Multi-Channel Data Transfer Using Air-Coupled Capacitive Ultrasonic Transducers

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Abstract - **In some situations, wireless data transfer using radio waves or microwaves is not permitted as it may interfere with other sensitive electronic equipment. Optical beam modulation methods may also be unsuitable due to the presence of atmospheric contamination. The feasibility of using air-coupled ultrasound to transmit binary data at practical rates has been investigated. A prototype system was constructed using a single pair of broadband capacitive ultrasonic transducers (CUTs) with a central frequency of 250kHz and a 300kHz bandwidth. Two transmission schemes for sending ASCII data across short distances were investigated. Amplitude Shift Key (ASK) modulation was successfully implemented using 8 separate data channels at frequencies from 215kHz to 320kHz with a channel spacing of 15kHz, allowing 8-bit data packets to be sent in parallel. Orthogonal Frequency Division Multiplexing (OFDM) was also implemented successfully, using 32 parallel 1kHz channels and a 250kHz carrier frequency to send 32-bit data packets. Data transfer rates of up to 80kbit/sec were achieved over distances of up to 0.5m with direct line-of-sight between the transmitter and receiver. Higher transfer rates should also be possible, and over greater distances.**

I. Introduction

Wireless information is typically transmitted at high data rates using radio waves, but in certain locations this may not be permitted as the transmissions may interfere with sensitive electronic equipment, or there may be security issues as the signals may travel too far through walls or other barriers. Modulated infra-red (IR) light is also used for short-range communication between electronic devices such as personal computers and mobile phones, or in remote controls for domestic electronics. However, in certain situations, smoke or other atmospheric contamination may prevent effective transmission, and interference from high-frequency fluorescent lighting has also caused problems [1]. Ultrasonic waves are often used for underwater acoustic (UWA) communication and recent applications have included a high data rate underwater link for video transmission [2], but applications in air and other gases have been very limited. One of the original applications was an ultrasonic remote control for televisions, but this was superseded in the 1980's by the use of IR devices. More recent applications have included ultrasonic communication inside gas pipelines for flow telemetry [3] or using audio frequencies for data transfer [4], but the application of such systems are restricted by low transmission rates. This is due in part to the lack of suitable ultrasonic transducers that operate efficiently in air and other gases with sufficient bandwidth. In this work, air-coupled capacitive ultrasonic transducers (CUTs) [5-7] that operate at 250kHz with a 300kHz bandwidth were used to transmit binary information at realistic data rates of up to 80kb/s in air over short distances.

II. Carrier Wave Modulation Techniques

In order to transmit data using ultrasound, an ultrasonic carrier wave is typically modulated in response to the desired data signal [8]. The basic modulation scheme used in the current work is Amplitude Shift Keying (ASK), in which the amplitude of the carrier wave is switched between a high amplitude and a low amplitude for a time T_B (the symbol period) to represent the two different logic levels in binary data. Provided that there is sufficient bandwidth, multiple carrier waves using different frequencies for different data channels may be combined together into a single ultrasonic signal. Other modulation schemes include Frequency Shift Keying (FSK), in which the frequency of the carrier wave is shifted slightly for a period T_B, and Phase Shift Keying (PSK) in which the phase of the carrier wave is shifted.

Another method known as Orthogonal Frequency Division Multiplexing (OFDM) [8, 9] is based on the approach of sending data at a slow rate through many parallel channels rather than at a very high rate through a single channel. OFDM is a well-known technique for overcoming inter-symbol interference (ISI) which occurs when a transmitted symbol arrives at the receiver and interferes with another symbol that has been delayed from the same data stream. In OFDM, the transmission bandwidth is divided into a large number of overlapping, narrow-band sub-channels or sub-carriers and the data are transmitted in parallel. The channel frequencies are chosen to form an orthogonal set which occurs when the frequency spacing is $1/T_B$. In practice, a stream of serial data may be split into N parallel blocks, where N is the number of channels. The data are then modulated using a scheme such as ASK before the channels are multiplexed together and the signal transmitted.

