A NEW APPROACH TO VERTICAL ECHO SOUNDING

by

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INTRODUCTION

Transducers employed in acoustic fish detection systems are capable of providing signals in the range 1 microvolt to 10 volts, thus receivers which are connected to these transducers require a dynamic range of at least 140 dB's if they are to cope with signals from noise levels up to levels expected from large targets close to the transducer. Modern fixed gain amplifiers have typical dynamic ranges of between 60 and 80 dB's. It is therefore not possible to match a single fixed gain amplifier to a transducer. Historically, this problem has been solved by using analogue electronic methods of dynamic range compression usually in the form of a variable gain or logarithmic amplifier which effectively reduces the dynamic range of the signal at the output of the receiver to approximately 60 dB's. These receiver circuits are conventionally followed by an analogue detector which removes the carrier and derives the signal envelope for further processing by either digital or analogue techniques. Both variable gain amplifiers and analogue detection circuits are difficult to design and construct as they tend to suffer from drift and gain instabilities which reduce their accuracy, stability and reliability from the theoretical optimum.

Recent advances in analogue switching techniques, analogue to digital converters and high-speed digital multipliers have enabled new approaches to be made to this old problem. This paper describes one such approach.

GENERAL DESCRIPTION OF THE RECEIVER

Figure 1 illustrates the basic concept of the receiver unit. The receiver is isolated from the transmitter with Reed relays and protected by back-to-back diodes. In receive mode the transducer is matched into a resistor equal to the operating impedance of the transducer, this forms the effective input impedance of the receiver. Three high impedance differential amplifiers are connected in parallel across the matching resistor, the differential input impedances of the amplifier is 10^{11} Ohms. The amplifier gains are staggered by 30 dB's, that is, the first amplifier has a gain of 6 dB's, the second a gain of 36 dB's and the third a gain of 66 dB's. The outputs of the differential amplifiers form the inputs to a high-speed analogue switching circuit which is controlled by a computer. The selected output from the analogue switch is then filtered (in the current model the filter has a Q of 10 and a centre frequency of 38 kHz), and fed into a sample and hold circuit which feeds a high-speed 12 bit analogue to digital convertor. (The input of the A/D is scaled to accept signals in the range ± 10 Volts.)

The differential amplifiers in the input stage each have a dynamic range of approximately 75 dB's, thus, by selecting the appropriate amplifier, an overall dynamic range of 135 dB's can be attained without exceeding a dynamic range at the output of the analogue switch of more than 75 dB's. The sample and hold/analogue to digital convertor system has a dynamic range of 72 dB's and is well-matched to the ouput of the analogue switch. Thus a 14 bit digital signal, two bits controlling the analogue switch and 12 bits output from the analogue to digital convertor, provides digital information with the equivalent of 135 dB's of dynamic range referred to the input of the receiver.

Figure 2 illustrates the operational sequence of the receiver. If this system is applied to an analogue wave form it is capable of producing vast quantities of digital information describing the input wave form. The potential throughput of this circuit is 200 kHz, thus a typical sonar transmission from surface to 600 m could produce 80 kilowords of information (each word containing 14 bits), which would enable a 38 kHz wave form to be reproduced with a high degree of accuracy. Not only would this vast quantity of data be difficult and expensive to utilize using current computer techniques, but a considerable proportion of it is redundant within the context of normal fisheries acoustics, and a method of summarising the data into a more manageable form has to be introduced. The following method was devised to summarise 256 samples into a single figure which represents the energy returned from a one metre depth slice.

The signal obtained from hydro-acoustic transducers is normally an analogue of the pressure at the face of the transducer. However, it is often more interesting to measure the amount of energy returned by the acoustic targets and this may be achieved by squaring the signal from the transducer, which is proportional to the pressure wave, and integrating the resultant intensity with respect to time. To this end, the output of the analogue to digital convertor is fed into a 12 bit multiplier and accumulator circuit. The x and y inputs of the multiplier are parallelled so that the multiplier is effectively a squaring circuit which squares the output from the analogue to digital convertor. The circuit then accumulates successive multiplications for a fixed period of time, in this case 1.3 msecs, which is equivalent to the time taken for the acoustic wave to travel 1 m in water (two-way transmission). Thus the output of the 12 bit multiplier and accumulator is proportional to the integrated echo energy returned from a 1 m depth slice and is derived from 256 individual samples of the input wave form.

To enable the computer to work at peak efficiency, the receiver formats the information into a floating point notation which consists of two 16 bit computer words. This is achieved by logically left-shifting the output from the multiplier until the first digit to the left of the binary point becomes one and counting the number of shifts. This not only transforms the output of the multiplier and accummulator into computer notation, but is also ensures that the computer receives the maximum amount of digital information, that is, leading zeros are suppressed and the computer receives a 23 bit fraction and an 8 bit exponent. The two output words are stored in registers with three state outputs for approximately 1 msec and can be accessed by computer on demand, by putting a control line either high or low.

GENERAL DESCRIPTION OF THE ECHO SOUNDER

Figure 3 illustrates the complete echo sounder which is based on a Computer Automation LSI 4/90 computer. The computer is programmed to control the sequence of operation of the transmitter and receiver, to apply TVG functions to the signal received from the receiver, to perform bottom elimination functions, to compile and present data summaries to the operator and to store the information for each transmission on magnetic tape to enable a complete survey to be replayed transmission by transmission for detailed analysis.

The system consists of the following general purpose computer peripherals:-

(a) A visual display unit and key board through which overall control of the system is maintained.

(b) A DC 300A magnetic cassette storage system which is used to input computer programmes.

(c) A dot-matrix line printer which is used to output data summaries.

(d) A Versatec printer-plotter which is used to produce a 'conventional' echo trace similar in format to that obtained from a standard scientific sounder, with additional Alpha numeric information summarising the data presented in graphical form.

(e) A 35 mega-byte reel-to-reel magnetic storage unit. This device records each one metre sample for every transmission. One seven inch reel of magnetic tape will store all the information acquired during a 24 hour survey period.

The computer is also connected to a 2 kilowatt modular transmitter unit designed by Loughborough University for the Marine Laboratory and a receiver as described in the first part of this paper.

Figure 4 shows the block diagram for the computer programme. The data from the receiver is fed into the computer in floating point format using direct memory techniques. The computer then applies a TVG function equivalent to the normal $20 \log R + 2 \alpha R$ function, performs bottom elimination, stores the data on magnetic tape, outputs data to the printer-plotter in the form of a conventional echo trace and prints summaries of the data on the dot-matrix printer.

The computer issues control pulses which select the appropriate pre-amplifier to be connected to the analogue to digital conversion system, notes the gain of the amplifier and inserts this into the TVG programme so that the output from the TVG routine is corrected for gain. The computer also outputs control pulses to initiate a transmission signal which fires the transmitter and resets the receiver circuit preparing it for a new sequence of signals.

CONCLUSION

The system outlined above applies commercially available electronic devices, eg., high-quality differential amplifiers; analogue switches; filters; sample and hold and analogue to digital conversion units; fast digital multipliers etc., and combines them into a fast digital receiver which digitises the incoming wave form at a very early stage of signal processing. This effectively eliminates the difficulties previously encountered in the design and construction of variable gain amplifiers and analogue detection systems. The receiver conserves computing time by organising the data into standard two-word floating point notation which can be readily accepted by the computer without further manipulation. The digital receiver produces high-accuracy output free from the distortions and non-linearities normally associated with analogue receiving systems.

Once the data are in the computer's memory, a fully range of software techniques can be applied to the data to produce accurate time varied gain corrections and sophisticated bottom elimination algorithms, The computer uses standard peripherals and interfaces which are comparitively cheap and readily available. The electrostatic printer-plotter presents a conventional echo trace to the operator allowing the system's performance to be compared with normal echo sounders.

The high-capacity, reel-to-reel bulk storage system allows each metre sampled for every transmission to be recorded, thus an acoustic survey can be replayed to allow analysis to be performed. For example, it is often desirable to examine a transect in an echo survey in retrospect and isolate the returned echo energy associated with the traces which have been identified by independent means. This facility is not currently available in commercial equipment used in acoustic surveys and should eliminate much of the uncertainty in partitioning biomass estimates into their various component stocks.

