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ACOUSTOOPTIC PULSE-ECHO

TRANSDUCER SYSTEM

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Abstract

A pulse-echo transducer system which uses an ultrasonic generating element and an optical detection technique is described. The transmitting transducer consists of a concentric ring electrode pattern deposited on a circular, x-cut quartz substrate with a circular hole in the center. The rings are independently pulsed with a sequence high-voltage signals phased in such a way that the ultrasonic waves generated by the separate rings superimpose to produce a composite field which is focused at a controllable distance below the surface of the specimen. The amplitude of the field reflected from this focus position is determined by the local reflection coefficient of the medium at the effective focal point. This reflected wave produces both normal and parallel components of particle displacement on the surface of the specimen at the location of the transmitting transducer and a sensitive, wideband optical system not affected by low-frequency background vibration is used to measure the normal displacement through the center hole. By processing the signals received for a range of ultrasonic transducer array focal lengths, the system can be used to locate and size anomalies within solids and liquids. Applications in both nondestructive evaluation and biomedical scanning are suggested.

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I. INTRODUCTION

In many ultrasonic NDE applications, it is important to be able to internally scan a specimen with a well characterized input acoustic field and to detect the resulting output field with a sensitive and calibrated receiving transducer. Conventional pulse-echo systems simplify this process in one sense by taking advantage of the nearly reciprocal properties of some transducer designs, but rarely can the properties of a single transducer simultaneously optimize both input and output performance. In consequence, ultrasonic pitch-catch systems which utilize different input and output devices having specific design advantages can usually be employed for overall better system operation [1]. In this paper, such a hybrid pitch-catch system is considered which uses a concentric ring array acoustic input transducer and an interferometric optical output transducer. The independent operation of each transducer and the combined operation of the entire system is described.

II. FOCUSING INPUT ULTRASONIC TRANSDUCER

Increased resolution in ultrasonic NDE scanning systems may be achieved by appropriately controlling the amplitude and phase profiles of the generated acoustic field. For a piezoelectric transducer, such a field may be passively shaped by altering 1) the geometry of the entire transducer crystal, 2) the piezoelectric coefficient as a function of position on the surface of the crystal, 3) the shapes and/or spacings of individual electrodes which combined form the transducer, or by using 4) external transmitting or reflecting elements to modify the field after it has been launched [2-4]. Passive focusing may similarly be achieved using curved transducer surfaces, proper electrode shapes and spacings, or external acoustic lenses [5,6]. Alternatively, scanning via adaptive focusing can be implemented electronically by phasing the signals which are applied to individual elements in a transducer array [7,8]. Array phasing theory has been well developed in electromagnetics for the case of steady state excitation, but these results must be modified in acoustics to account for spatially localized disturbances associated with pulses or pulse-gated continuous wave signals [9]. Using such a modified approach reported by Hildebrand [10], a focusing piezoelectric input transducer having concentric ring electrodes was designed [11].

The input transducer was fabricated from a circular x-cut, 2.25 MHz crystal quartz substrate 1.81 cm in diameter, with a 1 mm diameter hole drilled normally through the center. Concentric ring electrodes around this hole were constructed on the upper flat surface of the transducer using photographic etching techniques. Electrode widths and spacings were determined by considering the transducer diameter and frequency and the desired focal length and gated pulse length and repetition rate. Individual leads were attached to the electrodes as shown in Figure 1 and a thin layer of non-conducting epoxy around the center hole used to strengthen the lead-electrode bond. Coaxial cables were attached to each lead and the entire transducer potted in a PVC case to provide additional strain relief. The bottom wear plate surface of the transducer served as a ground plane.

To achieve field focusing, fast-rising, high-voltage gated pulses were applied to the correct sequence of electrodes at the proper times. This pulse control was achieved using the circuitry shown in block diagram form in Figure 2. Since the transducer was designed to include as many rings as could be fit on the surface without electrical breakdown occurring between adjacent rings, this circuitry was used to select the ring electrodes necessary to achieve focusing at a particular distance, and to initiate the pulse sequencing to those rings. The microprocessor controls a two step process which involves electrode addressing and pulse timing. Addresses of electrodes identified as necessary to contribute to the focused field at a particular focal distance are first transferred to the tri-state buffer latches. Second, the internal clock provides appropriately phased leading edge signals at low level; these signals are then amplified and applied to the selected electrodes in phase sequence.

