SHORT RANGE ULTRASONIC COMMUNICATIONS IN AIR USING QUADRATURE MODULATION

Chuan Li, David Hutchins and Roger Green
School of Engineering, University of Warwick, Coventry, U.K.

Keywords: Digital communications, Modulation, Ultrasonic signals.

Abstract: A study has been undertaken of ultrasonic communications methods in air, using a quadrature modulation method. Simulations were first performed in order to establish the likely performance of Quadrature Phase Shift Keying (QPSK) over the limited bandwidth available in an ultrasonic system. QPSK modulation was then implemented within an experimental communication system, using capacitive ultrasonic sources and receivers. The results show that such a system is feasible in principle for communications over distances of several metres, using frequencies in the 200-400 kHz range. Data rate is typically at 200 kbps.

1 INTRODUCTION

In recent years, short range wireless communications have been mostly dominated by RF systems, using a wide variety of technologies, including popular commercial protocols such as IEEE802, and Bluetooth amongst others. Here, a short range is usually defined as 10m to 50m indoors and 50m to 200m outdoors, although propagation over longer ranges is possible. Other techniques for short range use include infrared communications (Kueda, 1979), using protocols such as those of the IrDA (Bloch et al. 2008). The data rate in such communication systems can typically be from kbps to Gbps. These methods are successful and in widespread use. However, there are other types of signal by which information can be communicated over short distances, which may have an advantage in certain situations. One such consideration is security (Nakrop et al 2008). For instance, RF signals are easy to intercept, and various forms of encoding are needed to maintain secure data transfer (Tsusomu et al 1990). Infrared technology is, in principle, more secure for short-range use, but it is also generally more directional, and does not pass through most barriers such as walls and partitions.

An alternative approach is to consider the use of ultrasound in air for communications. This offers several advantages over existing methods, especially for security – it is effectively blocked by most barriers, and has a limited propagation range, making interception from outside a room very difficult. It also has other qualities. For instance, the slow propagation speed in air allows the location of sources to be tracked. In addition, problems due to multi-path effects (interference from direct and reflected signals) can potentially be reduced, because of the difference in propagation time for multiple paths. Despite these attractive qualities, development of ultrasonic short-range communication systems has been somewhat restricted, due to the narrow bandwidth of available acoustic transducers and the high attenuation of ultrasound signals in air at frequencies above 2 MHz. However, with recent developments in transducer technology for use in air, including wide bandwidth capacitive designs used in this work (Li et al, 2008), the effective operating bandwidth now stretches to 1 MHz and beyond. As a result, reasonable data rates of up to several hundred kbps can be expected, provided suitable modulation data recovery methods are developed.

In this paper, we describe the use of Quadrature Phase Shift Keying (QPSK) in an ultrasonic communications system for use in air. The properties and characteristics of this approach have been measured and simulated, as will now be described.

2 RAISED COSINE FILTER

One of the best filter forms to minimise the effect of Inter Symbol Interference (ISI) as well as reducing the frequency range of the transmitted signal is to

Li C., Hutchins D. and Green R. (2009).
SHORT RANGE ULTRASONIC COMMUNICATIONS IN AIR USING QUADRATURE MODULATION.
In *Proceedings of the International Conference on Wireless Information Networks and Systems*, pages 100-104
DOI: 10.5220/0002224601000104

apply Raised Cosine (RC) filtering to baseband binary stream. The effective bandwidth of such filter is determined by the roll of factor α, and can be related to the symbol rate R_s by the following expression

$$R_s = R_b \cdot \log_2 L = \frac{B}{1+\alpha} \qquad (1)$$

where R_b is the bit rate of the baseband signal in bps, L is the modulation level (L=4 for QPSK), and B is the absolute filter bandwidth in Hz.

3 EXPERIMENT

The experiments used a capacitive transducer to transmit and receive ultrasonic signals in air. These devices, which have been described in a previous publication (Li et al, 2008), were constructed with a micromachined silicon backplate and a 3-5 μm thick Mylar membrane. For such a transducer, the bandwidth of the signal is dependent on the applied dc bias voltage, film thickness, and the nature of the transient voltage used for excitation. Ultrasound is generated by applying a transient voltage *V(t)*, generating a field between the front surface of the membrane and the conducting backplate. The efficiency and bandwidth are both increased by superimposing a dc bias field upon the transient voltage. As a receiver, the detected sound wave at the membrane varies the capacitance, and in the presence of the dc bias, a dynamic charge is generated on the electrodes.