FIG. 1 BLOCK DIAGRAM OF RECEIVER/TRANSMITTER

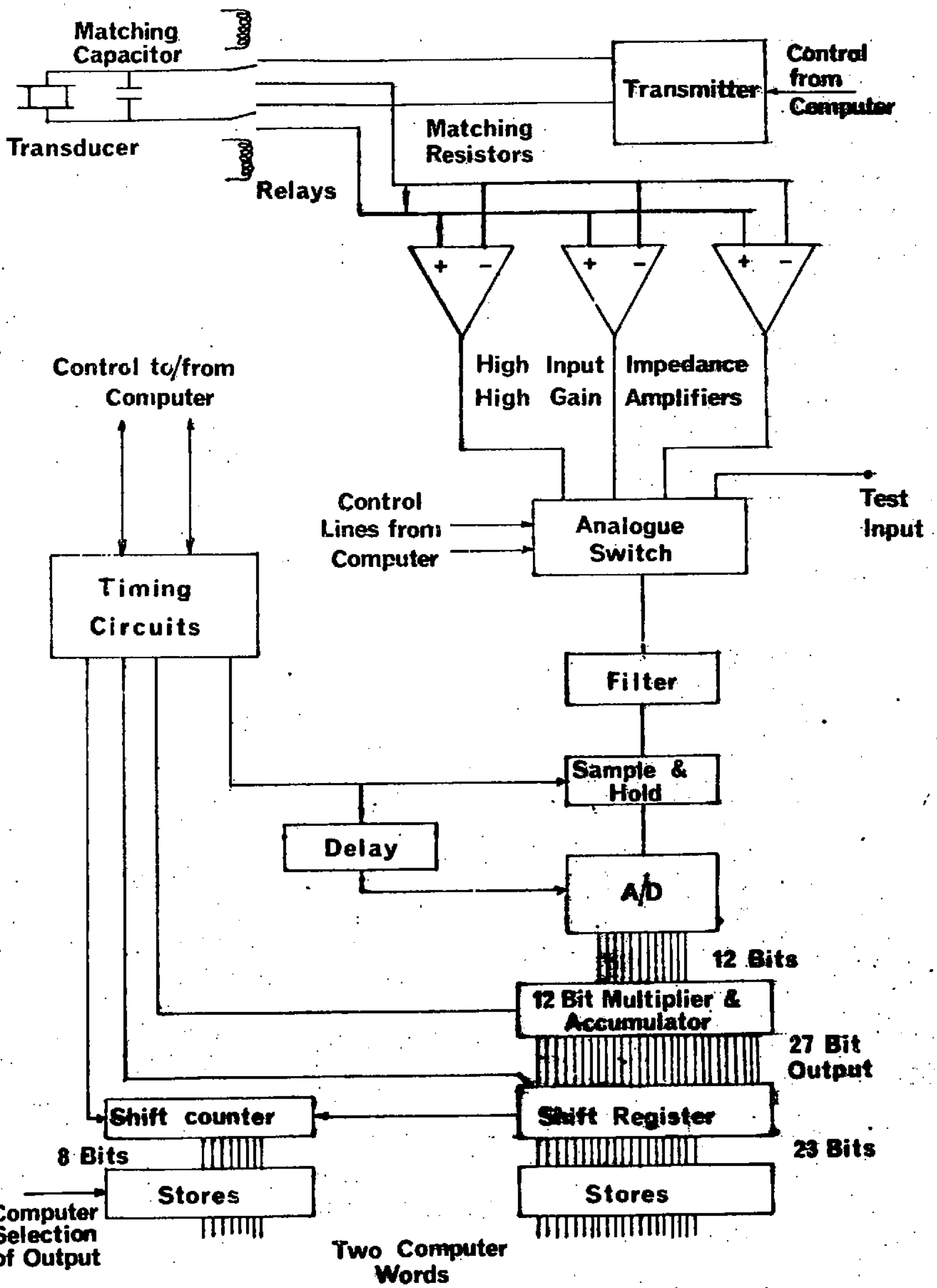


FIGURE 2

OPERATIONAL SEQUENCE OF RECEIVER

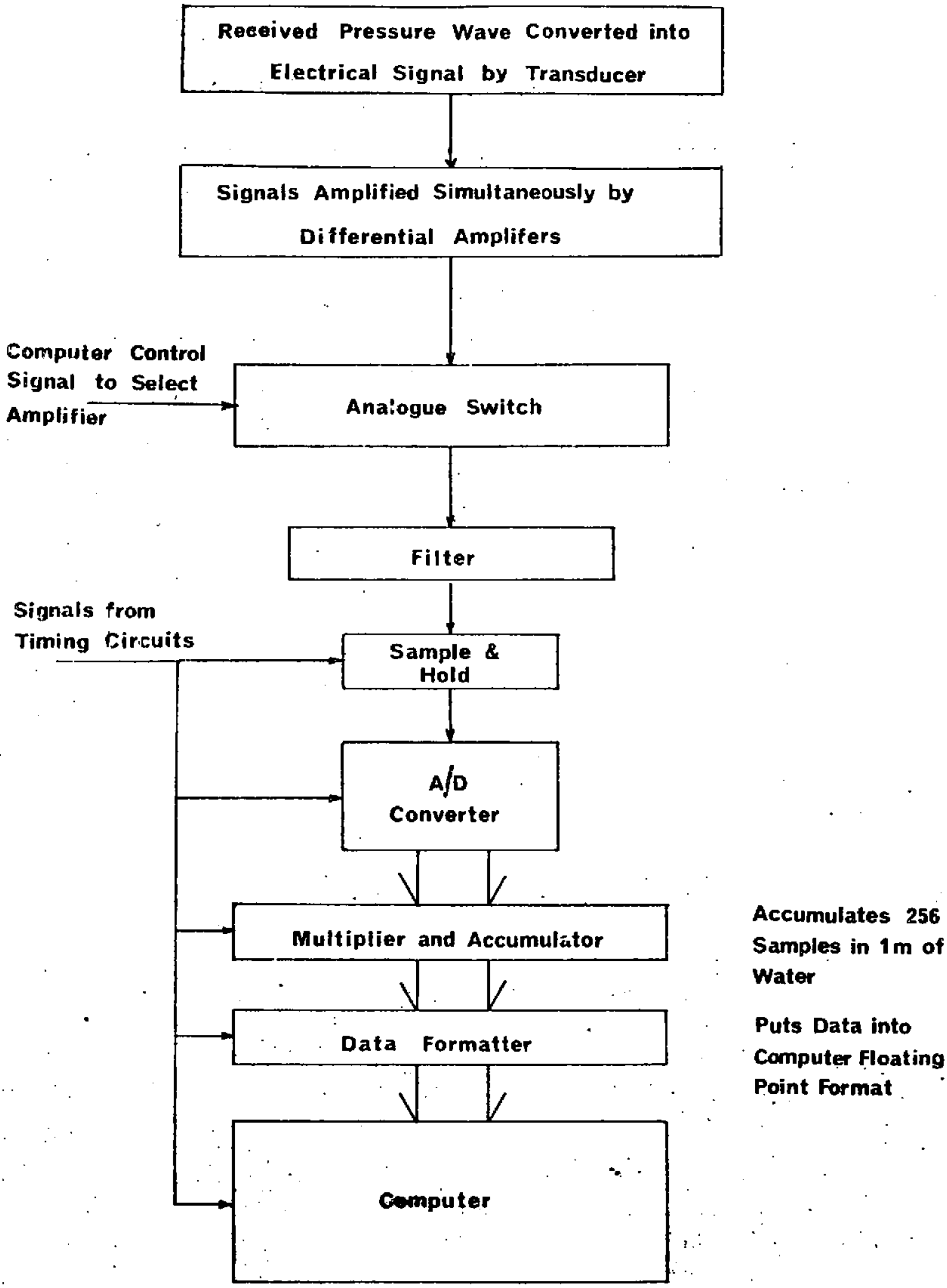


FIG. 3 BLOCK DIAGRAM OF COMPUTER-BASED SYSTEM

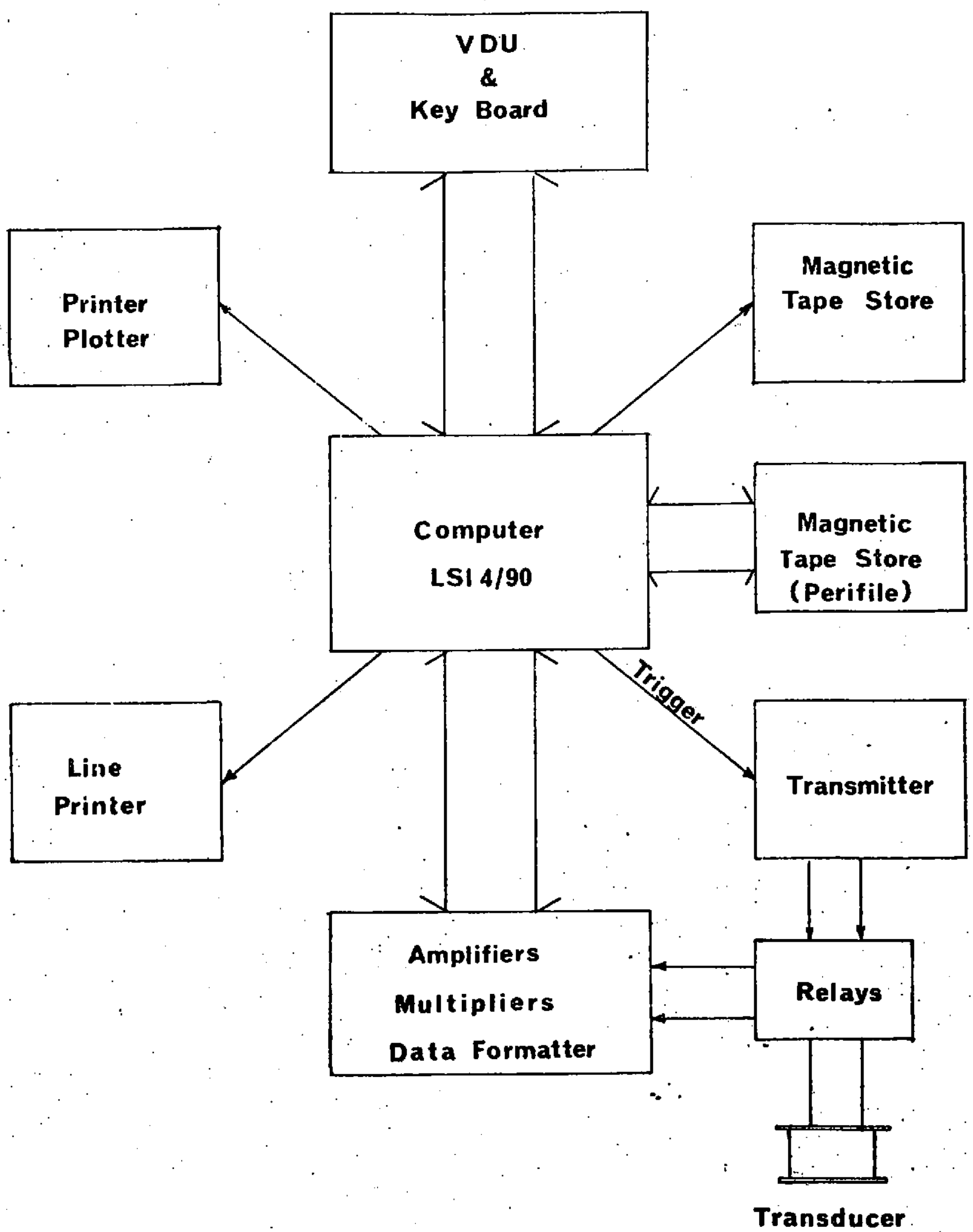
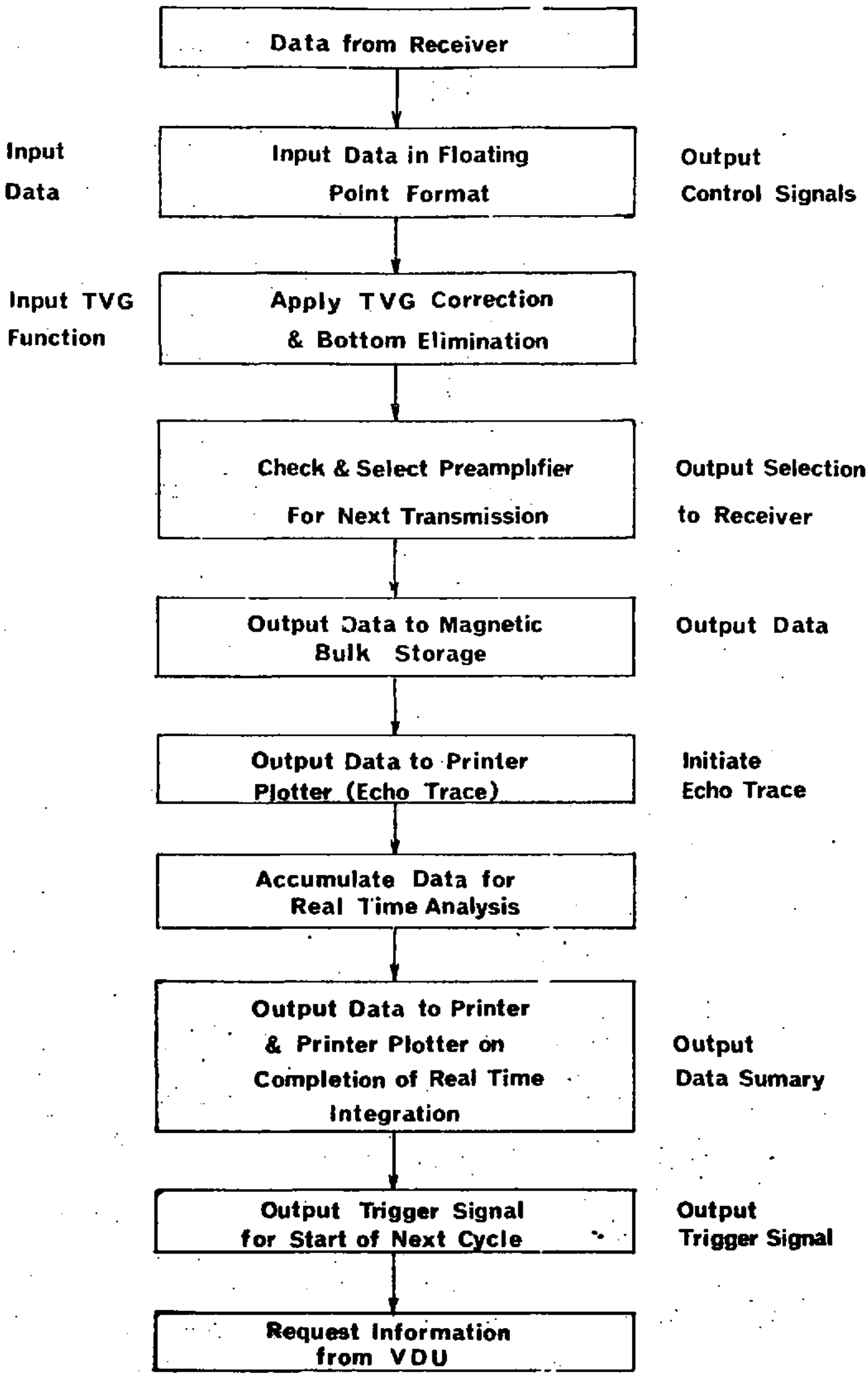


FIG. 4 BLOCK DIAGRAM OF COMPUTER PROGRAMME



A digital echo recording system for fish population assessment.

Coombs R.
MAF, Wellington, New Zealand.

A suitable manuscript for this paper was not received in time for publication in these proceeding.

RECENT DEVELOPMENTS IN REAL TIME ULTRASONIC IMAGING

THE ULTRASONIC CAMERA SYSTEM

An ultrasonic television system bears a close resemblance in many respects to its optical counterpart. The object plane is perpendicular to the viewing axis, the object is irradiated continuously and the reflection is focussed on to the image plane by a converging lens. Electrical signals are produced by an electron beam scanned image converter and pictures are displayed in real time on a television picture monitor. (reference 1).

