UNDERWATER COMMUNICATION SYSTEM FOR SHALLOW WATER USING MODIFIED MFSK MODULATION

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The paper describes the design and operation of the Modified MFSK system for underwater communication. Its function is to transmit data and commands from ships to underwater objects in shallow coastal waters and lakes. The system was primarily required to ensure energy efficiency in its underwater section and the minimum of transmission errors. The emphasis was on non-linear distortions produced in piezoelectric transducers, an untypical source of errors.

INTRODUCTION

Underwater communication systems are usually designed for long ranges and maximal data transmission data rate at the minimum of errors. Because of strong interference from the direct wave and waves reflected from the medium’s boundary surface, shallow waters and strong refraction are not conducive to such requirements. Another cause of interference can be multi-path transmission caused by refraction. The result are temporary amplitude changes of the signal received and even a possible loss of signal. When the paths of the direct wave and reflected waves are significantly different, the delay between reflected signals and direct signals can be quite substantial. Both effects lead to transmission errors and efforts to reduce these also reduce transmission data rate. In addition, refraction frequently results in limited system ranges, even more than acoustic noise or absorption attenuation.

To reduce the negative effect of reflection and refraction in digital underwater communication systems, FSK and MFSK single-band digital modulations are applied for their resistance to interference in selective frequency channels [1] [2]. Equalisers, especially in stationary systems work very well, too, and can partially eliminate the delayed reflected signals [3].

This digital underwater communication system was developed and tested for its ability to transmit short commands and data from onboard a ship to independent underwater objects and to transmit data back. Energy efficiency and minimisation of transmission errors were the priority requirements with transmission data rate given a secondary importance. The design assumes infrequent commands and data and a short transmission time incrementally in proportion to total running time without recharging the batteries. In addition, part of the system in the underwater object must be ready at all times to receive signals from the ship and to send data back. There may also be other underwater objects operational within the system's range.

1. SYSTEM DESIGN

To meet the energy efficiency requirement, the system has no choice but to adopt specific functions and design solutions. Because of the disproportions between system running time and total transmission time, energy usage in between transmissions had to be minimal at the same ensuring sufficient energy during the actual transmission. The underwater part of the system meets these requirements. Figure 1 shows its functional diagram.

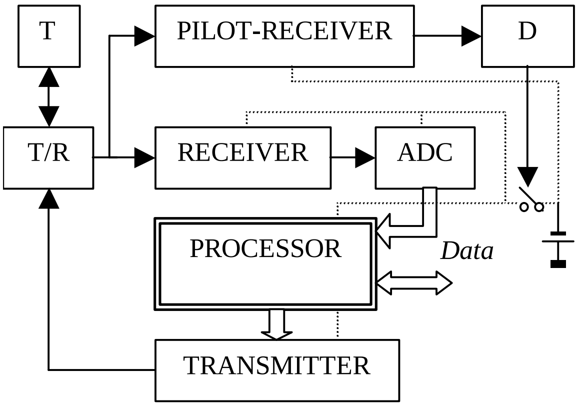

Fig.1 Block diagram of the system's underwater section (T – transducer, D- detector, T/R – transmitter-receiver switch, ADC – analogue to digital converter)

The system can receive and transmit signals as depicted in Figure 2. The pilot signal is a fixed frequency sinusoidal signal with a long duration. After a fixed interval, the address code is generated consisting of a sequence of 7 bits, of which the first 4 are information bits and the next 3 are correction bits. The entire sequence is Hamming code where one error is corrected at any code position. The fixed interval is followed by command or data codes with a structure identical to that of the address code. Modified MFSK signals are used to transmit the codes; the logical value of 1 is matched by a sinusoidal signal whose frequency depends on the position of symbol 1 in the code. The signals are orthogonal.

Fig.2 Sequence of signals

Permanently connected to the source of power is the pilot signal's receiver. It has a narrow-band AGC amplifier tuned to the pilot signal's frequency and an energy detector with a threshold (D). When the energy detector's signal exceeds the threshold, power is supplied to the receiver, analogue-digital converter and the processor, and sampling begins a little later. The pilot is followed by the address signal. The signal from receiver output is sampled and the processor calculates its Fourier transform. The position of spectral lines when they exceed the pre-defined threshold matches the code of the signal received. Figures 3 gives an example for code [0 0 1 1 1 0].

