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PATSY: THE PULSED ACOUSTIC TELEMETRY SYSTEM

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INTRODUCTION

PATSY was developed under a joint contract with the Department of the Environment and the Joint Research Centre, to provide a means of transmitting information from a Deep Ocean Model Penetrator (DOMP) buried in sediment.

A penetrator is a 2 tonne projectile that is allowed to fall from a ship, reaching a terminal velocity of around 50 m/sec before impacting with the sediment. Penetrations of between 20 and 40 metres have been achieved.

Penetrators have been equipped with continuous wave acoustic transmitters (operating at 12 kHz). The doppler shift in the signal, received at the ship, has been used to measure the penetrator's velocity and by differentiation and integration, the depth of penetration and the deceleration, respectively.

It was desired to measure directly the deceleration of the centre-of-mass and log data from a range of sensors during the descent through the water-column, during deceleration and after the penetrator had come to rest. The sensors were to include tilt-meters, accelerometers, a temperature sensor and differential pore-pressure gauges.

A computer controlled logging system was developed able to sample sensors at a variety of rates during the descent of the penetrator and then to encode and transmit these data.

A number of advantages to be gained over the doppler system include:-

(i) The information would not be transmitted through the noisy wake of the penetrator.
(ii) Deceleration could be sampled faster than the information bandwidth of a doppler system.
(iii) A great deal more information could be transmitted.
(iv) A lower frequency could be used to reduce the effect of attenuation through the sediment.

DESIGN CONSIDERATIONS

<u>Signal to noise ratio and operating frequency</u>
The signal level received at the ship from the penetrator transmitter, in 30 to 40 metres of sediment and 6000 metres of water, should be higher than the noise level in poor weather conditions by at least 10 dB. In deep water beyond about 1 kHz the dominant noise is due to breaking waves and the oscillation of vapour bubbles and falls off at about 5 to 6 dB/octave [1]. As attenuation in water is rising at about 6 dB/octave the signal to noise ratio can remain substantially constant in the range 1 to 20 kHz. However, the attenuation in the sediment is an exponential function of both frequency and

penetration depth and this dictates the use of a low frequency.

Using a figure of 0.1 dB $m^{-1}kHz^{-1}$ for the attenuation in deep ocean sediments (Clay and Medwin [2]) the attenuation through 40 metres of sediment would be:-

at 1 kHz 4.0 dB
at 20 kHz 80.0 dB.

(Measurements made in the Great Meteor East Abyssal Plain at 12 kHz suggest a figure of about 0.05 dB $m^{-1}kHz^{-1}$ [3]. This low figure may be due to the fact that the sediment drawn in behind the penetrator is not as compact as undisturbed sediment).

Ship's self noise can become dominant in the low kHz but this is at least an avoidable source as the ship can be allowed to drift with main engines off during listening.

A frequency of 3.5 kHz was chosen (slightly lower than optimum) because the Institute uses this frequency for sub-bottom profiling and thus receiving equipment would be available.

Sonar calculations were made assuming this frequency and the use of a commercially available ceramic ring transducer with about 200 Hz bandwidth. PATSY was designed both to telemeter data at a crystal controlled rate as well as to transpond to interrogation by the ship's 3.5 kHz transceiver.

Sonar Calculations

Assuming:-

Operating frequency	= 3.5 kHz
Water depth	= 6000 m
Penetration depth	= 35 m
Attenuation in sediment	= 0.1 dB/m-kHz
	= 12 dB one way
Power of ship's system	= 2 Kw
with directivity index	= 10 dB
Power of telemetry system	= 100 W
with directivity index	= 5 dB
and with 5 msec pulse, bandwidth	= 200 Hz
Sea-state 6 noise in 200 Hz bandwidth	= -42 dB re 1 Pa