This television approach to acoustic imaging has resulted in a reasonably robust and simple system whose image quality is unlikely to be transcended by any synthetic aperture or other array system with the same aperture.

Figure 1 shows the configuration of a reflective imaging system. The object is irradiated from a number of transducers which may be conveniently mounted around the lens. A biconcave plastic converging lens is designed for minimum spherical aberration at a given working distance. The image converter housing and camera body, which may be equipped with an extra pressure resistant window, is made sufficiently robust to stand the required immersion depth and is connected to the control console and display at the surface by the camera cable. The complexity of the camera cable depends on the chosen arrangement of system components as shown in Figure 2. The smallest camera body with the least internal electronics may be fed by a multiway cable whose length would be limited by its influence on scan waveform and pulse timing. Such a system would provide the most compact camera for shallow water applications with maximum access to the electronics during operation.

One alternative system shown in Figure 2 can have nearly all the electronics packaged in the camera body and a relatively simple camera cable providing power, gain and sonoptical focus controls and a signal path. It is most efficient to transmit the picture information as a modulated carrier through the long submerged cable and demodulate at the surface. Such an arrangement would be suitable for deeper immersion and Figure 3 is a photograph of a camera system which contains most of the electronics and has a pressure window suitable for immersion to a depth of 300 metres. The insonification transducers are not shown.

THE ULTRASONIC IMAGE CONVERTER TUBE

The ultrasonic image converter is pictured in Figure 4 and a cross section of the faceplate construction is shown in Figure 5. A robust assembly is achieved by gluing the fragile quartz sensor to an epoxy resin supporting faceplate and joining this faceplate to the glass envelope with a soft indium metal vacuum seal. (reference 2). The scanning electron beam effectively connects each picture element in turn into the head amplifier input circuit. Modulation of the electron beam current at a frequency which is related to the ultrasound frequency permits the rejection of spurious signals which are generated by the capacitive coupling to earth of all the picture elements. When imaging with 2 MHz ultrasound, the electron beam is modulated at 3 MHz and the required video signals appear as a modulation on carriers at 1 MHz and 5 MHz. The spurious signals are independent of electron beam scan and remain at 2 MHz. The 1 MHz carrier is selected by the bandpass amplifier and processed linearly before demodulation.

ULTRASONIC IMAGE QUALITY

The valuable and at the same time disconcerting differences between the performances of ultrasonic and optical systems arise from the relatively long wavelength and the coherence of the ultrasound. The long wavelength makes imaging possible in very turbid water where the optical visibility is virtually zero.

The spatial resolution is limited by the spread of mechanical energy in the quartz sensor and by diffraction due to the lens aperture.

At 2 MHz, the half wavelength resonant thickness of the quartz is 1.4 mm and the minimum picture point size due to energy spread is about 1 mm. The lens which was used to produce the images pictured in this paper is an F/1, aspheric lens with a focal length of 230 mm working at a magnification of 0.3. The resultant diffraction-limited minimum picture point separation for coherent irradiation has been measured as 0.9 mm giving about 100 picture points per width of useable area of the 100 mm diameter quartz disc.

Speckle fringes are produced by the coherent interaction of adjacent image diffraction patterns. These fringes are similar in character to those seen on objects irradiated with laser light but they are much coarser corresponding to the 1000 times greater wavelength of ultrasound.

The surface roughness of many submerged objects is less than the ultrasound wavelength in water and predominantly specular reflections will give rise to images with a shiny, polished appearance.

Figure 6 illustrates how a specularly reflected beam of ultrasound must be collected by the lens or the reflection will not be imaged at all (SP_3). Where the object surface (SC) is rough enough to scatter in all directions, this surface will always be imaged (SC') if the energy collected by the lens is sufficient. The addition of more irradiating transducers around the lens will increase the number of places on the object surface which are correctly angled to reflect into the lens. This means that for a given position of the object there will in general be more bright patches in the image. There will also be a greater range of object orientations which give a useful set of specular reflections. Where the object surface is rough enough to scatter, the additional transducers will increase the displayed brightness of these areas and the excessive contrast range in the image will be reduced.

The deployment of several irradiating transducers whose beams overlap in the object plane will further complicate the interference fringe patterns in the image if coherent, single frequency insonification is used. It becomes necessary to feed the transducers with narrow band random noise in order to destroy coherence and then most of the interference fringes disappear. The progressive realisation of an interference-free image by increasing the noise bandwidth is shown in Figure 7.

The use of random noise can also reduce unwanted background effects in some circumstances. Figure 8 shows the images of a pulley wheel and of a rubberised horsehair background taken separately and then together at 2 MHz. Figure 9 shows the same object and background imaged with 2 MHz ± 200 kHz of random noise.

An example of the ability of 2 MHz ± 2 kHz ultrasound to penetrate a 10 mm layer of silt in addition to 2 metres of very turbid water is shown in Figure 10.

The maximum viewing range of the camera is governed by attenuation and backscatter usually caused by suspended matter in the water. At 2 MHz for example a 0.2% concentration of 10 μ suspended particles will produce an attenuation of 3 dB/metre. The maximum range for imaging by specular reflections with 100 watts of irradiation transducer power is then calculated to be 10 metres.

CONCLUSION

Real time ultrasonic television images in the low megahertz domain can provide recognisable images at short range. Some applications such as the monitoring of sea bed engineering or mining operations, collision avoidance for submersible craft and the inspection of submerged structures are already well defined. It is possible that transmission imaging will play a useful part in medical or biological applications. Further possibilities may be encountered in association with the enormous potential of marine farming activities.

The development of the ultrasonic camera system continues in an effort to increase sensitivity, range and resolution, while retaining a compact assembly.