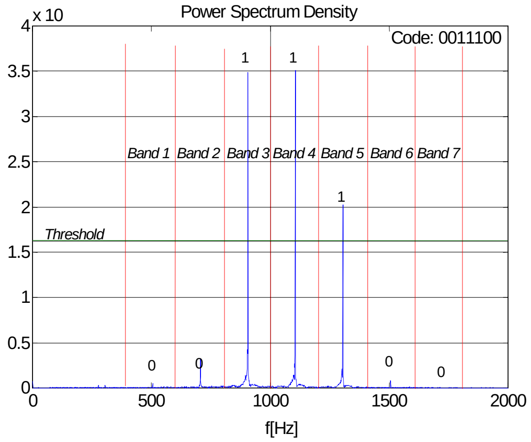

Fig.3 Spectrum of the signal matching code [0 0 1 1 1 0 0]

The processor corrects errors, if any, and compares the decoded address with its underwater object's address. Where different, the systems switch off automatically and the device goes into stand-by, listening in for pilot signals. When the addresses match, data or commands are received. When the underwater object completes the commands, the transmitter goes into operation and sends to an onboard part of the system a copy of the signal received. If the signal received onboard matches that sent to the underwater object, the transmission is found errorless and the commands are followed through. Otherwise, the transmissions are repeated until successful.

2. TRANSMISSION ERRORS AND WAYS TO REDUCE THEM

The main source of errors in this and similar underwater communication systems is multi-path transmission. Acoustic signals using longer paths to reach the transducer get there later than a signal taking the shortest path, i.e. the direct path, if there is no refraction. The type of error in this case will depend on how big the delay is. Figure 4 illustrates this.

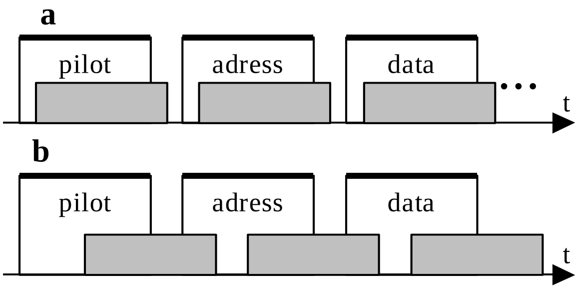

Fig.4 Received direct and delayed signals

For small delays (Fig. 4a) errors are caused by interference, because they change the amplitude of spectral lines. In a bad scenario a spectral line can be lower than the detection threshold, set above the level of noise spectral lines based on an assumed probability of a false alarm. The higher the noise-to-signal ratio at detector input, i.e. the lower the detection threshold, the less probable an error is. Because Fourier transform is the digital realisation of filtration matching sinusoidal signals, SNR=E/N, where E is the energy of the signal received, and N – power spectrum density. In the system in question for signals lasting 0.5s the result in a lake was SNR≈-80÷-60dB. Signal losses can be reduced using *chirp* signals. Because of the space constraints, no test results can be discussed here.

Long delays of signals reflected from medium boundaries (Fig.4b) can cause the data signal spectrum to show lines from the address signal. Signal loss can occur as well, because the frequencies in the address signal and data signal are the same. To eliminate this from happening, long intervals were introduced between consecutive signals.

3. ERRORS PRODUCED BY SYSTEM NON-LINEARITY

During the tests the spectrum of received signals would show signals of lines with frequencies that were not present in the signal as it was transmitted. The lines are a source of frequent errors, difficult to explain with a too low detection threshold of acoustic noise. The number of errors is at times greater than one, making it impossible for Hamming code to correct them. Figure 5 shows an example.

