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AMPLITUDE MODULATED CONTINUOUS EMISSION ACOUSTIC RANGING TECHNIQUE

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INTRODUCTION

A wide range of sonar systems now exists, operating at acoustic carrier frequencies of up to 700kHz, and covering distances from a few metres to many kilometres, and for purposes which include navigation, detection, location and classification of underwater objects and echo-sounding [1].

In the majority of sonar systems, target discrimination is achieved by using the pulse/echo technique whereby the range to any particular target can be estimated from the echo-return time and the speed of sound in water. In order to achieve accuracy closely spaced targets, short pulse lengths and consequently wide bandwidth systems are required with the attendant penalty of noise susceptibility.

An alternative to the conventional pulse/echo technique for which a high degree of range resolution is claimed is the use of a frequency modulated carrier, range being calculated from the frequency difference between transmitted and returned signals. Such systems present major problems however, and complex circuitry is required for their realization in hardware.

A need was identified for a simple ranging system capable of accurate measurement of distance to a single target underwater, for example the sea-bed, ship's hull etc., one possible application being use for altitude control of a remotely operated vehicle (ROV). This paper describes such a system, in which a carrier is amplitude modulated at selected modulating frequencies and transmitted continuously and range is calculated from the phase difference between transmitted and received signals. Accuracy is ultimately limited by the accuracy of phase shift measurement at the carrier frequency.

CONCEPT OF THE RANGEFINDING TECHNIQUE

This ranging technique is based on the linear phase delay of the received signal with respect to the transmitted signal due to the finite time taken by the wave front to travel from the transmitter to the receiver via the reflecting surface [2]. In the present system, in addition to the carrier frequency f3, two low frequency sinusoidal signals at f1 and f2 are used to modulate the carrier sequentially. The phase shift of the modulating frequency with the longest wavelength gives the first approximation to the range, and the phase shift of the second frequency with a shorter wavelength gives a more accurate measure of the range when considered together with the phase information given by the first approximation. Use of this approximate range information enables accurate estimation of range from the carrier phase shift. Ultimate accuracy is determined by the acoustic carrier frequency in the present system 40kHz corresponding to range accuracy of $\pm$1mm assuming approximately $\pm$10 degree accuracy in phase shift measurement at the carrier frequency. In order to avoid measurement ambiguities, f3/f2 and f2/f1 should not exceed, say, 10. The carrier amplitude modulated by the lowest frequency modulating signal, f1, is transmitted and the phase difference between the modulating signal and the received signal at f1 after demodulation recorded. The approximate range is given by:

$$R1 = \frac{1}{2} \left(\frac{\phi_1}{360} \right) \lambda_1 \qquad (1)$$

The value of R1 measured at the longest wavelength is only approximate because a large displacement has to be made for a small change of phase angle, and a small displacement is difficult to measure accurately. In order to obtain a more accurate reading, the shorter modulating wavelength λ_2 is used (where $\lambda_1/\lambda_2<10$). The shorter modulating wavelength enables greater accuracy in range measurement. While greater accuracy can be achieved at the shorter wavelength λ_2, it is necessary to ascertain the number of complete wavelengths (N2) contained in the total path length from the transmitter to the receiver. If the first approximation given by R1 is used as a first indication of the range, the integer number of wavelengths N2 of the shorter wavelength signal λ_2 enclosed in R1 is given by:

$$N2 = \mathrm{Int} \left\{ \frac{\lambda_1}{\lambda_2} \times \frac{\phi_1}{360} \right\} \qquad (2)$$

The total number of wavelengths N2 plus the fractional phase change ϕ_2 (< 360) of the shorter wavelength signal gives:

$$R2 = \frac{1}{2} \left(\frac{\phi_2}{360} + N2 \right) \lambda_2 \qquad (3)$$

The value of R2 is a more accurate measure of the displacement. Greatest accuracy is achieved by using the phase shift of the carrier itself (ϕ_3) at frequency f3, following the same procedure where the integer number N3 of wavelength enclosed in R2 is given by:

$$N3 = Int\left\{\frac{\lambda_2}{\lambda_3}\left(\frac{\phi_2}{360} + N2\right)\right\} \quad (4)$$

Thus range R3 is:

$$R3 = \frac{1}{2}\left(\frac{\phi_3}{360} + N3\right)\lambda_3 \quad (5)$$

A difficulty in evaluating N2 and N3 may arise due to the inaccuracy of measuring R1 and R2 respectively. Whenever the conditions $R1 \simeq N2\,\lambda_2$ or $R2 \simeq N3 \cdot \lambda_3$, equations (2) and (4) may cause N2 or N3 to be incorrect by 1 integer. In order to overcome the problem, the algorithm used incorporates a simple check to establish the correct N2 or N3 value. N2 is taken as $\{Int(\frac{\lambda_1}{\lambda_2} \cdot \frac{\phi_1}{360} \pm 1)\}$, whichever gives R2 nearest to R1. Similarly N3 is taken as $\{Int[\frac{\lambda_2}{\lambda_3}(\frac{\phi_2}{360} + N2) \pm 1]\}$, whichever gives R3 nearest to R2. If the transmitter and the receiver are adjacent, then the distance (D) of an object is given by D = R/2.