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ACKNOWLEDGEMENTS

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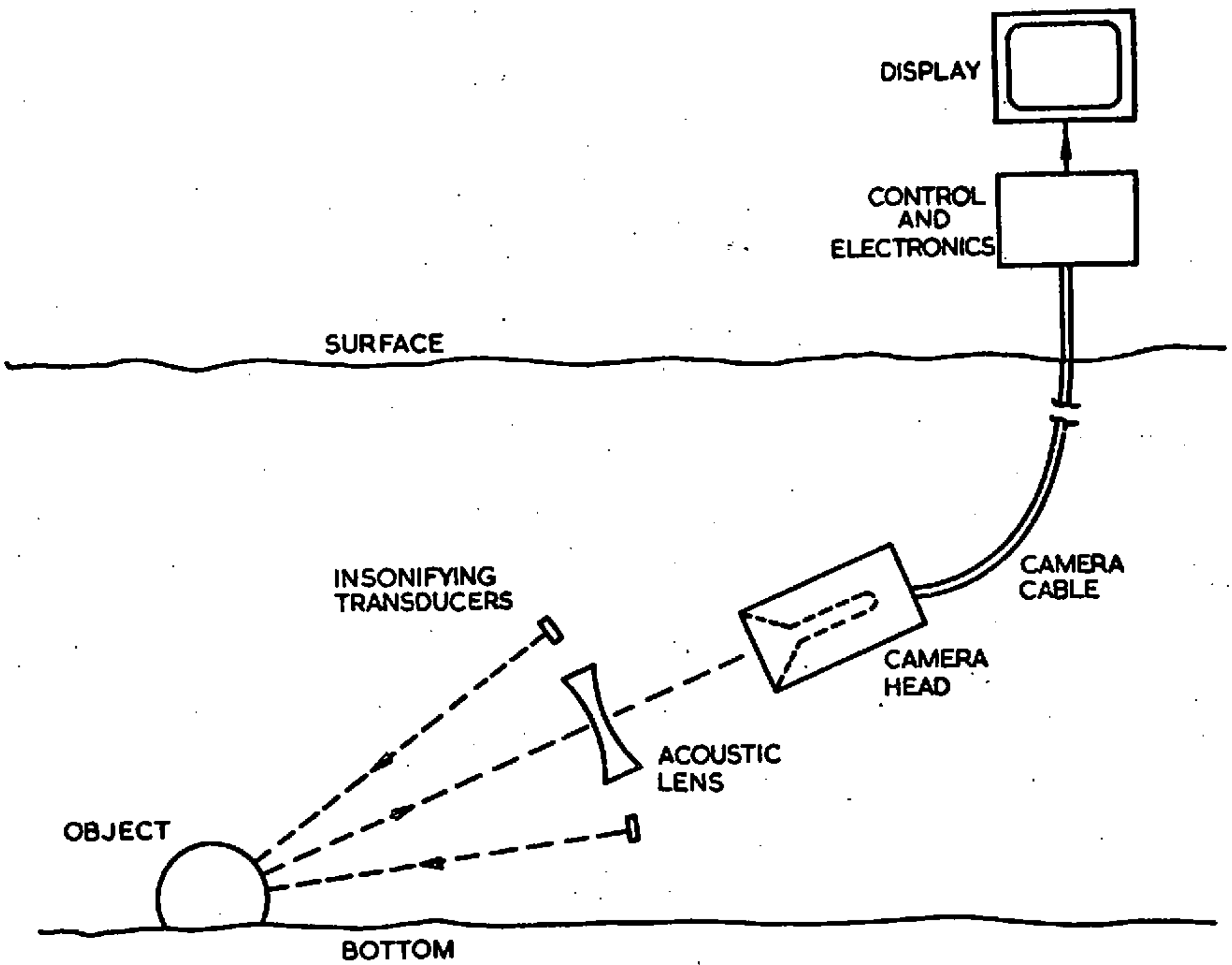
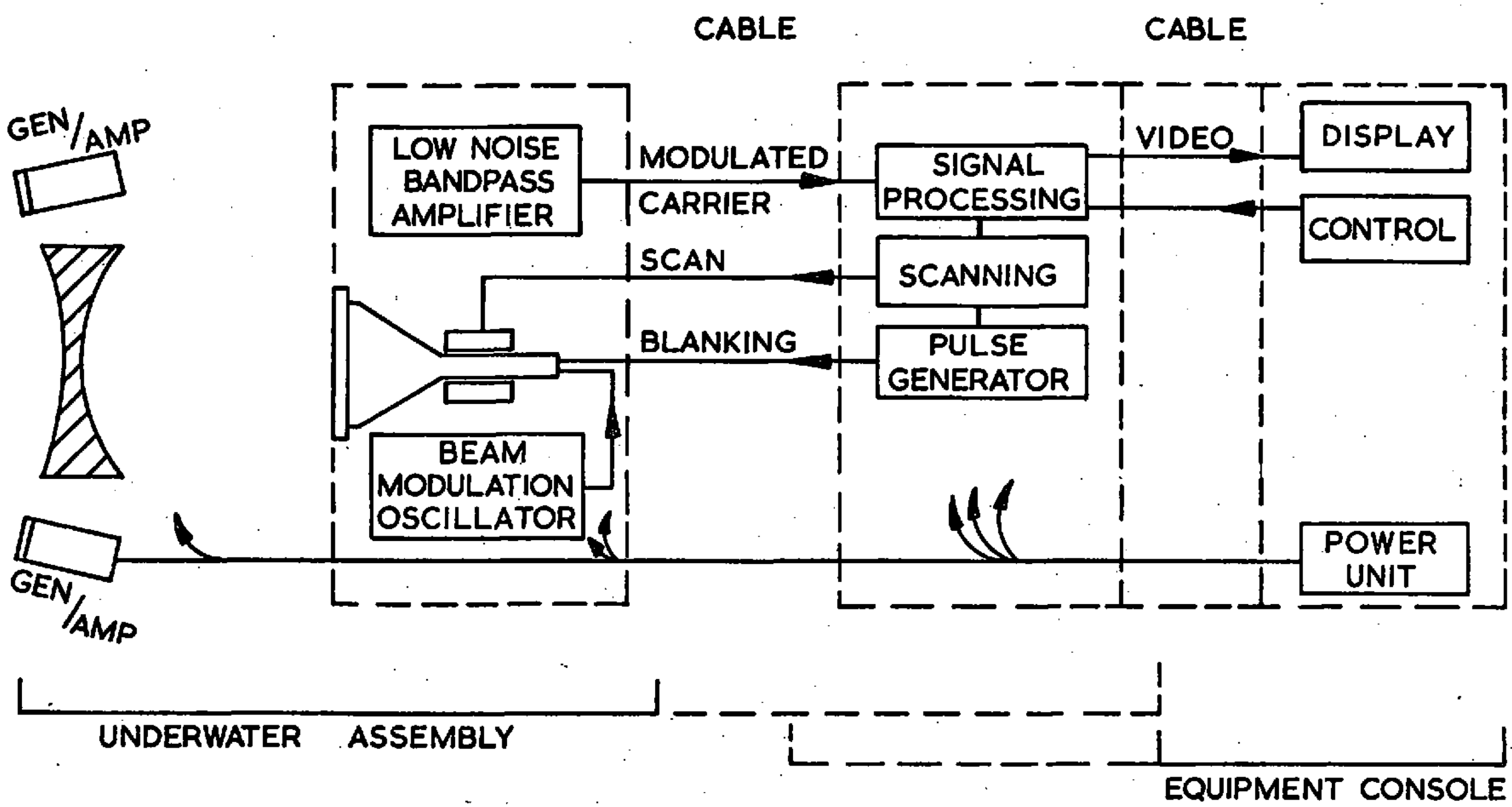


ULTRASONIC IMAGING SYSTEM.

