EVM (\%) = \sqrt{\frac{P_{error}}{P_{reference}}} * 100\% \quad (3)$$

Where P_{error} is the RMS power of error vector, and $P_{reference}$ is defined as the reference constellation average power. Generally, the error vector magnitude should be lower than 20%, otherwise the digital data can not be sent correctly.

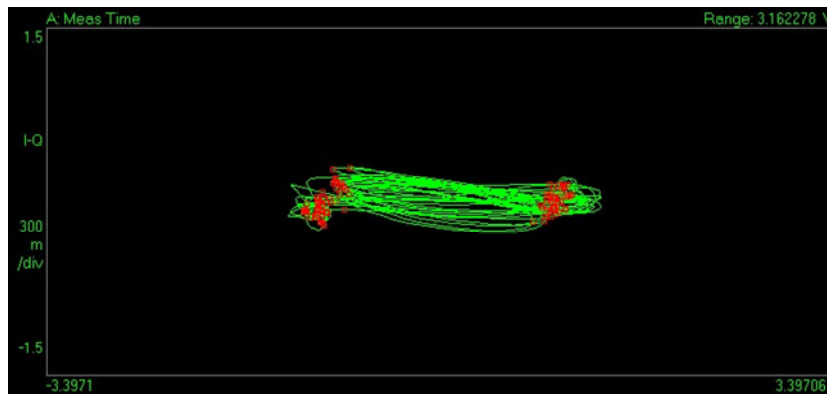


Figure 8. Constellation diagram for BPSK

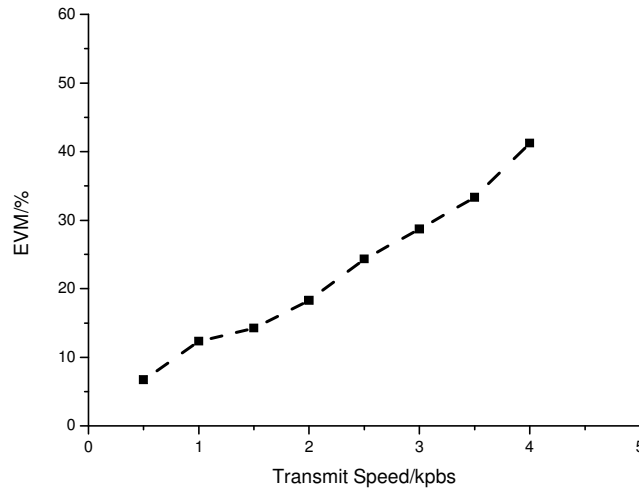


Figure 9. Transmit speed of BPSK

Figure 8 shows the experiment result of constellation diagram of BPSK signal. In this result, almost all constellation points are shown on the real axis, at 0 degree and 180 degree. It proves that phase modulation method can be used for ultrasound communications. In this experiment, the transmit speed is set as 1 kpbs. So in figure 9, error vector magnitude for different transmit speed has been measured. The error vector magnitude, as conventionally defined for signal carrier modulation, should lower than 20 percent. So the highest transmit speed is about 3 kpbs when we use BPSK method.

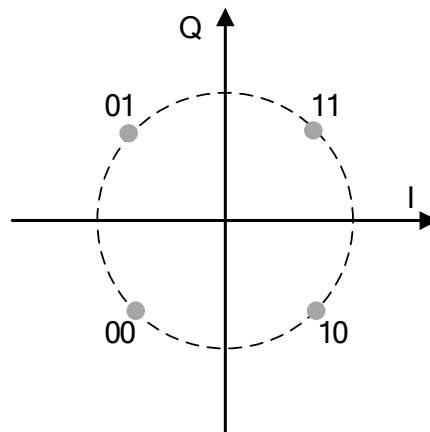


Figure 10. Example of constellation diagram for QPSK

In order to increase transmit speed, another phase modulation method has been tested. This modulation method is Quadrature Phase Shift Keying(QPSK). Sometimes this is also known as 4PSK. This method uses four points on the constellation diagram, equispaced around a circle. The example of constellation diagram for QPSK is showing in Figure 10. Because using four phases, this method is able to encode two bits per symbol. Generally, the main advantage of QPSK is that it can reach a data rate twice of BPSK and preserving similar levels of bit error rate.

Also, the general form for BPSK can be described by the following equation:

$$s_n(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c t + (2n-1)\frac{\pi}{4}\right), n = 1, 2, 3, 4 \quad (4)$$

Different from BPSK, in this equation E_s means energy per symbol and T_s means symbol duration. Other parameters in this equation is the same to the BPSK equation.