CIRCUIT IMPLEMENTATION

The block diagram of the rangefinder circuit is given in figure 1. The sinusoidal frequencies used in this rangefinder were generated by two RS8038 waveform generator ICs [3]. One RS8038 was permanently tuned to generate the carrier (nominally 40kHz), and the other one generated one or other of the modulating signals (nominally 400Hz or 4kHz) as required by switching in the appropriate timing resistors through analogue switches. The amplitude modulation was performed by an analogue multiplier RS1495 used as a balanced modulator. The carrier and the modulating signals are generated simultaneously from the two RS8038 devices, and fed to the inputs of the analogue multiplier. The modulation index was set to < 1 by adjustment of the amplitude of the modulating signals by using the dc offset at the input to the multiplier. The AM signal at the output of the multiplier is amplified and used to drive the transmitting transducer, separate transducers being used for transmission and reception. For the present (initial) experiments, custom built transducers were not used as one of the objectives was to establish optimum design criteria with regard to mechanical and electro-acoustic features and operating frequencies.

The demodulator circuit comprises a differential amplifier and an envelope detector. The differential amplifier is used to eliminate any common mode noise present at the output of the receiving transducer. The envelope detector is a diode circuit followed by a 4th-order active bandpass filter. Two sets of 4th-order bandpass filters are required, tuned to the two modulating signal frequencies (i.e. nominally 400Hz and 4kHz), the appropriate filter being switched in by reed relays when required.

The ranging technique requires accuracy of phase measurement. A phase comparison measurement technique was designed to measure the phase difference of two sinusoidal waves inputs over a wide range of frequencies. The principle of operation is demonstrated in figure 2. The two sinusoidal signals are converted into square waves, and the rising edges of the two square waves used to modulate the "on" time of the Q output of a D-type flip-flop. The Q output of the D-type flip-flop thus gives a rectangular pulse train with pulse width corresponding to the phase difference between the sinusoidal signals. The rectangular pulse is integrated to produce a dc output proportional to the pulse width, providing a convenient input to the microprocessor. The simple phase comparator described above was used to measure phase shifts between 0 - 180 degree, and a second D-type flip-flop, with the transmitted and received signals connected to the "D" and clock inputs respectively, was used to provide additional "lead/lag" information to enble phase shift measurements in the range 0 - 360 degree.

RESULTS

Preliminary experiments were carried out in air using commercially available (identical) transmitting and receiving transducers at a carrier frequency of 40kHz, with modulating frequencies of 400Hz and 4kHz. For the in-air experiments, receiver "bandwidth" was minimized by mechanical means and the ranging system used to scan a number of objects at distances up to 5m. Since this distance could be considerably greater than half wavelength at the lowest modulating frequency, (i.e. 40cm at 400Hz), the system was used to measure increments in range of not greater than 40cm). Figure 3 shows the variation of phase shift at the modulating and carrier frequencies with the transmitting and receiving transducers facing each other. Figure 4 shows the results obtained when the ranging system was used, with transducers side-by-side, to scan the edge of a box-shaped object against a flat baseplate. Regions of uncertainty are evident corresponding to the edge of the object. Figure 5 shows the results of scanning a "V" preparation with 45 degree angled sides weld joint using the carrier frequency alone (40kHz) for which ultimate range modulation (in air) is 4mm. The correlation between acoustic scan and the actual "V" shape is evident.
In-water experiment to date have been limited by available transducers and, as stated earlier, one objective of the

initial experiments was to determine optimum design criteria. The system was mounted on a buoy, with transmitter and receiver transducers pointing downwards beneath the water surface. After initial "calibration" experiments the same arrangement was used in a large 10m diameter tank with adjustable water "depth" (actually achieved by varying the depth of a wooden floor of approximately the same diameter as the tank). Figure 6 shows the floor depth as recorded by the ranging system as a function of actual depth. Figure 7 shows the results obtained when the system was used to scan a large box-shaped object.