FIG.1



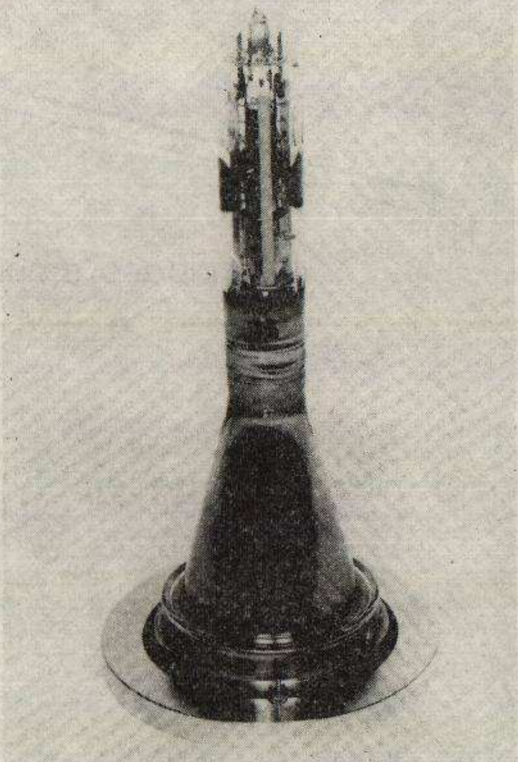
EQUIPMENT SCHEMATIC DIAGRAM

FIG.2

FIG. 3

ULTRASONIC CAMERA FOR IMMERSION TO 300 METRES DEPTH

FIG. 4



ULTRASONIC IMAGE CONVERTER TYPE D 2014

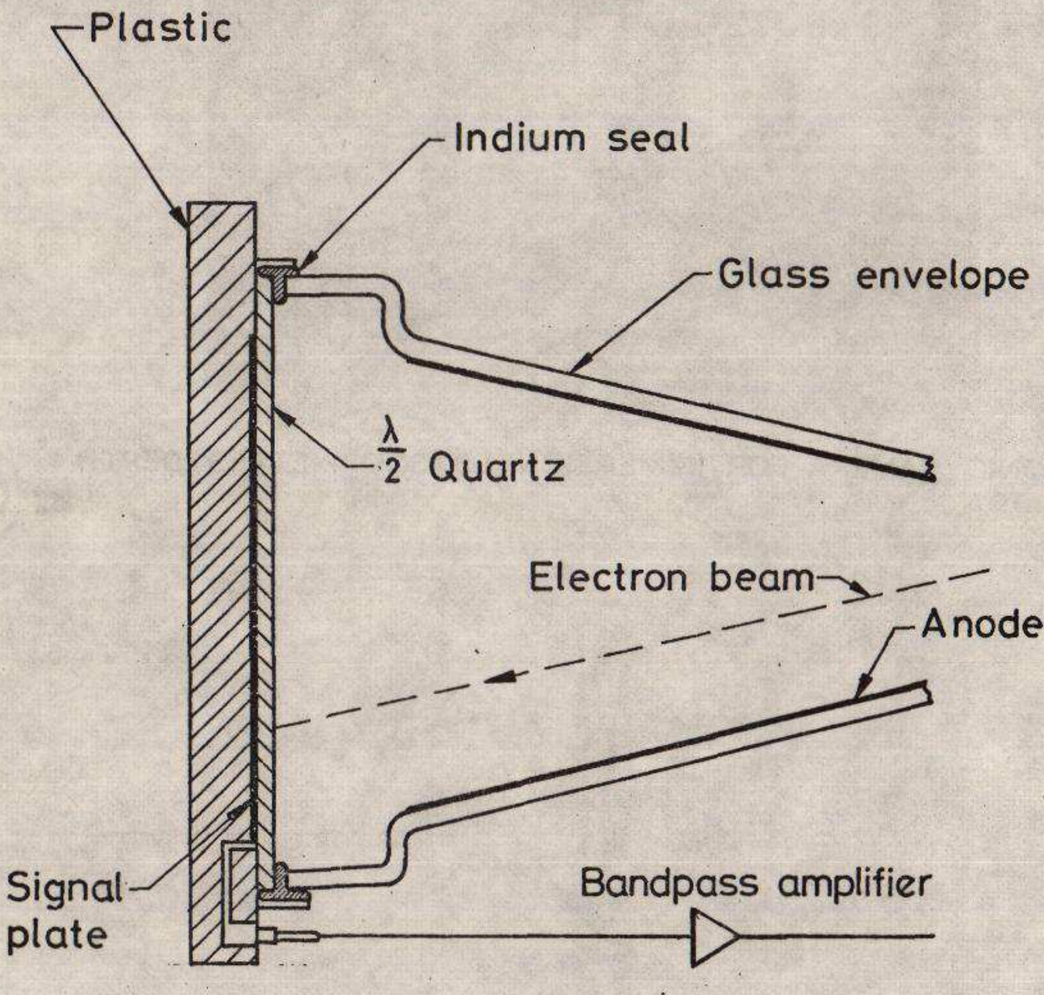
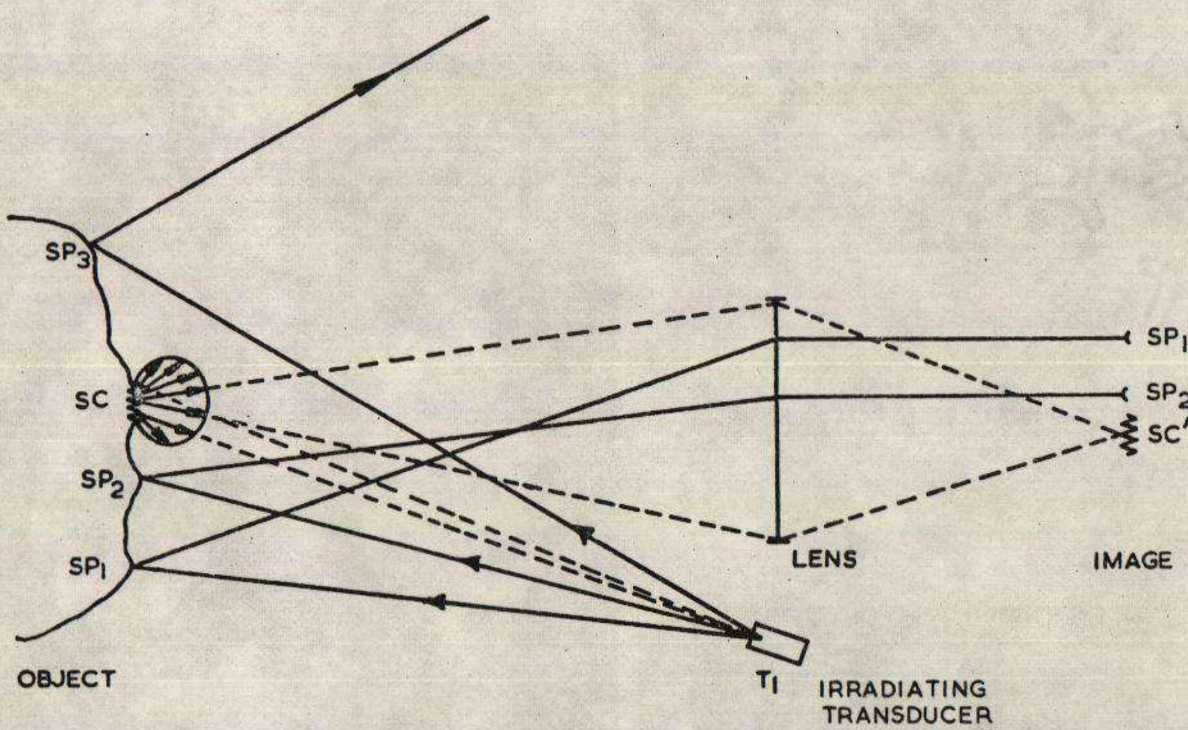


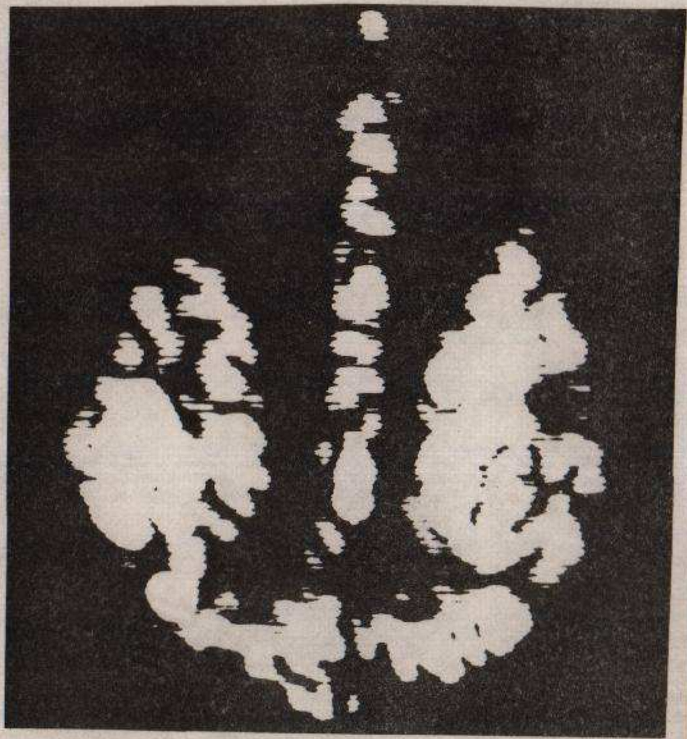
Diagram of faceplate assembly

FIG. 5

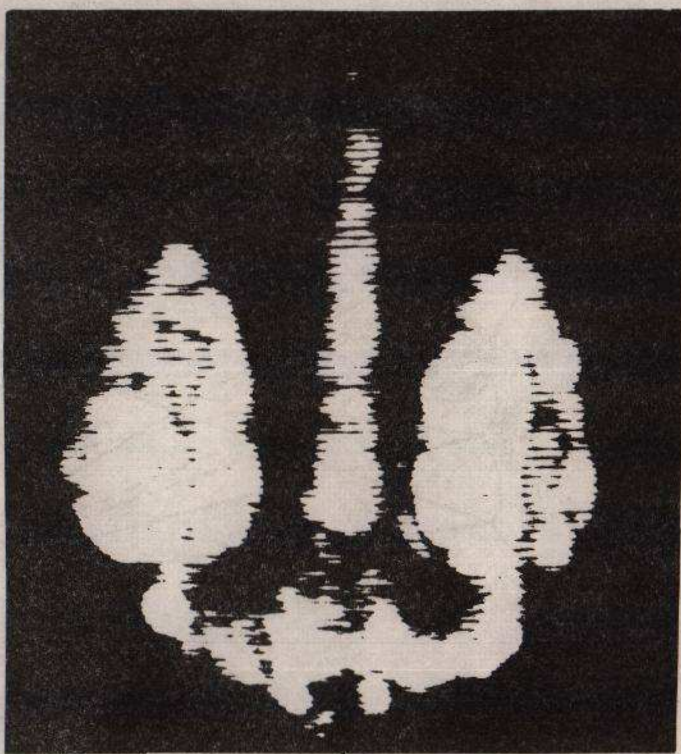


PRODUCTION OF SPECULAR AND SCATTERED IMAGES.