(1) Sound pressure level at transducer

Transceiver source level	= 33 dB re 1 watt
+ 50.8 dB re 1 Pa/watt @ 1 metre	= 83.8 re 1 Pa
+ 10 dB directivity index	= 94 dB re 1 Pa
Losses:	
Spreading loss over 6000 m	= 75.6 dB
Water attenuation (@ 0.25 dB/km)	= 1.5 dB
Scattering loss	= 3.0 dB
Loss due to acoustic impedance mismatch at the bottom	= 1.0 dB
Attenuation through sediment	= 12 dB
Total	= 93 dB
Thus sound pressure level at transducer	= 1 dB re 1 Pa

(2) Sound pressure level at the ship	
Transducer source level	= 20 dB re 1 watt
+ 50.8 dB re 1 Pa/watt @ 1 metre	= 70.8
+ 5 dB directivity index	= 76 dB
With the same losses the level at the surface will be	= -17 dB re 1 Pa

This is about the same level as the profiler's bottom echo assuming 30% reflectance.

Thus the signal to noise ratio at the ship would be about 25 dB.

(3) Sing-round level at transponder	
The total losses will be greater by 6 dB because of the double path plus the remaining losses repeated, i.e.	= 93 dB
Extra distance	+6
Other water losses	+5.5
Sediment attenuation	+12
Total	= 116.5 dB re 1 Pa
With a transponder source level of 76 dB re Pa the sound pressure level back at the transponder will be	= -40.5 dB re 1 Pa

This is about 40 dB below the expected level from the ship. This assumes 100% reflection at the surface.

(4) Noise level at transducer	
The level near the surface will be about -42 dB re Pa and there will be a few dBs drop in the water-column due to attenuation, scattering and refraction. It is expected that the noise will receive a similar attenuation in the sediment, as the signal. Allowing 15 dB for these losses	
Noise level at transducer	= -57 dB re Pa
Ship's noise could, however, add considerably to this.	
(5) Transducer receiving sensitivity	-95 db re 1V/Pa

Data Encoding

The encoding techniques available for acoustic telemetry of data include modulation of the phase, frequency or amplitude of a carrier and modulation of the time interval between pulses.

Amplitude and phase modulation of a carrier are impractical in deep water for at least three reasons:-

(1) Signal to noise ratios better than 20 dB are rarely achieved so there would be very limited dynamic range.
(2) Acoustic signals do not travel by simple "line-of-sight" paths but by multiple paths differing by only fractions of a wave-length due to small angle scattering and turbulence. The combination of signals produces randomly varying amplitude and phase distortions at the receiving hydrophone.
(3) Reverberation from layers within the sediment and from the water surface interfere with the direct signal, although the effect can in theory be removed if the pattern of echoes is constant or only changing slowly.

Frequency modulation suffers like phase modulation unless frequency shifting is used though this uses available bandwidth and energy less efficiently than other techniques.

Time modulation, using the time delay between two short pulses to carry the information, can be very efficient and can have a large dynamic range. Its disadvantage is that it is slow, though signals can be multiplexed to increase the effective data rate.

Digital coding using frequency shift keying could have unlimited resolution by merely extending the number of bits in a sequence but is very expensive in energy. Pulse interval telemetry (P.I.T.) uses only one pulse per data word (plus one reference pulse) and the resolution is limited only by the maximum time that can be allowed to elapse between the pulses. P.I.T. is, however, a form of analogue modulation and will suffer from timing noise. This will arise from amplitude noise riding on the signal and variations in path-length as the receiving "fish" heaves up and down with the swell.

The effect of additive noise is to produce a timing jitter on the edge of the received pulse of about:

$\Delta t = \left(\frac{VN}{VS}\right) tr$ where tr is the pulse rise time
VN is the rms noise voltage
VS is the pulse amplitude

The assumption is made that the signal to noise ratio is at least +6 dB.