CONCLUSIONS

System effective for measuring distance accurately to large flat surface, e.g. sea-bed. Application for depth, height monitoring, height control of ROV.

Further experiments will determine transducer requirements and optimum operating frequencies for useful sea-bed type measurements.

References

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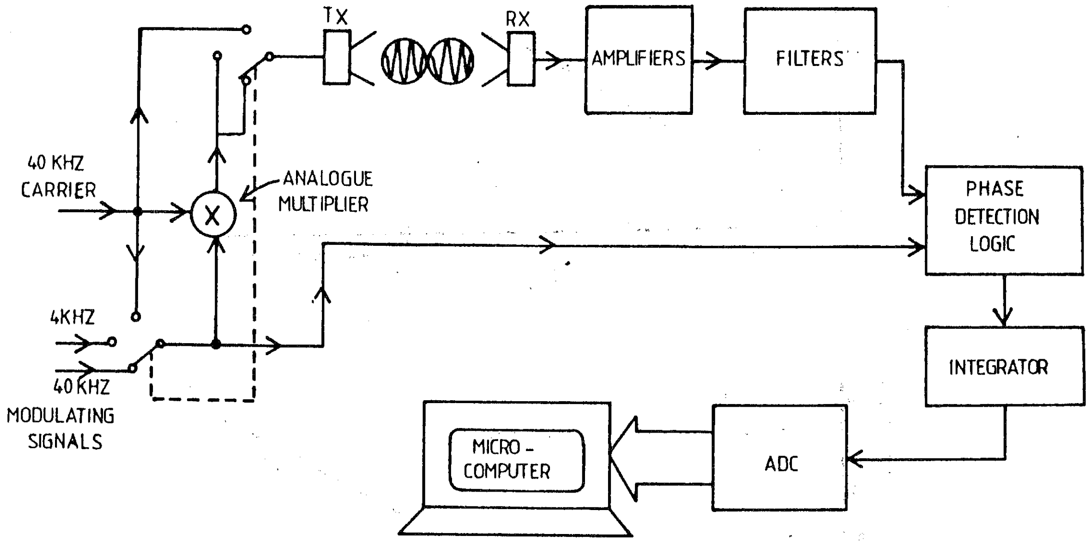

FIGURE. 1.

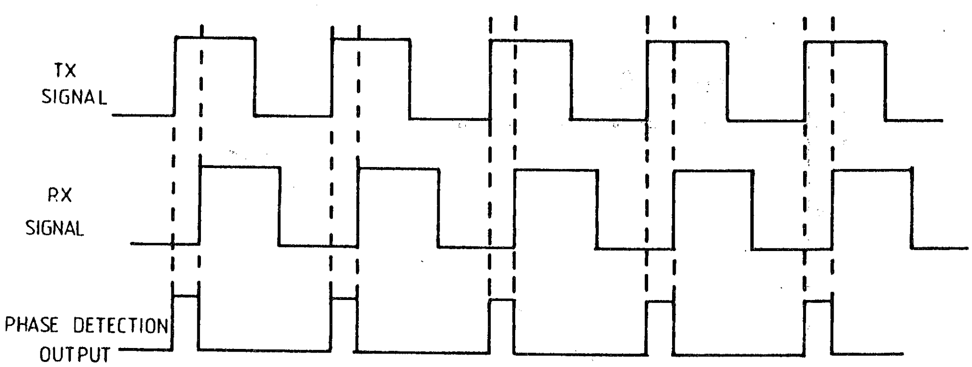

FIGURE. 2.

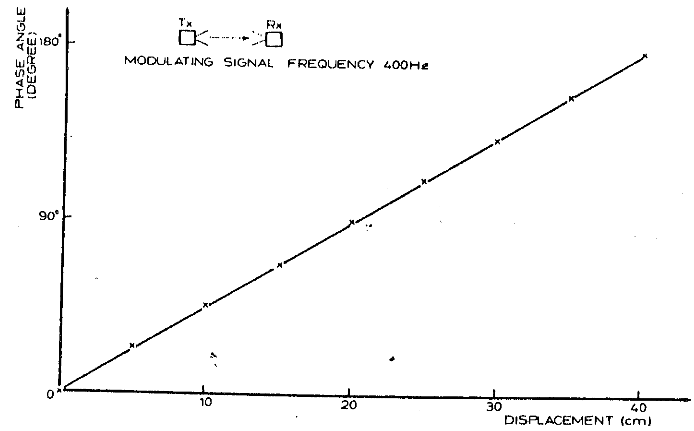

FIGURE. 3 (a).