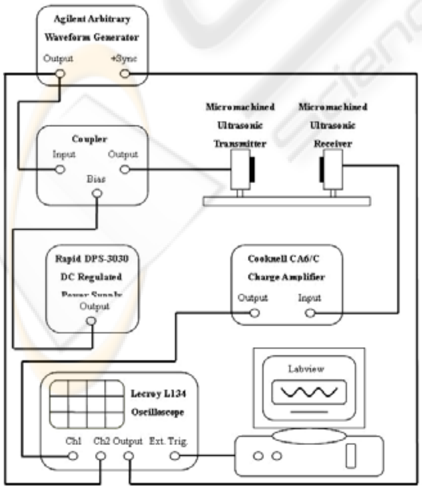


Figure 1: Schematic diagram of the apparatus used to transmit ultrasonic communications signals in air.

Figure 1 shows a typical experimental arrangement, where the transmitter and receiver are placed at a distance of 1.2 metres apart. The transmitter has a membrane thickness of 5 um, so as to withstand higher excitation voltages without causing damage to the polymer membrane. The source was driven by an Agilent 33120A Arbitrary Waveform Generator, with a superimposed +100 V dc bias voltage generated by a dc power supply. This supplied the required digital signal for transmission. A linear power amplifier with a gain of 25 dB was used to boost the output of the waveform generator before application to the transmitting transducer. The receiver had a film thickness of 2.5 um and was followed by a Cooknell CA6/C charge amplifier with a gain of 250 mV/pC. The response was then fed into a LeCroy LT342 digital oscilloscope for signal analysis. Finally, the waveforms were saved on a PC running LabVIEW programs for offline signal processing. A physical synchronisation link was established between the waveform generator and the oscilloscope. This removed the need for wireless handshaking, which would be needed in a real application.

Note that the signal amplitude from the linear power amplifier applied to the transmitting transducer was typically set at 200V peak-to-peak, and the received signal amplitude was typically around 5 mV RMS at 1.2 metres range. The experiment was performed in an indoor laboratory, where room temperature was about 25 °C, and where the relative humidity was around 79%. The recorded background noise level was around 600 µV RMS, with negligible air turbulence to influence the signal transmission.

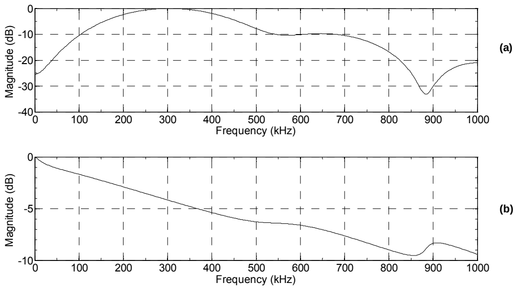


Figure 2: (a) magnitude and (b) phase response of the ultrasonic system as measured experimentally.

The measured overall response of the communication channel (in terms of amplitude and phase) was required, for the simulations of the quadrature approach which appear in the next

Section of this paper. As shown in Figure 2(a), the magnitude response peaks at 300 kHz, but has a dip at 880 kHz. The 6 dB bandwidth of the measured channel is about 350 kHz, and the usable frequency range is about 900 kHz. Figure 2(b) shows that the phase response of the channel is roughly linear across the 6 dB bandwidth.

4 RESULTS AND DISCUSSION

As can be seen in Figure 3, a pulse-shaped QPSK signal outperforms an unfiltered QPSK signal at the receiver in terms of BER at the same level of E_b/N_o, as the improvement in bandwidth efficiency achieved by shaping reduces the noise bandwidth relative to the unshaped signal bandwidth. The above data was obtained by simulating the channel response with Additive White Gaussian Noise (AWGN).The E_b/N_o level was incremented in 0.5 dB steps from 8- 22 dB. Even with a roll-off factor as small as 0.2, at a bit rate of 200 kbps, the overall bandwidth of the modulated carrier was reduced from 200 kHz to 120 kHz (referenece to Eqn.1), at the same time producing a lower BER. Note that, as the level of E_b/N_o increased, the benefits of using shaped pulses instead of unshaped pulses were enhanced further.