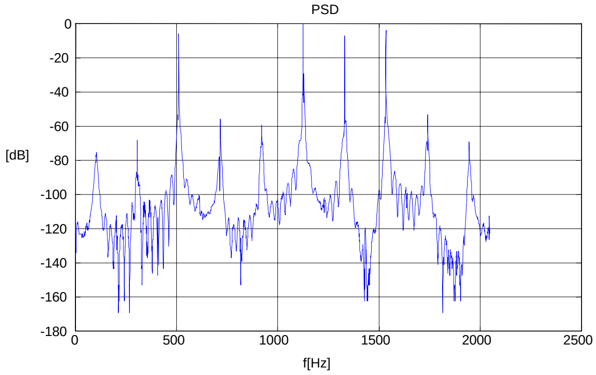

Fig.5 Signal spectrum with the extra lines

It was found that the number and position of the lines depend on the code being sent, suggesting that they come from non-linear transmission patterns of the transmitter or receiver. Further measurements showed that non-linear characteristics of the electronic systems of the transmitter, receiver and matching coil are negligible compared to the non-linearity of the cylindrical piezoceramic transducers. The electric signal spectral lines produced by the transmitter with the electric substitute system of the transducer did not disturb the system operation. Spectral analysis of signals received by the hydrophone showed that there was a relation between the relative amplitude of extra lines and the voltage of signals going into the transducer, as shown in Fig. 7. The relative height of the lines changes from –55 dB at 160V, to – 37 dB at 680V.

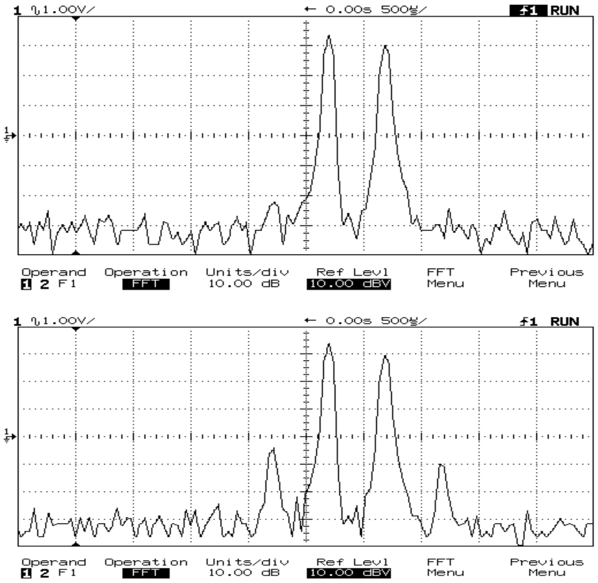

Fig.6 Signal spectrums for voltage of signals 160 [V] and 680 [V]

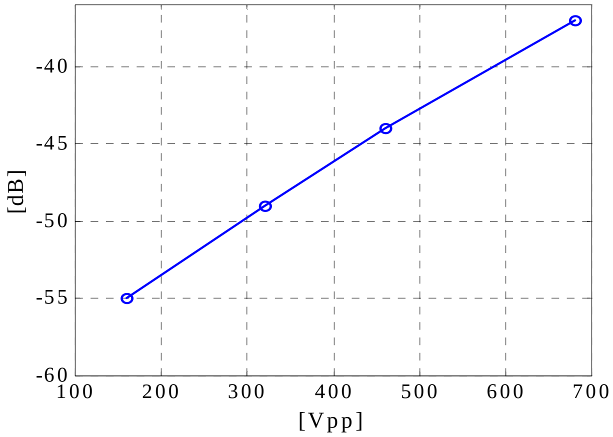

Fig.7 The relation between the relative amplitude of spectral lines caused by transducer non-linearity and the voltage of signals

ACKNOWLEDGEMENTS

Non-linear distortions are one of the sources of errors in Modified MFSK underwater communication systems and should be taken into account at the design stage. Because they make low detection thresholds impossible, the number of interference-based errors goes up. In this method of a radical reduction of non-linear distortions varying frequency signals are generated serially during the time needed to send a single code. Signal duration must be reduced but that does not diminish the energy, because signal amplitude can be increased in proportion. There is no signal summation here; it limits the amplitudes of component signals, when the limit of signal amplitude in the power amplifier is reached. What happens, however, is that the risk of false alarms caused by long delays goes up (Fig. 4.b). This can be prevented by applying longer intervals between the signals and only has a slight effect on transmission data rate.

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