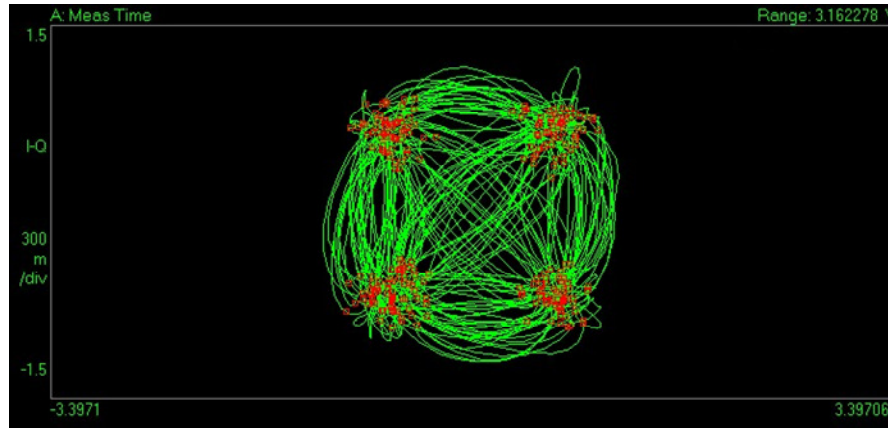


Figure 11. Constellation diagram for QPSK

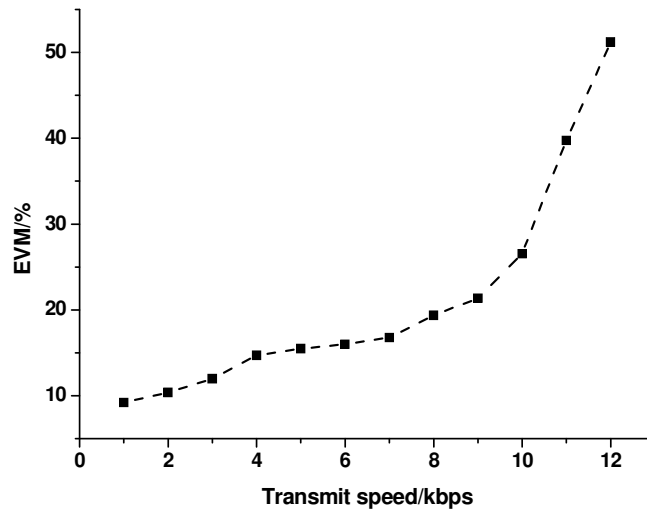


Figure 12. Transmit speed of QPSK

Figure 11 shows the constellation diagram of QPSK signal, and figure 12 shows the error vector magnitude for different transmit speed. This experiment proves that QPSK method can also been used for ultrasound wireless communication, the same to BPSK method. The highest transmit speed for QPSK can reach 8 kbps, twice higher than BPSK.

Actually, phase shift keying not only contains BPSK and QPSK. Any number of different phases may be used for a PSK constellation, just like 8-PSK or 16-PSK. Generally, these modulation

methods are known as higher order PSK. Higher order PSK can offer higher transmit speed, however the error rate may become too high. And the requirement of device will also increase. This paper has tested 8PSK method, in order to make sure whether higher order PSK can be used for ultrasound wireless communication.

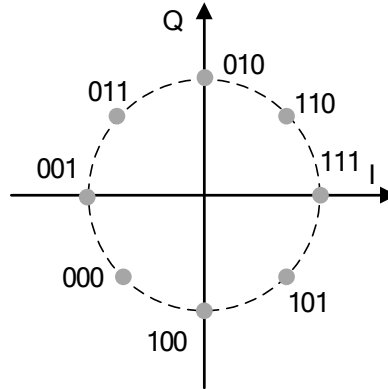


Figure 13. Example of constellation diagram for 8PSK

The constellation diagram for 8PSK is showing in figure 13. This method uses four phases, and is able to encode three bits per symbol. Also, the general form for BPSK can be described by the following equation:

$$s_n(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left(2\pi f_c t + \frac{(n-1)\pi}{4}\right), n = 1, 2, \dots, 8 \quad (5)$$

The parameters in this equation is the same to the QPSK equation.

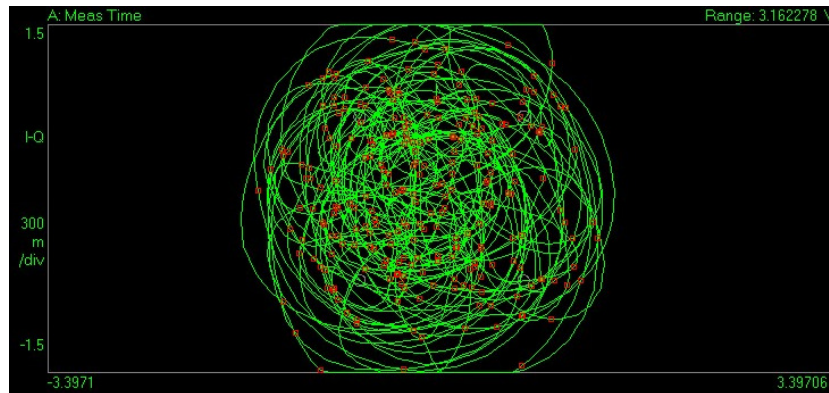


Figure 14. Constellation diagram for 8PSK

The experiment result is showing in figure 14. Obviously, there was no signal arrived at the receive side. In the further experiment we test many other cases, including different distance, different transmit speed and different power. However the 8PSK signal still can not transmit successfully. This experiment proved higher order PSK was not suited for this ultrasound communication system. The QPSK method should be the best choice.

3. CONCLUSIONS

The modulation method using for ultrasound communication system has been studied in this paper. Initial experiments identified the frequency response of this ultrasonic transmitter. This was used to decide the modulation method. Then three modulation methods have been tested. According to the experiment result, QPSK modulation method would be a good choice for ultrasound communication system in air. Both of EVM and transmit speed have been obtained in the experiment. These results have indicated that QPSK can be used to propagate ultrasonic signals in air. Other research about ultrasound communication, including simulation method and ultrasound phased array, has been published in Wireless Communications and Networking Conference 2014.

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