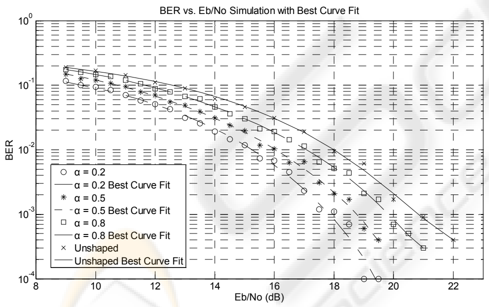


Figure 3: Simulation of performance with and without pulse shaping.

The above simulations indicated that ultrasonic communications based on QPSK signals would be feasible across a distance in excess of 1 m in air. Experiments were thus performed to confirm that this was the case, and to indicate how the performance was modified by changes in factors such as the roll-off factor (α) of the RC filter used with QPSK modulation.

Figure 4 shows the results of an experiment in air, using two capacitive transducers in the arrangement shown earlier in Figure 1. The distance between the transducers was 1.2 m, and the bandwidth used was 120 – 200 kHz, depending on the roll off factors α (reference to Eqn.1). Bit rate was chosen to be 200 kbps, and the frequency of carrier is 300 kHz. The figure shows the received ultrasonic waveform for four values of α on the left, with the equivalent frequency spectrum on the right in each case. It can be seen that the amplitude of the received QPSK waveform increased with an increase of the pulse shaping roll-off factor. The received unshaped QPSK signal tended to give the strongest signal of the four cases; however, it occupied the widest bandwidth, and this is a disadvantage when bandwidths are limited in an ultrasonic communication system.

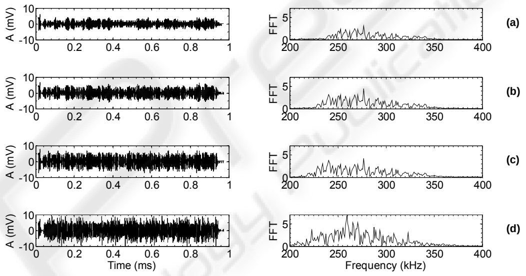


Figure 4: Results of a QPSK ultrasonic transmission across air for values of α of (a) 0.2, (b) 0.5, (c) 0.8 and (d) an unshaped experiment (α = 1), at distance of 1.2 m. Time waveforms are on the left, frequency spectra on the right.

It is also clear that in all four spectra, transmitted signals have been 'filtered' by the channel magnitude response, which includes the response of the frequency selective attenuation in air whilst propagating over a relatively long range, such that the higher frequencies are attenuated more than the lower frequencies.

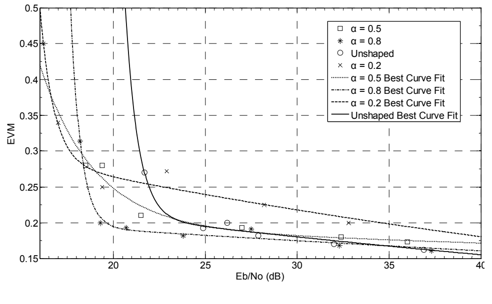
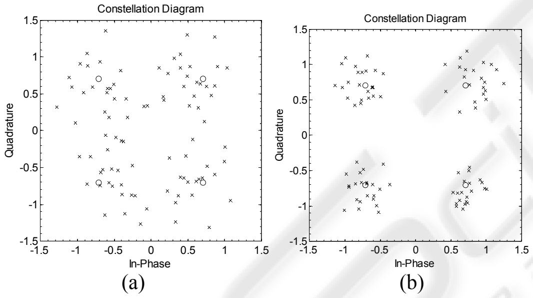


Figure 5: Experimental EVM and Eb/No that results from the transmitted QPSK signal at 1.2 metres, for various values of α.