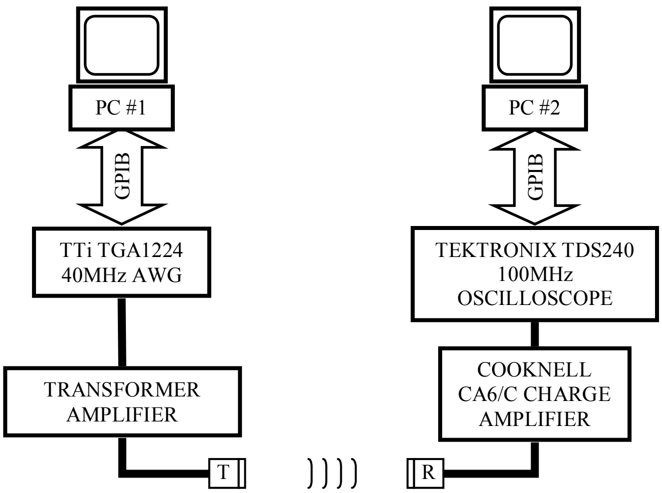

Figure 1: Schematic diagram of experimental apparatus.

III. Experimental method

The system constructed to test the different transmission methods is shown schematically in Fig. 1. The data to be transmitted were encoded into the appropriate waveform using MATLAB® on a PC, and then sent to a TTi TGS1224 Arbitrary Waveform Generator (AWG) using a GPIB interface. The output of the AWG was then amplified via a simple transformer amplifier before being sent to the capacitive ultrasonic transmitter. The bandwidth of the capacitive ultrasonic transducers constructed from 5μm PET membranes and roughened metal backplates was approximately 300kHz with a centre frequency of 250kHz. After propagating through a 0.5m air gap, the resultant waveform was detected by a capacitive ultrasonic receiver, amplified using a Cooknell CA6/C charge sensitive amplifier and digitized on a Tektronix TDS240 100MHz digital oscilloscope before being sent to a second PC via a GPIB interface for decoding and storage.

IV. Results

A. Amplitude Shift Key (ASK) modulation

The 8 channels used for ASK were at 15kHz intervals from 215kHz to 320kHz inclusive. The AWG amplitude for a binary ‘1’ was set to 20V and for a ‘0’ was set to 4V. As an illustrative example, the word ‘wireless’ was encoded and transmitted using ASK. The binary representation of each ASCII character is shown in Table 1. Each character was then encoded on a separate frequency channel. ‘w’ was modulated at 215kHz on channel one as shown in Fig. 2.

Table 1: ASCII character data representation for ASK.

ASCII	Decimal	Binary	Channel (kHz)
w	119	01110111	215
i	105	01101001	230
r	114	01110010	245
e	101	01100101	260
l	108	01101100	275
e	101	01100101	290
s	115	01110011	305
s	115	01110011	320

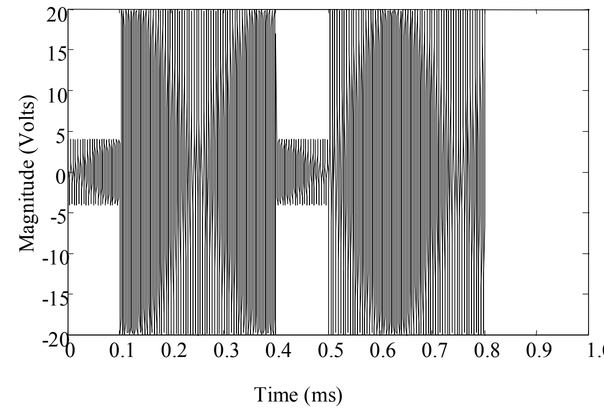

Figure 2: ASK modulation of ASCII 'w' (binary 01110111) at 215kHz.