This jitter will be present on both the reference and signal channels but will be uncorrelated, so the jitter on the time difference is:-

$$\sqrt{2}.\left(\frac{VN}{VS}\right).tr$$

If the maximum time delay available is tm then the resolution of the channel is

1 part in $\frac{1}{\sqrt{2}} . \left(\frac{VS}{VN}\right) . \frac{tm}{tr}$

given $tr \approx \frac{.4}{B}$ B = 200 Hz

tm = 2 seconds, say

and $\frac{VS}{VN} = 2$, i.e. 6 dB S/N

then the resolution is 1 in 1414, i.e. between 10 and 11 bits. The bit rate is thus around 5 bits/sec for a single channel. However increasing the number of channels from 1 to N is straightforward, the only decision required concerns whether the pulse intervals for different channels will be allowed to overlap, in which case for (N+1) pulses transmitted 10N bits equivalent are communicated. In previous underwater applications of P.I.T. overlapping intervals have been allowed and not found to cause undue confusion using a form of direct line scan recorder display. However, this feature clearly relies on the recognition of which pulse belongs to which channel at every new frame of pulses.

If the shipborne receiving transducer is heaving at a rate V m/s between the arrival of reference and signal channel pulse, the timing error introduced in addition to the random noise component above is given by (V/C) td where C is the sound speed (~1500 m/s) and td the signal delay. Generally V will be less than 1.5 m/s, in which case the error amounts to less than .1% of the signal.

THE FINAL DESIGN

To cope with the complexity of sequencing the logging of a variety of sensors at different rates and then encoding and transmitting these data; the design was based around a microprocessor running FORTH. Signals were sampled via an eight way multiplexor and a 12 bit digital-to-analogue converter under direct control of the microprocessor and stored in about 40 kilobytes of memory. Duplicate accelerometers were sampled at 500 Hz during the critical phase of deceleration through sediment. Figure 1 shows the appearance P.I.T. received and displayed on a line-scan recorder with a repetition period of 2 seconds. The two accelerometer signals were encoded with different offsets from the reference pulse to separate the displays and to allow for the small negative excursion as the penetrator bounces up about 1 cm before coming to rest.

Each return represents a 5 millisecond pulse of 100 watts at 3.5 kHz. This data was recorded in shallow water in the Mediterranean off Cap d'Antibes. During this experiment some 760 Kbits of data were transmitted at an average baud-rate of 13.6.