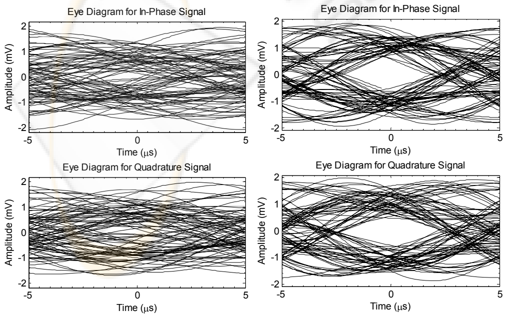
Using the transmitted QPSK as a reference, the experimental performance in terms of EVM can be evaluated. Discrete experimental results are presented, together with a best fitting curve to the data in Figure 5, for various values of α. Note It has been found in this experiment that an EVM value higher than 0.2 will lead to a severe BER in decoding, which could cause the transmitted information to become unusable. thus, whilst the unshaped response may appear attractive in terms of amplitude, there are other factors to be considered in a real communication system.

Figure 5 shows that at high *Eb/No* (over 35dB), unshaped QPSK appears to achieve a lower value of EVM, and hence a better performance. However, at low *Eb/No* values (less than 22 dB), a shaped QPSK becomes of more value. With α = 0.8, a reliable communication link could be established when *Eb/No* is greater than 20dB. On the other hand, if bandwidth efficiency is the top priority, by setting α = 0.2, the channel will not be sufficiently robust unless the *Eb/No* ratio reaches a value of 35 dB. However, with α = 0.5, a reasonable compromise between bandwidth occupation and performance can be expected, within the range 19dB - 33 dB.



(a) (b)

Figure 6: Constellation diagram for received QPSK with (a) α = 0.2 and (b) α = 0.8. The crosses represent the amplitude of each channel after decoding.



(a) (b)

Figure 7: Eye diagram for (a) 0.2 and (b) 0.8 roll off.

Figure 6-7 show the constellation and eye diagrams for QPSK with α = 0.2 and α = 0.8. It can be seen that the linear phase response of the system has kept the QPSK constellation in place regardless of the unbalance of magnitude response. This again emphasises the advantages of using phase modulation. The more open the eye, the better the separation in the scatter plot, which also means that the SNR is better. Hence, signal transmission is likely to be more robust (less susceptible to noise). The horizontal width of the eye diagram (Figure 7) represents the time over which the signal can be successfully treated to decode the signal – i.e. the wider the eye the better. From Figures 6 to 7, it is evident that a wider eye has resulted from an increase in the value of α.

5 CONCLUSIONS

Initial simulations indicated that QPSK modulation would be a good choice for ultrasonic communications in air. Experiments identified the frequency response of the airborne ultrasonic system in terms of amplitude and phase. This was then used to design the approximate characteristics that would be needed in a QPSK system for ultrasonic use with the transducers used. Reasonable performance in terms of BER and E_b/N_o was obtained in both simulations and subsequent experiments. The results have indicated that a QPSK approach can be used to propagate ultrasonic signals in air over reasonable distances in the 1-2 m range indoors.

The choice of filter seems to have a relatively large effect on performance. This is characterised by the value of *α*. In most conventional RF communication systems, *α* tends to be set at a value of around 0.2, and indeed a value of *α* = 0.2 is recommended for ultrasonic use. The above work was performed over relatively short distances in a laboratory environment. In practice, other factors are likely to influence performance (e.g. turbulence, frequency-dependent attenuation in air, multi-path problems etc). All these factors are currently under investigation.

REFERENCE

Keda Y., K., Yoshihiro, O. and Hiroshi, U. (1997) “International standard of infrared data communication, IrDA", *Shapu Giho/Sharp Technical Journal,* n 68, pp. 11-17

Bloch M., Barros J., Rodrigues Miguel R.D., and McLaughlin SW. (2008), "Wireless Information-theoretic Security", *IEEE Transactions on Information Theory,* v 54, n 6, pp. 2515-2534.

Nakrop, J., Sodsai, W., Prasit N. and Atipong, S. (2008), "Security System against Asset Theft by Using Radio Frequency Identification Technology", *5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, 2008, pp. 761-764

Tsutomu, T., Masahiro, S. and Susumu, Y. (1990), "Multipath delay estimation for indoor wireless communication", *Proc. IEEE Vehicular Technology Conference*, pp. 401-406.

Li C., Hutchins D.A. and Green R.J. (2008), "Short-range ultrasonic digital communications in air", *IEEE Trans. Ultras. Ferr. Freq. Contr.* v. 55, pp. 908-918.