Phased switching signals of 425 V amplitude and risetimes of less than 10 ns produce individual shock-excited electrode fields similar to those shown in Figure 3. Superimposed electrode fields produce the focusing field shown in cross-section in Figure 4. Minimum half power beam radii of less than 0.65 mm were obtained at a focal length of 10 cm in water.

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III. OPTICAL DETECTION SYSTEM

The transducer and associated pulsing electronics discussed above are used to generate a selectably focusable acoustic field. If that field is incident upon a bulk material anomaly, part of the reflected and scattered field will propagate back to the transducer and produce a displacement of the free surface of the specimen at the center of the transducer. The normal component of this surface displacement may be detected using the optical Michelson interferometer shown in Figure 5. Here, light from the monochromatic light source is split by the beam-splitter and focused on the surfaces of both the reference mirror and the specimen. The reflected fields are then recombined by the beam-splitter and focused on an optical detector after being spatially filtered by a Ronchi ruling. The normal component of displacement at the center of the hole in the transducer alters the optical path-length of the light in the sample arm, causing a fringe shift in the detected output interference pattern. The detector output is proportional to the amplitude of this displacement [12].

The Michelson interferometer is inherently sensitive to random environmental noise which can mask the small signals created by the surface particle displacements. To eliminate the low frequency noise components, the reference mirror may be mounted on a piezoelectric translation stage rather than a stationary mount [13,14]. This piezo-electric transducer is then fed with an amplified low frequency signal from the detector. Additionally, this feedback correction circuit fixes the gain of the interferometer and may therefore be adjusted to maximize the gain. Although the feedback technique has non-linear stability limitations because the voltage compensation cannot be made infinite, it enables improved system operation in acoustically hostile environments.

IV. EXPERIMENT

The transducer system described above was used to detect a 3.18 mm diameter stainless steel sphere suspended by crossed thread supports in an 80 cm cubic water tank as shown in Figure 6. The sphere was located 10 cm below the center of the bottom of the input ultrasonic transducer which was positioned so it just made contact with the surface of the water in the tank. Under microprocessor control, the transducer varied its focal length from 2.5 cm to 17.5 cm in discrete 1.0 cm steps and the maximum detected optical signal amplitude for each acoustic focus location is shown in Figure 7. The optically detected signal corresponding to an acoustic focal length of 10 cm is shown in Figure 8. Agreement between measured and actual positions of the sphere is better than two percent.

V. SUMMARY

The generation of a focused acoustic field using a pulsed concentric electrode array transducer has been examined. The focusing phenomena is based on the geometric superposition of the pulsed fields from each of the rings at the position and time where and when the fields interact. The focused field may be used as a point probe to interrogate internal media structure which enables the tomographic reconstruction of the acoustic impedance field of the medium.

Internal media reconstruction is possible because the amplitude of the reflected field is determined by the local reflection coefficient of the medium. Variation in this reflection coefficient distribution due to material anomalies causes a field amplitude variation which may be used to infer local structure. The feedback stabilized optical receiving transducer detects the normal component of surface displacement which results when the reflected field reaches the surface. The system has applications in both biomedical scanning and the characterization of solid material specimens.

VI. ACKNOWLEDGEMENTS

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Bibliography

[1] W. Sachse and N. N. Hsu, "Ultrasonic transducers for materials testing," Physical Acoustics, Vol. 14, W. P. Mason and R. N. Thurston, eds. New York: Academic Press, 1979.

[2] A. D. Vopilkin, et. al., "Wide-band ultrasonic transducer and its uses," United States Patent #3968680, July 1976.

[3] F. D. Martin and M. A. Breazeale, "A simple way to eliminate diffraction lobes emitted by ultrasonic transducers," J. Acoust. Soc. Am. 49, 1668 (1971).

[4] P. S. Zerwekh and R. O. Claus, "Ultrasonic transducer with Gaussian radial velocity distribution," Proc. IEEE Ultrasonics Symposium 2, 974 (1981).

[5] G. W. Willard, "Focusing ultrasonic radiators," J. Acoust. Soc. Am. 21, 360 (1949).

[6] H. T. O'Neil, "Theory of focusing radiators," J. Acoust. Soc. Am. 21, 516 (1949).