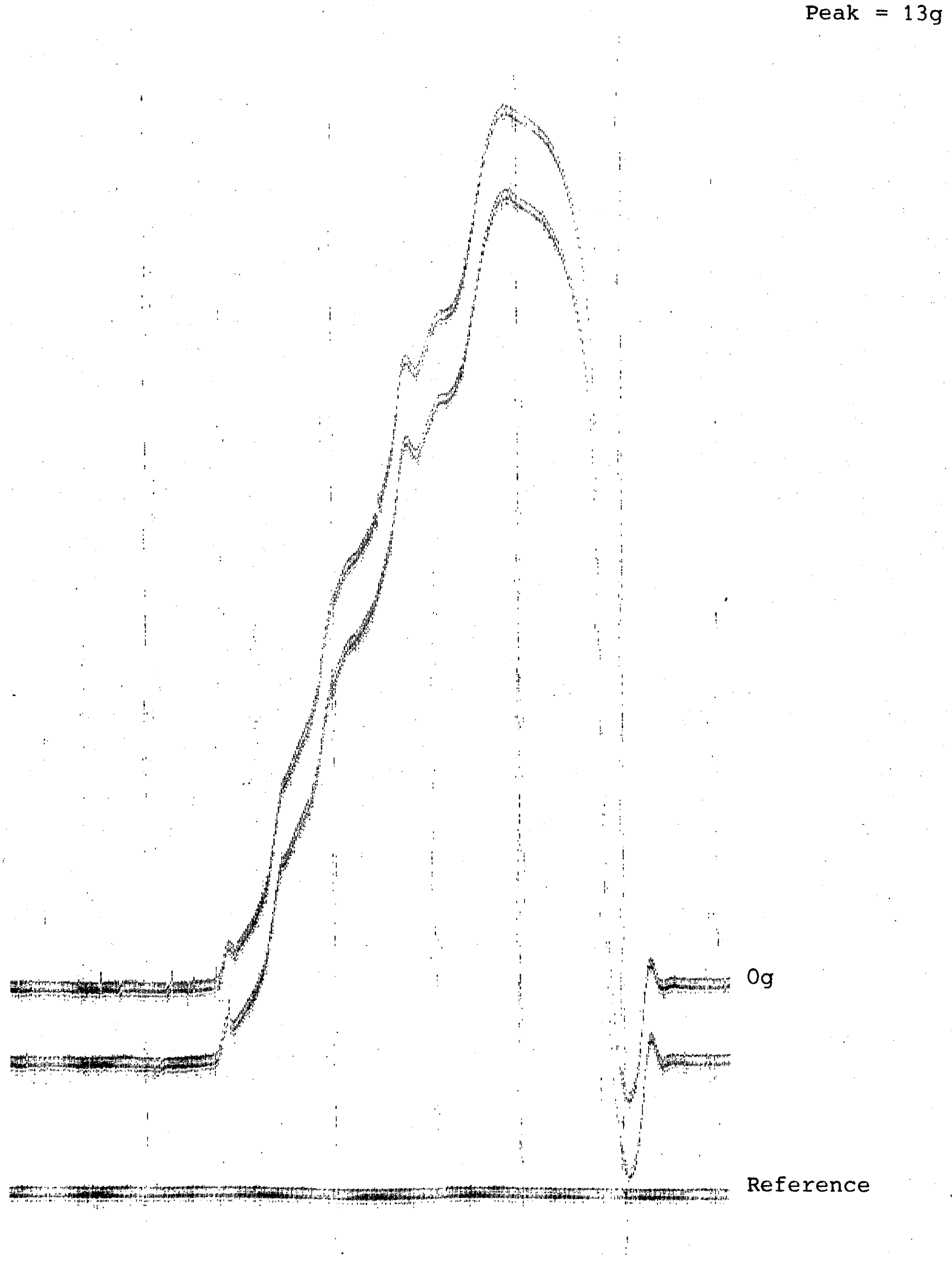

Fig. 1   P.I.T. of deceleration through sediment.
Sampled at 500 Hz. Duration of deceleration = 570 mSec.

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FINMAP - A DIVER-CARRIED, UNDERWATER, NAVIGATION, MAPPING AND DATA AQUISITION SYSTEM

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INTRODUCTION

FINMAP (Fig. 1) is an acronym for Fisheries Navigation and Mapping by Acoustical Positioning and consists of an underwater computer, a data logger and a personal navigation system that allows a scuba diver to navigate and map his or her way on the sea floor, simultaneously recording marine observations. The FINMAP computer controls a diver-carried active sonar, transmitting to triad of underwater acoustic transponders. The sonar system provides personal navigation and mapping during day and night, and does away with the need for underwater grids for the collection of marine data. The underwater keyboard provides the diver with means of entering data observations directly into computer memory. The display gives a direct read-out of position and depth which can be automatically stored in memory together with any observed data.

Keyboard switching is determined by infrared reflection from a diver's finger touching on a solid state key. The display unit is a memory mapped array of seven segment light emitting diodes (LEDS). Both the keyboard and display are totally encapsulated in a plastic potting medium and are thus able to withstand submersion to over 100 metres and the corrosive effects of seawater. Computer interfaces are being developed that allow the connection of marine instrumentation and the automatic collection of data such as temperature and salinity.

FINMAP will be used in marine research, underwater archaeological mapping, underwater surveillance and monitoring and underwater industrial applications.

COMPUTER

The computer (Fig. 2) is carried in a sealed waterproof tube on a diver's back together with the interfaced sonar navigation system. The microcomputer is the Rockwell R65F12, [1] an 8-bit NMOS chip, compatable with the well known 6502 microporcessor of the Apple computer. On a single chip, measuring 41 mm x 17 mm, is fabricated an enhanced 6502 microprocessor, an internal clock oscillator, 192 bytes of random access memory (RAM), 3K bytes of read only memory (ROM). 40 bidirectional input/output (I/O) lines, two 16-bit programmable counter/timers, a serial port and ten interrupts. Externally there are 16K bytes of memory and 16K bytes