The 8 carrier signals representing the message ‘wireless’ were combined together into a single waveform, shown in Fig. 3. This signal was then scaled to the maximum ±20V amplitude of the AWG before being transmitted. The signal received across the air gap may be seen in Fig. 4, showing excellent correlation with the original signal in Fig. 3. This signal was then bandpass filtered to extract each separate channel at the appropriate frequency, and the data from the first four channels corresponding to ‘wire’ are shown in Fig. 5. The different amplitudes corresponding to a ‘0’ or a ‘1’ in each bit interval are clearly identifiable. As T_B was 0.1ms, the theoretical data rate for the ASK scheme was over 80kb/s.

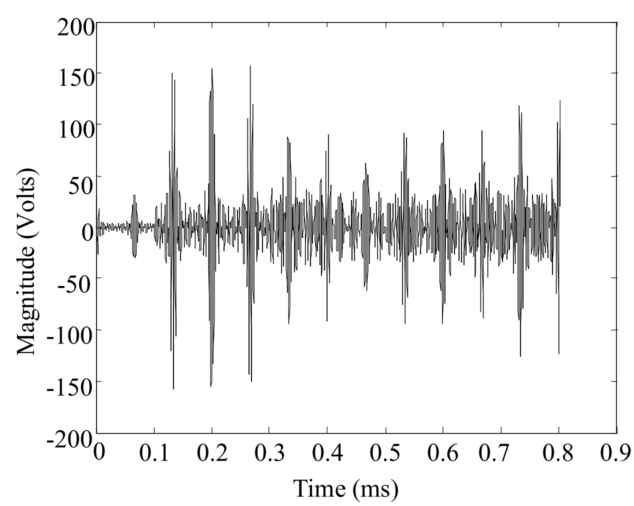

Figure 3: Transmitted 8-channel ASK modulation of the text 'wireless'.

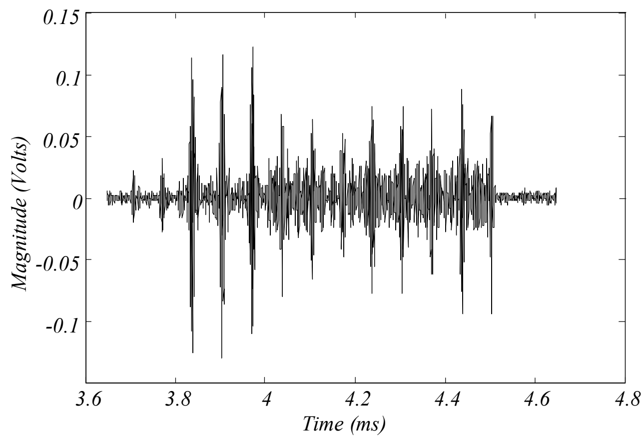

Figure 4: Received ultrasonic signal of the text 'wireless'.

B. Implementation of Orthogonal Frequency Division Multiplexing (OFDM)

32 bit data packets were transmitted using OFDM using a signal power reference channel and 32 1kHz data channels. Each data channel was modulated using ASK at its specified frequency at the correct amplitude to denote a '1' or a '0', and the 33 signals combined into a single signal. This was then AM modulated at 250kHz for optimum transmission by the capacitive ultrasonic transducers. As an illustrative example, the text 'HiWorld!' was encoded and transmitted. This consisted of 64 bits, sent as 2 data packets of 32 bits each. Each data packet was of 1ms duration, giving a theoretical data rate of at least 32kb/s. The ASCII character representation is shown in Table 2.

Table 2: ASCII character data representation for OFDM.