[7] A. Freedman, "Transient fields of acoustic radiators," J. Acoust. Soc. Am. 48, 135 (1970).

[8] P. R. Stephanishen, "Impulse response and radiation impedance of an annular piston," J. Acoust. Soc. Am. 56, 305 (1974).

[9] Y. A. Kondrat'ev, "Pulsed operation of a focusing piezoelectric transducer," Soviet J. of Nondestructive Testing 14, 688 (1978).

[10] B. P. Hildebrand, "An analysis of pulsed ultrasonic arrays," in Acoustical Holography, Vol. 8, A. F. Metherell, ed., New York: Plenum Press (1980).

[11] J. C. Wade and R. O. Claus, "Interferometric pulse-echo ultrasonic transducer system," J. Acoust. Soc. Am. S1, 71, S109 (1982).

[12] C. H. Palmer, "Ultrasonic surface wave detection by optical interferometry," J. Acoust. Soc. Am. 53, 948 (1978).

[13] C. H. Palmer and R. E. Green, "Optical detection of acoustic emission waves," Appl. Opt. 16, 2333 (1977).

[14] R. A. Kline, R. E. Green, and C. H. Palmer, "A comparison of optically and piezoelectrically sensed acoustic emission signals," J. Acoust. Soc. Am. 64, 1633 (1978).

Figure Titles

Figure 1. Piezoelectric ring array transducer electroding and construction.

Figure 2. Adaptive transducer focusing electronics.

Figure 3. Acoustically detected response (top) of one transducer ring due to computer-timed electrical pulse (bottom).

Figure 4. Acoustically measured crossection of focused transducer field. Half power points are plotted.

Figure 5. Optical detection of reflected acoustic field.

Figure 6. Experimental system for detection of 3.18 mm diameter stainless steel sphere.

Figure 7. Optically detected surface displacement caused by acoustic wave reflected from stainless steel sphere in water.

Figure 8. Time domain signal produced by optical detector for system focal length of 10 cm.

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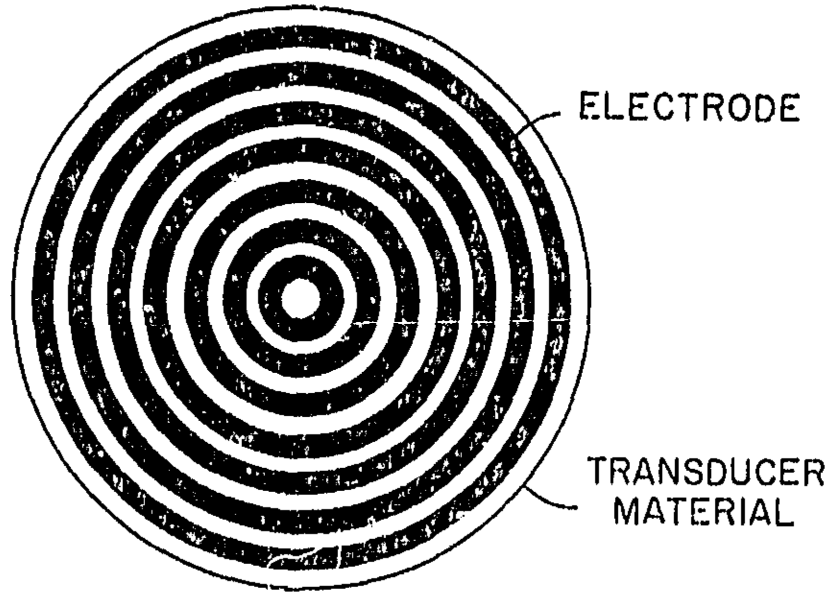