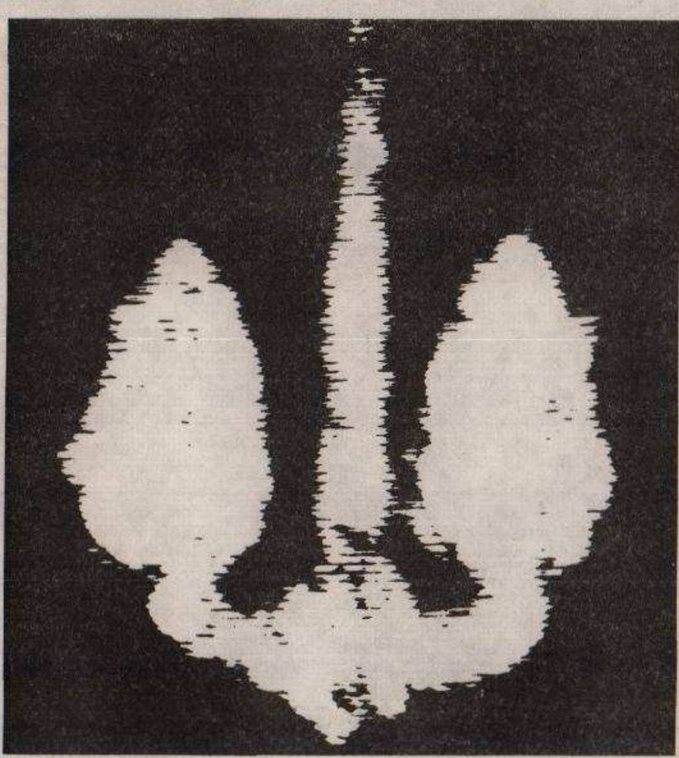
FIG. 6



← 2 MHz

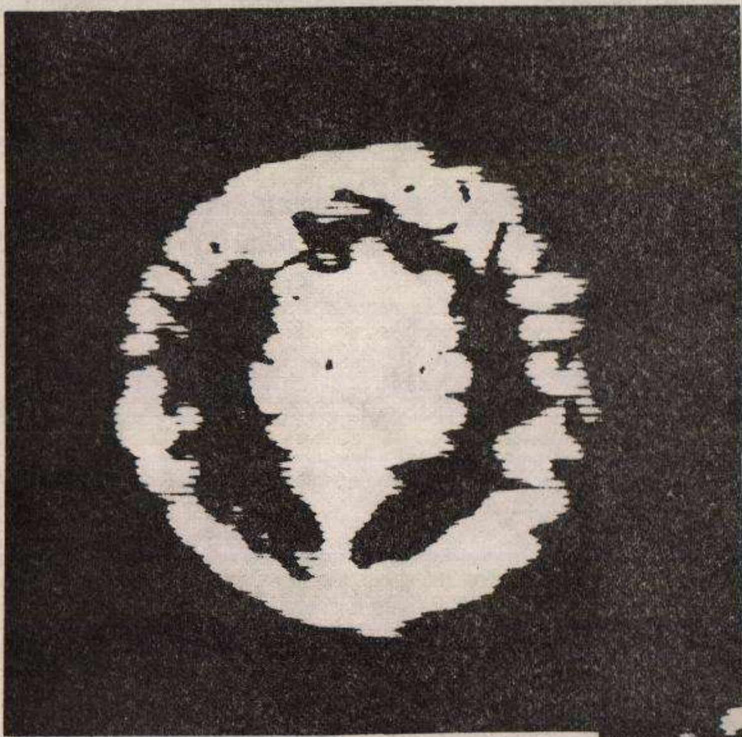


2 MHz ± 100 KHz →

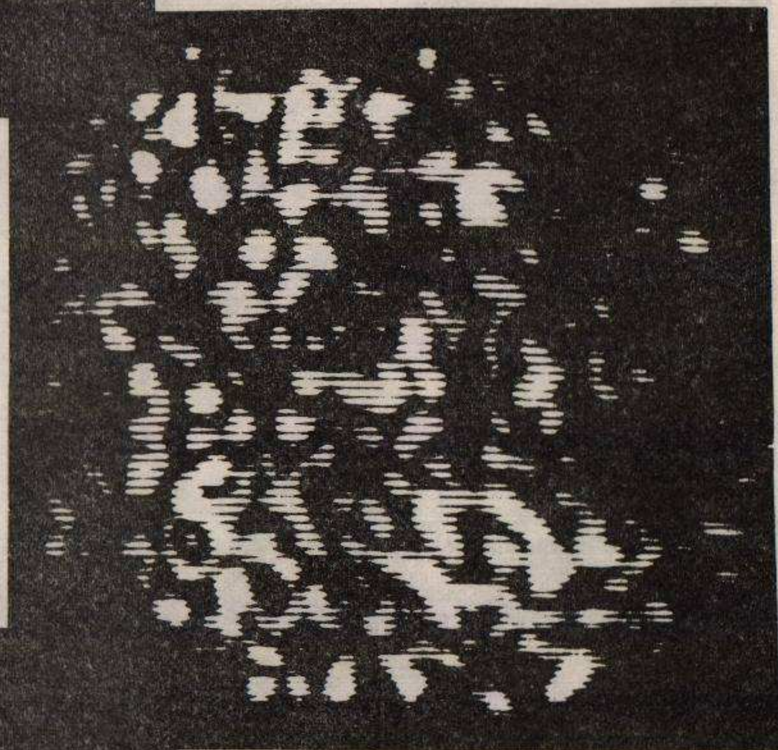


← 2 MHz ± 200 KHz

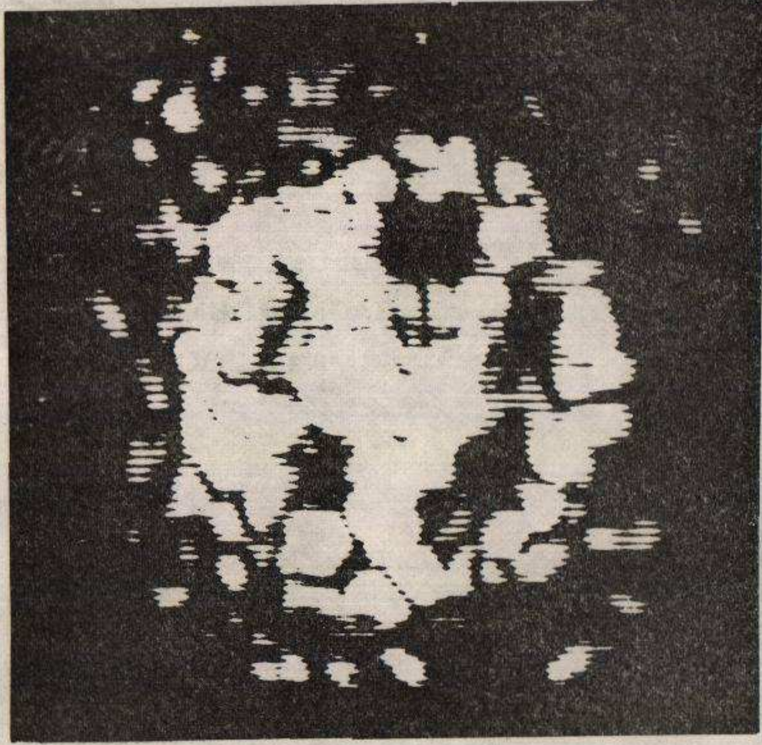
FIG. 7



PULLEY WHEEL
(2MHz)