ASCII	*Decimal*	*Binary*	*Channel (kHz)*
Packet 1			
H	72	01001000	2 through 9
i	105	01101001	10 through 17
W	87	01010111	18 through 25
o	111	01101111	26 through 33
Packet 2			
r	114	01110010	2 through 9
l	108	01101100	10 through 17
d	100	01100100	18 through 25
!	33	00100001	26 through 33

A reference data packet containing a '1' in all 33 channels was first transmitted and received to ascertain the power level in each channel that corresponded to a '1', as the sensitivity of the system was not uniform across the full bandwidth. The received data packets were then compared to this reference packet using MATLAB® to ascertain whether there was a '1' or a '0' in each channel. To extract the transmitted data, the received waveform was first AM demodulated at 250kHz, and then a fast Fourier transform (FFT) used to obtain the power

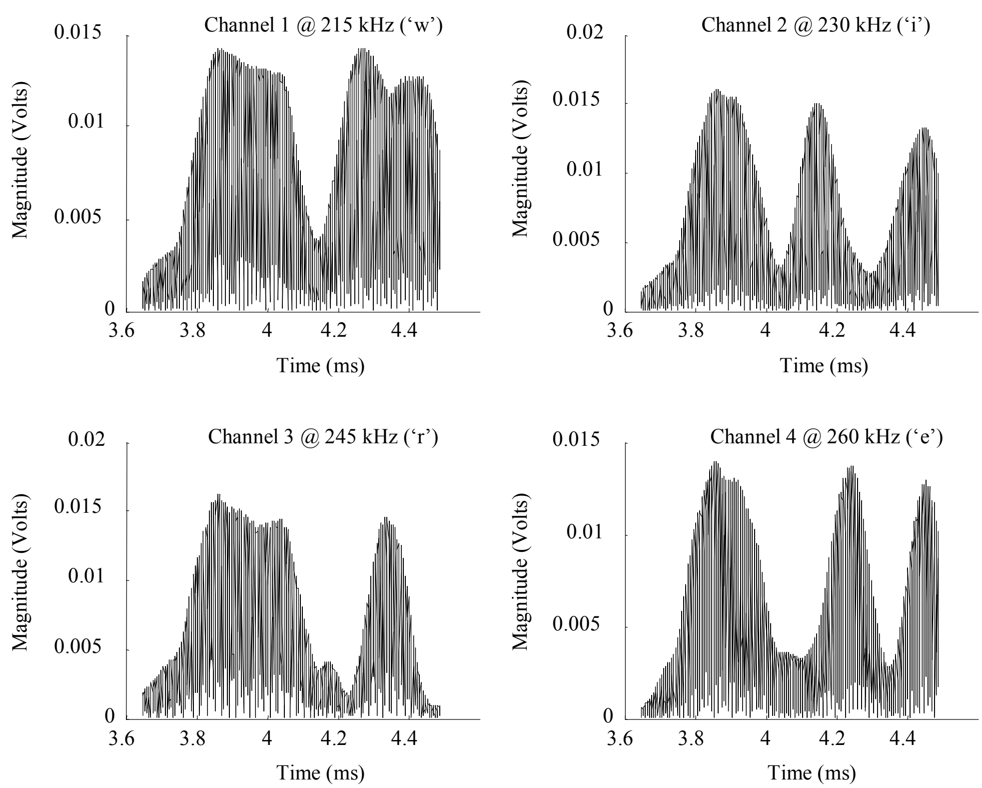

Figure 5: Demodulation of the first four ASK channels.

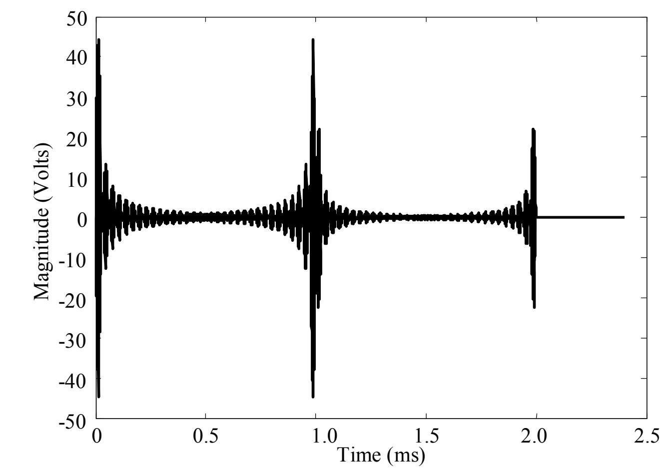

Figure 6: Transmitted 32-channel OFDM signal.