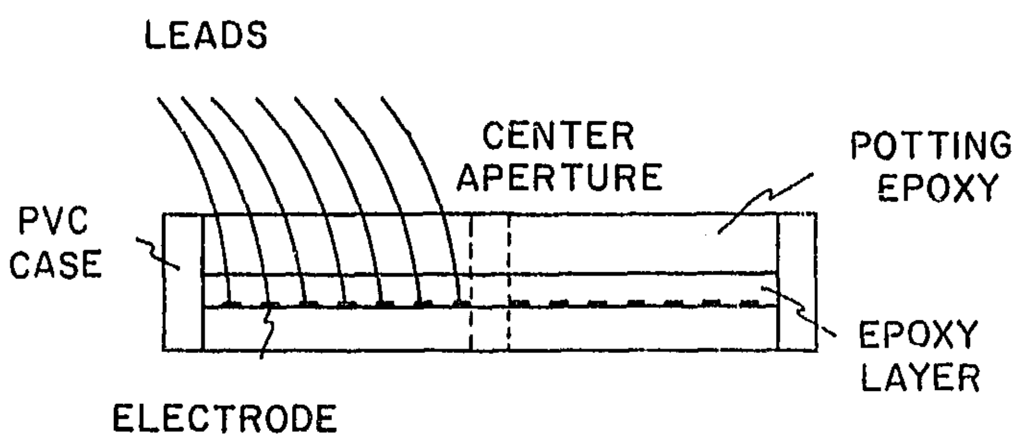

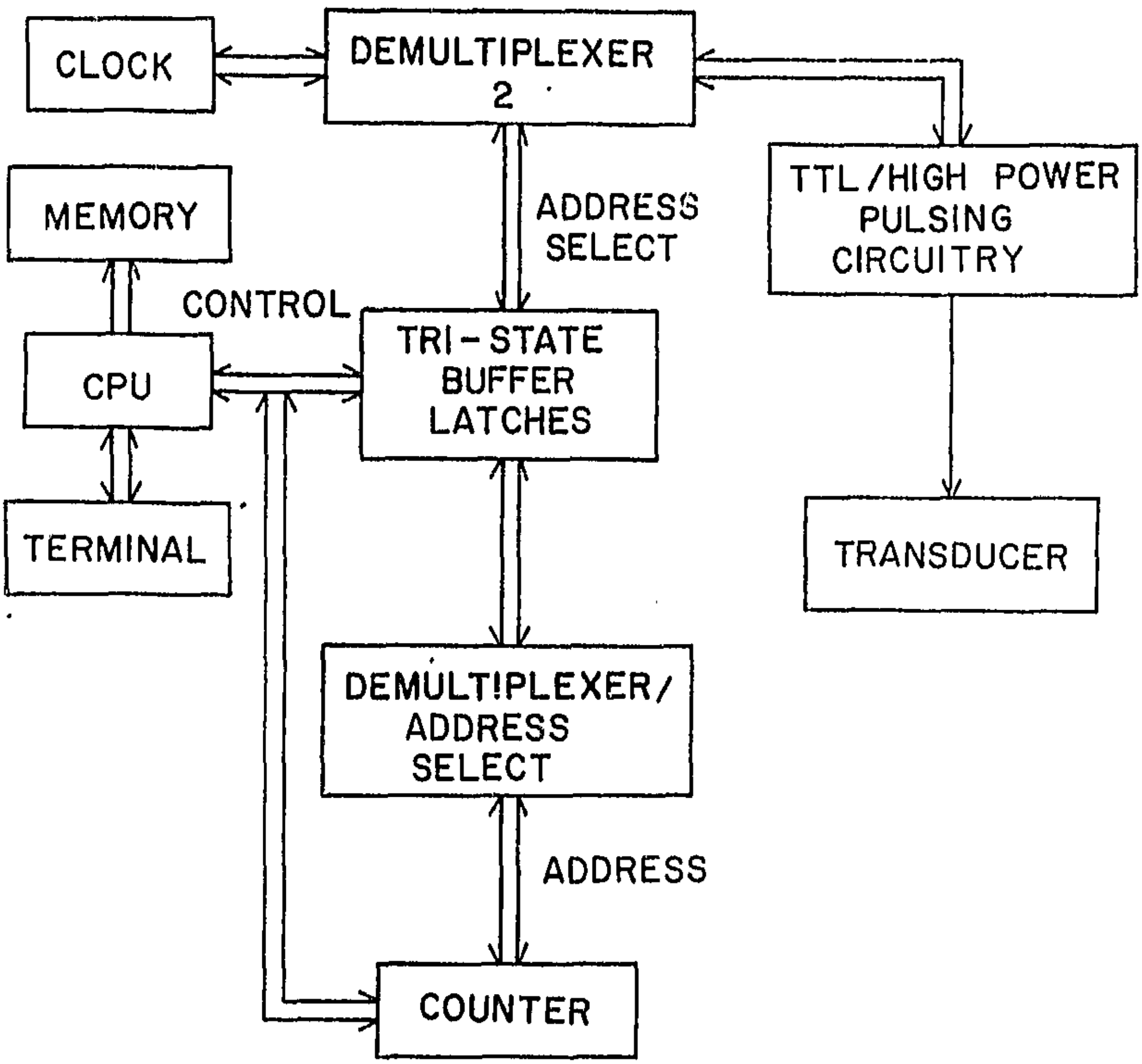
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