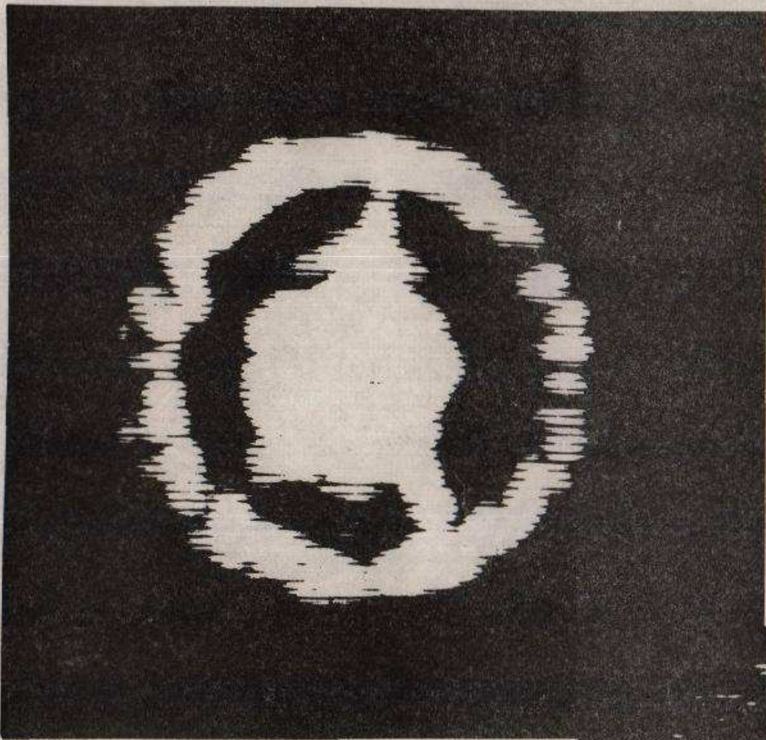


BACKGROUND
(2MHz)

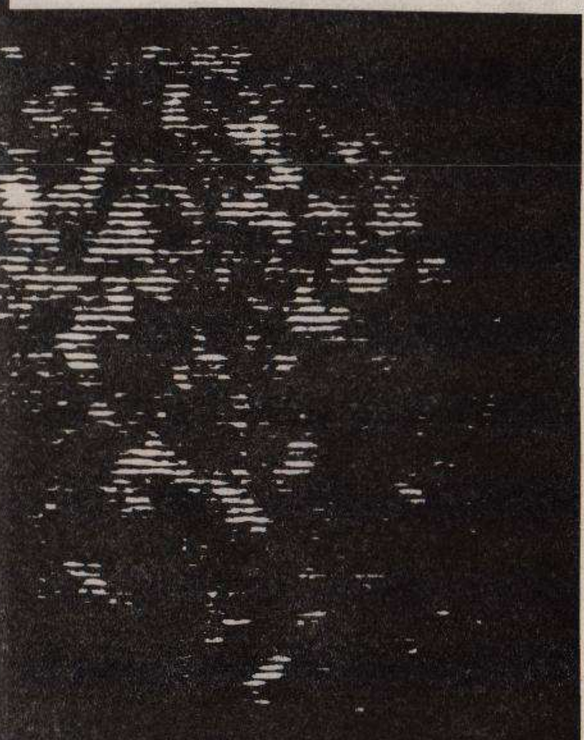


PULLEY WHEEL
WITH
BACKGROUND
(2MHz)

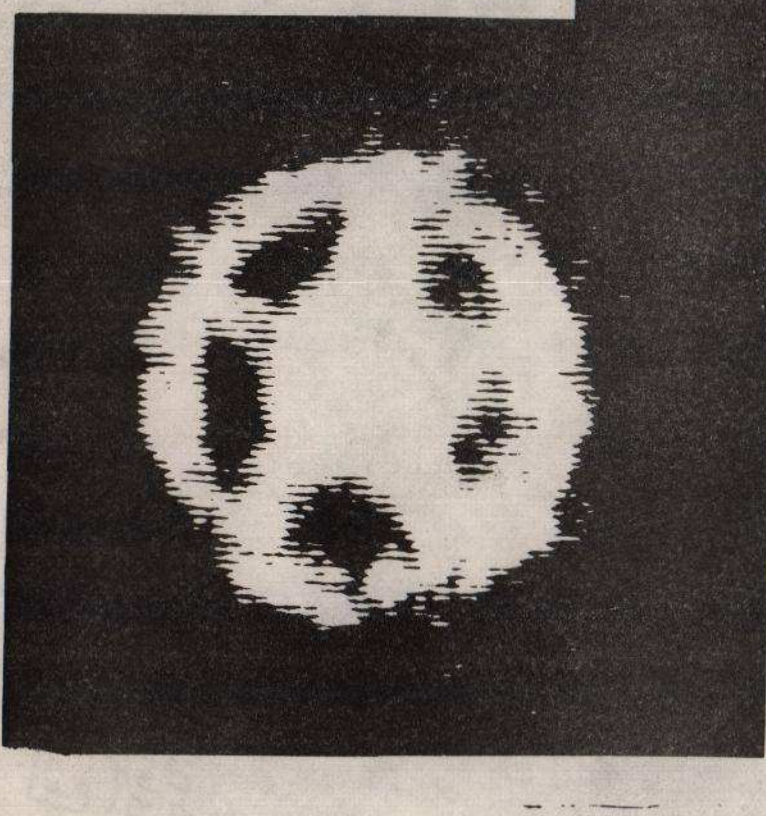
FIG. 8



PULLEY WHEEL
(2MHz ± 200KHz)



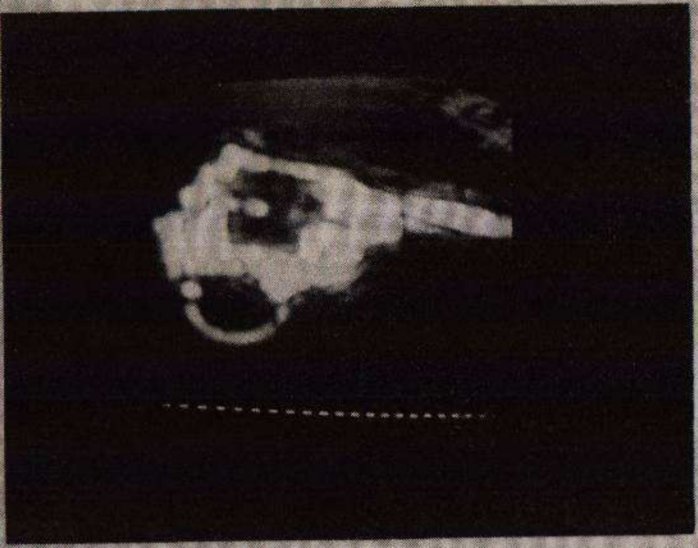
BACKGROUND
(2MHz ± 200KHz)



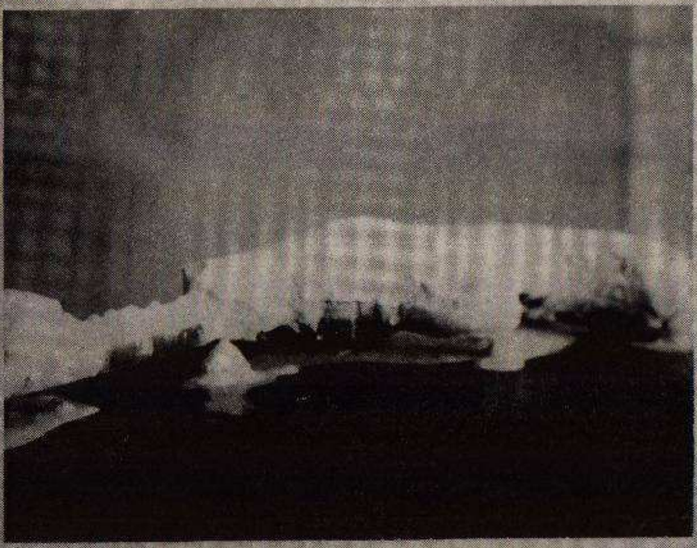
PULLEY WHEEL WITH
BACKGROUND
(2MHz ± 200 KHz)

FIG. 9

OPTICAL IMAGE OF REVOLVER UNDER 10mm OF SILT IN CLEAR WATER



ULTRASONIC IMAGE OF REVOLVER UNDER 10mm OF SILT IN TURBID WATER (2 MHz ± 200 KHz)



SILTED REVOLVER AFTER REMOVAL FROM WATER

FIG. 10