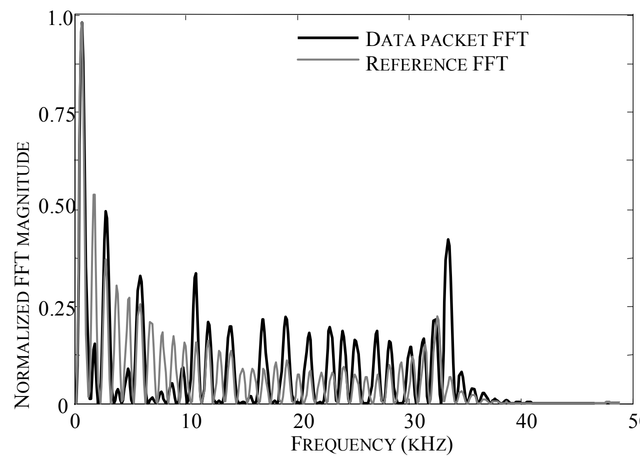

Figure 8: First 32-bit data packet representing the text 'HiWo' and reference spectra.

spectrum.

A typical signal containing two OFDM 32-bit data packets AM modulated at 250kHz is shown in Fig. 6 before being scaled to the maximum ±20V amplitude of the AWG and transmitted. The corresponding waveform received across the airgap is shown in Fig. 7. Despite the corruption of the original signal with noise and spurious signals at 1ms and 2ms, the OFDM technique was still able to extract both 32-bit data packets successfully. The length of the data packet that could be transmitted was restricted by the record length of the digital oscilloscope, which was only 2500 points.

As an illustrative example of data extraction from the OFDM scheme, the FFT spectra for the first four characters of the test message 'HiWorld!' are shown in Fig.8, where the first 32 bit data packet and the reference packet spectra are compared after reception and demodulation. The first channel at 1kHz is the power reference channel; the two spectra are both normalized with respect to this. The next 8 channels from 2kH to 9kHz are the first 8 bits of the data packet and a simple comparison of the received power levels in each channel with the reference spectra produces '01001000', which is the first character 'H' of the transmitted text.

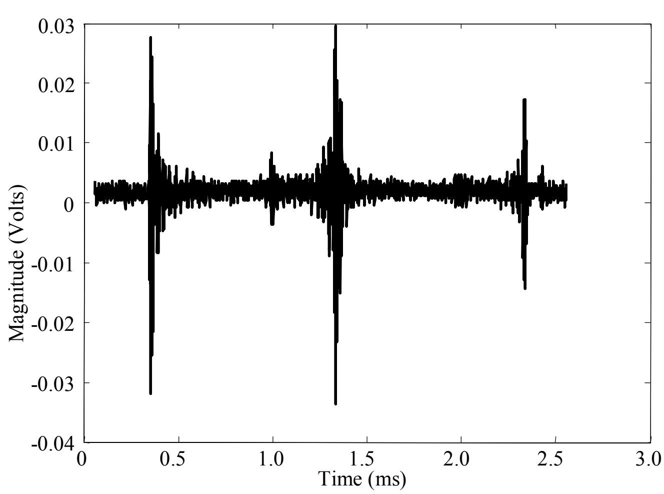

Figure 7: Received 32-channel OFDM signal.

V. CONCLUSIONS

It has been demonstrated that binary data can be transmitted at rates of at least 80kb/s using air-coupled capacitive ultrasonic transducers over short distances. Amplitude Shift Key (ASK) and Orthogonal Frequency Division Multiplexing (OFDM) schemes were successfully implemented using a pair of air-coupled capacitive ultrasonic transducers (CUTs) over distances of 0.5m. This range could be extended by selecting an appropriate frequency range.

VI. REFERENCES

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