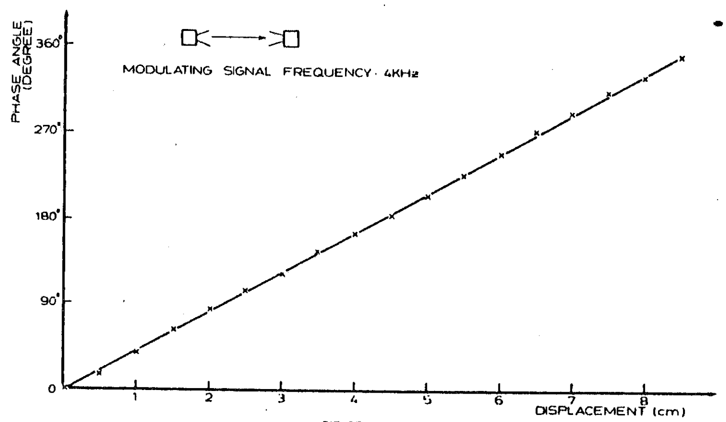

FIGURE. 3(b)

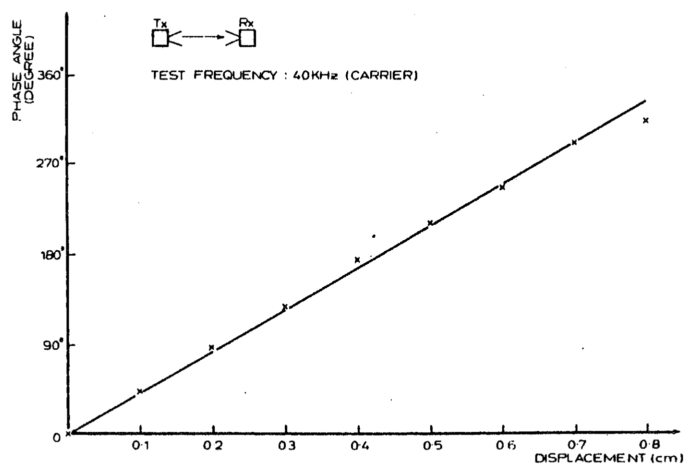

FIGURE 3(c)

