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CURRENT TRENDS IN UNDERWATER ACOUSTIC BIOTELEMETRY SYSTEMS

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The first 20 years of underwater biotelemetry research are summarized in reviews (Stasko and Pincock 1977; Mitson 1978; Ysenbrandt et al 1976) and by McKay (1970). More recent work can be found in Amlaner and MacDonald (1980). Both ultrasonic and radio signals are common but this paper will deal only with ultrasonic systems.

Ultrasonic telemetry, utilizing frequencies in the range 20-300 kHz, is used in studies involving aquatic animals in both fresh water and salt water. Radio telemetry at VHF and UHF frequencies can be effective in shallow fresh water environments, where the signals travel only a short distance underwater before escaping into the air. Radio systems are less susceptible to attenuation due to suspended matter and are capable of high data bandwidths.

Ultrasonic techniques have decided advantages over radio for many applications. Attenuation of radio signals in sea water is so severe (≅55dB/wavelength) that range at any frequency suitable for miniature transmitters is less than a few metres. Ultrasonics, on the other hand, are capable of 1 km range with modest power (<100 mW) and physically small acoustic projectors. These shorter wavelengths used also mean greater accuracy in position fixing systems.

Virtually all ultrasonic systems to date have been single frequency systems maintaining long intervals (at least several hundred mS) between transmitted pulses to avoid interference multipath effects. This causes no difficulties when the sole objective of the "telemetry" system is to locate or track the transmitter-equipped fish. When information is encoded from one or more sensors, however, data rates achievable with this approach may be inadequate. For example, pulse interval coding can be used to for slowly varying sensors such as depth, temperature and swimming speed (Pincock et al 1978); but more sophisticated methods would be required to code myograms or similar signals.

TYPICAL SINGLE FREQUENCY/TRANSMITTER SYSTEM

A typical biotelemetry system uses transmitters which codes a low frequency sensor output into a pulse repetition rate. Individual transmitters are identified by their transmission frequency. The main processing tasks at the receiving site are: interaction with the operator for selection of sampling rate for each transmitter; automatic receiver tuning; decoding of transmitted signal; display and storage of data etc. All of these, with the exception of measurement of pulse interval can be accomplished with a general purpose computer.

The system organization described above can be adapted to a wide range of studies. The required receiving components and hydrophone can be realized in a straightforward fashion and do not limit system performance. The major areas of customization to an application are the transmitters, software to carry out decoding, data storage, etc.

Computer and Software

The tasks to be accomplished by the computer portion of the ultrasonic biotelemetry system are not very different from those of any other biotelemetry, or for that matter, data acquisition system. Because time critical tasks are accomplished by the receiver and interface, the development of appropriate software for an application need not be a serious obstacle regardless of the number of transmitter or sensors per transmitter. A system which determines transmitter location can be realized by using three or more receiving systems and placing the hydrophones appropriately. We use a standard receiver interface which measures time of arrival and therefore a position fixing algorithm such as that described by Hawkins el al (1974) can be easily implemented. Of course, the particular hardware used, custom or off-the-shelf, will be influenced by processing requirements as well as the environment in which the system has to operate.

Transmitters

The design of the "RF" stages (gated oscillator, power amplifier and ultrasonic transducer) of a miniature ultrasonic telemeter can be relatively standard (Church, 1983) and are not discussed further here. Sensors and associated circuitry pose greater problems for the designer. Sensor and electrode outputs may need to be filtered and/or amplified prior to encoding for transmission. Early transmitters used single-ended amplifiers made from discrete components. While this technique may be suitable for some applications, increasing the gain usually leads to instability. Single-ended amplifiers are also very susceptible to interference, particularly in laboratory environments.

The appearance of micropower operational amplifiers greatly changed the makeup of ultrasonic transmitters. With quiescent currents as low as a few microamperes, it is now possible to use well established OP-AMP design techniques to construct complex transmitters. Recent applications use these OP-AMPs, along with digital CMOS circuits, in chip form to achieve further reductions in size. We used this latter technique to realize transmitters suitable for long-term attachment to 1 kg (approx.) fish. The more complicated of the transmitters uses myogram electrodes whose output is amplified, rectified and averaged and coded into a pulse repetition rate (Church and Pincock 1983). The multiplexing of pulse intervals from a number of sensors is also possible using similar circuitry (Voegeli and Pincock 1980).

LIMITATIONS OF CURRENT SYSTEMS

The approach outlined above has at least two serious limitations. First, only low data rates (several samples/second at most) are possible and, secondly, the number of transmitters which can be accommodated is small. The second problem can be overcome by identifying individual transmitters not by transmission frequency but by the use of transponders which respond to unique interrogation codes. The resulting increase in transmitter complexity is significant but manageable. The problem of increasing data rate is more difficult however.

The only generally applicable method of significantly increasing the data rate is to divide the available bandwidth into a number of narrow channels each of which is used sequentially (McIntyre, 1982). Thus, although multipath conditions limit the data rate of each channel, the effective data rate is increased by the number of channels. Unfortunately this approach, with a requirement for high speed frequency synthesis and associated controls in addition to other transmitter circuitry, is far too complex to realize with OP-AMP and small scale CMOS IC's.

In summary, significant advances in ultrasonic biotelemetry systems require that at least an order of magnitude more complexity be squeezed into transmitters. A general purpose telemetry transmitter can be built around a module consisting of multichannel A/D, processor and one or more frequency synthesizers. Such a transmitter could achieve a reasonable data rate from a number of sensors. To build it in a miniature form, large scale integrated circuit (LSI) chips need to be employed instead of the current discrete CMOS chips.

IMPROVING THE TECHNOLOGY

It would appear from the above discussion that all that is required to achieve the required transmitter complexity is to design around LSI chips instead of discrete components and simple CMOS functions. Unfortunately, the requirement for miniaturization imposes the use of small batteries and, therefore, circuitry must not only operate at micropower current levels but also with low power supply voltages (ideally 1.5 to 3 volts). In general, conventional circuits are not designed to operate in this environment and , for this reason, the technology used in transmitters has always tended to be at least a generation behind that of conventional electronics.

Instead of using old technology, one can design custom LSI circuits for ultrasonic biotelemeters. This has, until recently, been a prohibitively expensive option; but silicon foundry resources and easy-to-use design facilities are becoming available to more and more researchers. For example, we have designed two circuits - the first a micropower current controlled oscillator and the second a transmitter frequency synthesizer and controller - which, when fabricated and tested will be used to increase transmitter complexity. The second circuit is particularly interesting since it is programmable for a wide variety of applications. Using the experience gained from the design of these circuits, we will specify and design a set of LSI chips which will be easily configured for multichannel high data rate applications. We feel that such customization is absolutely essential for underwater biotelemetry to achieve its true potential. The required custom circuits, once specified, will not be that difficult to design since high speed operation is not necessary for this application.

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