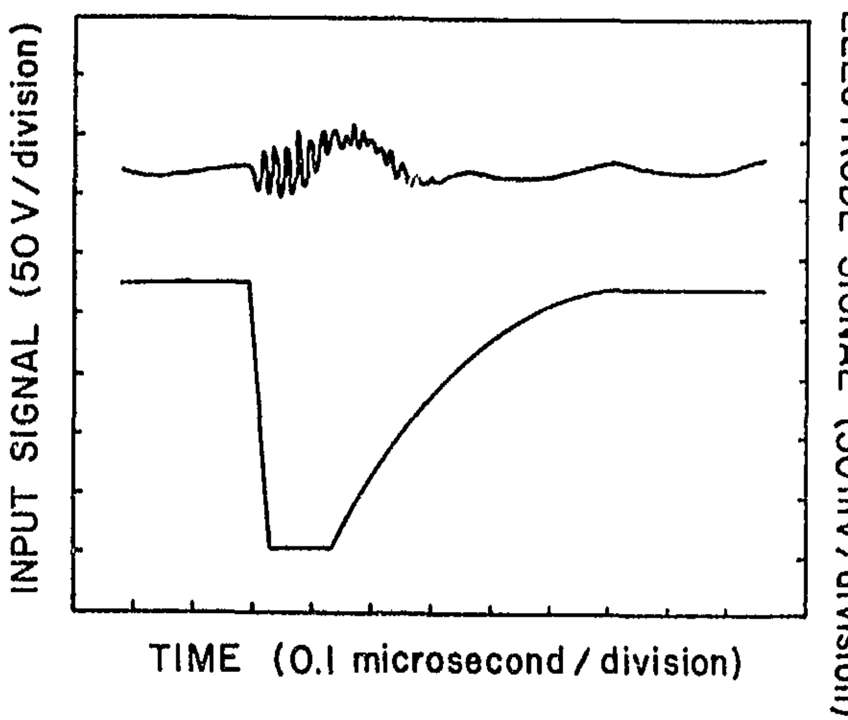
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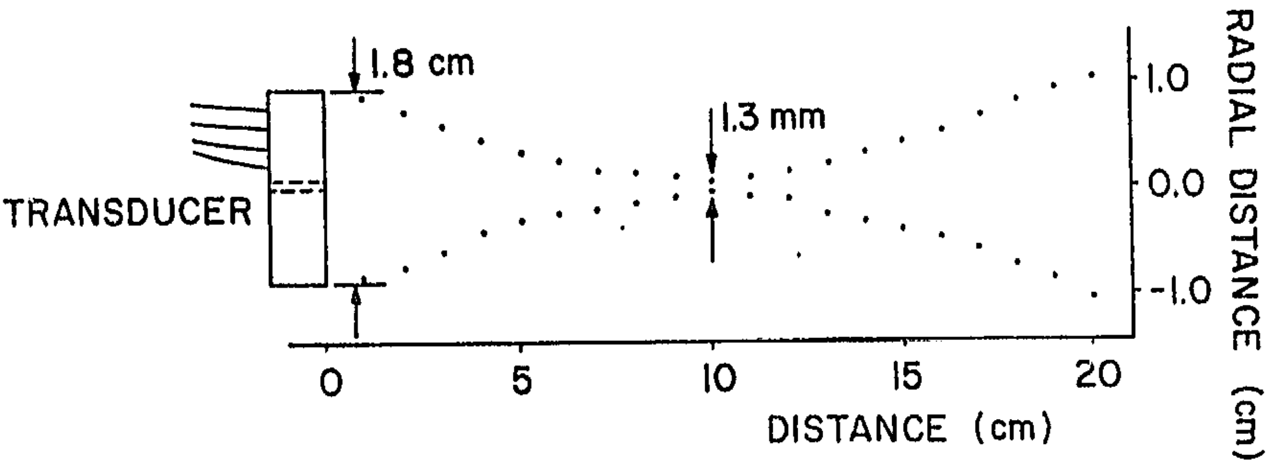