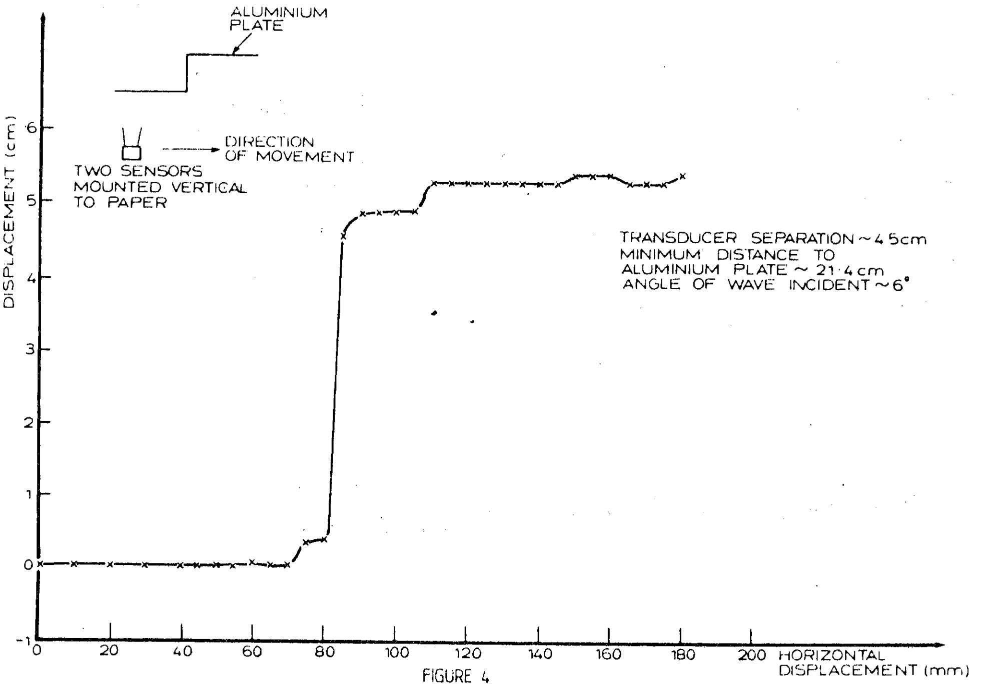

FIGURE 4

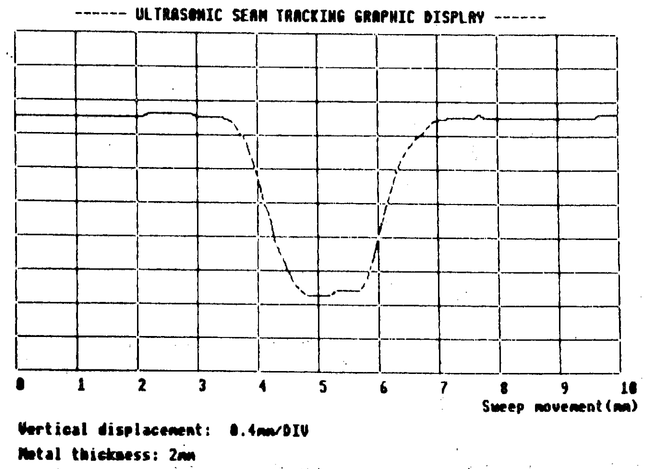

FIGURE. 5.

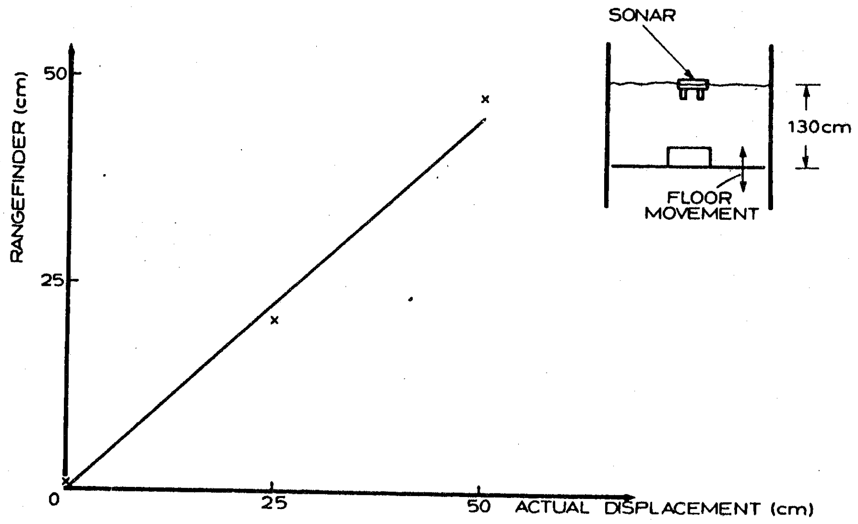

FIGURE. 6.

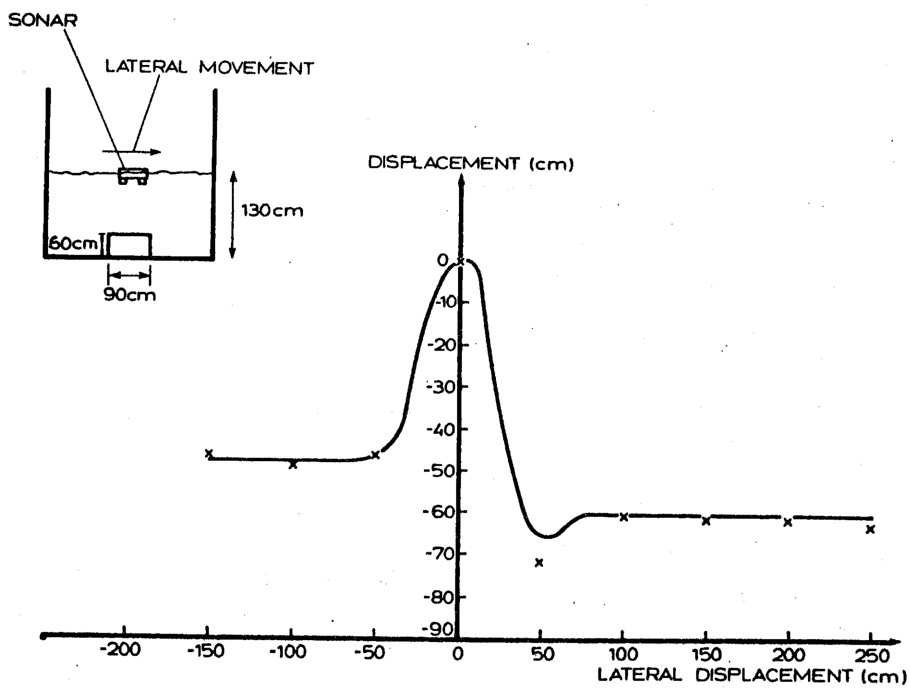

FIGURE. 7.