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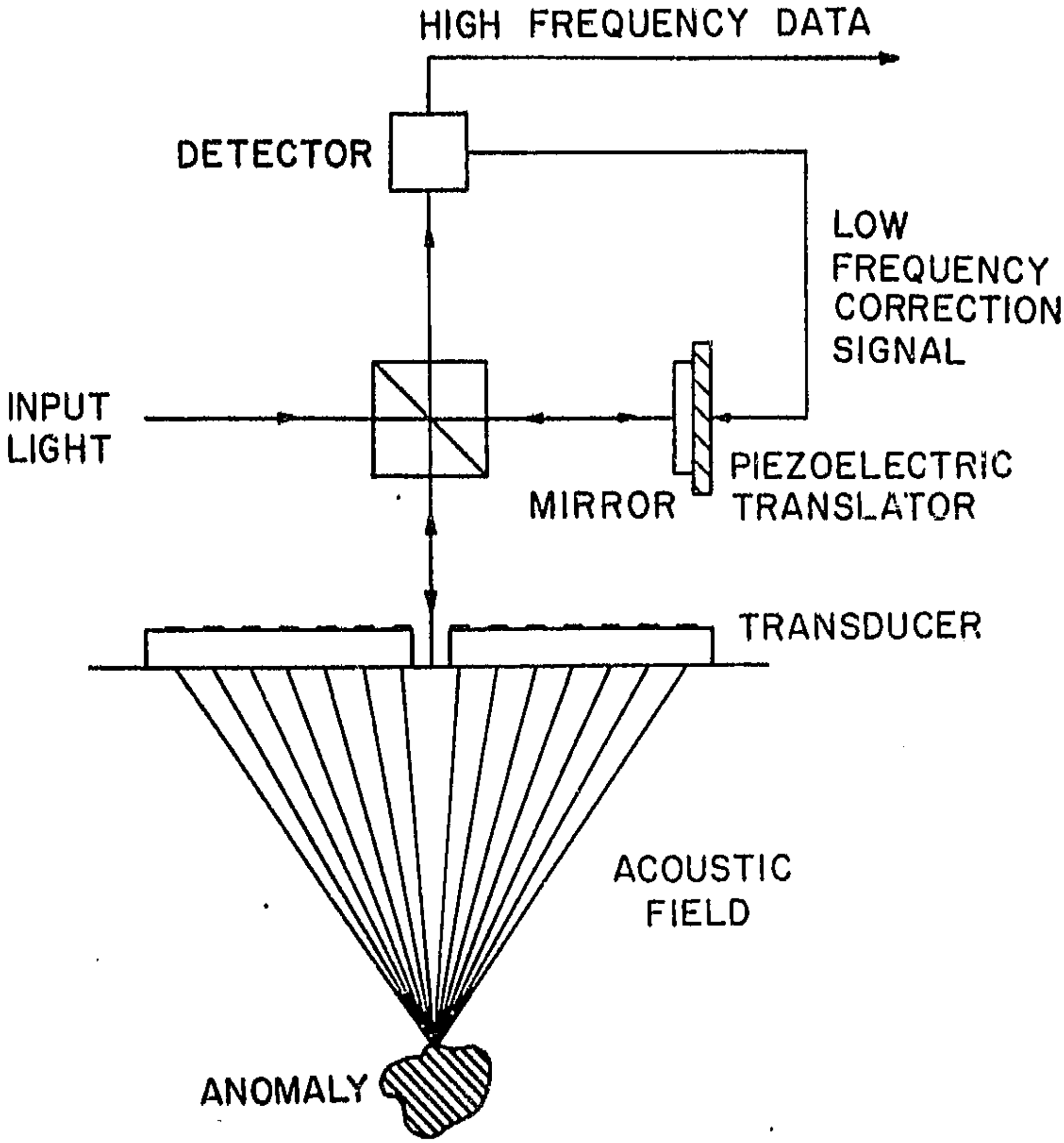
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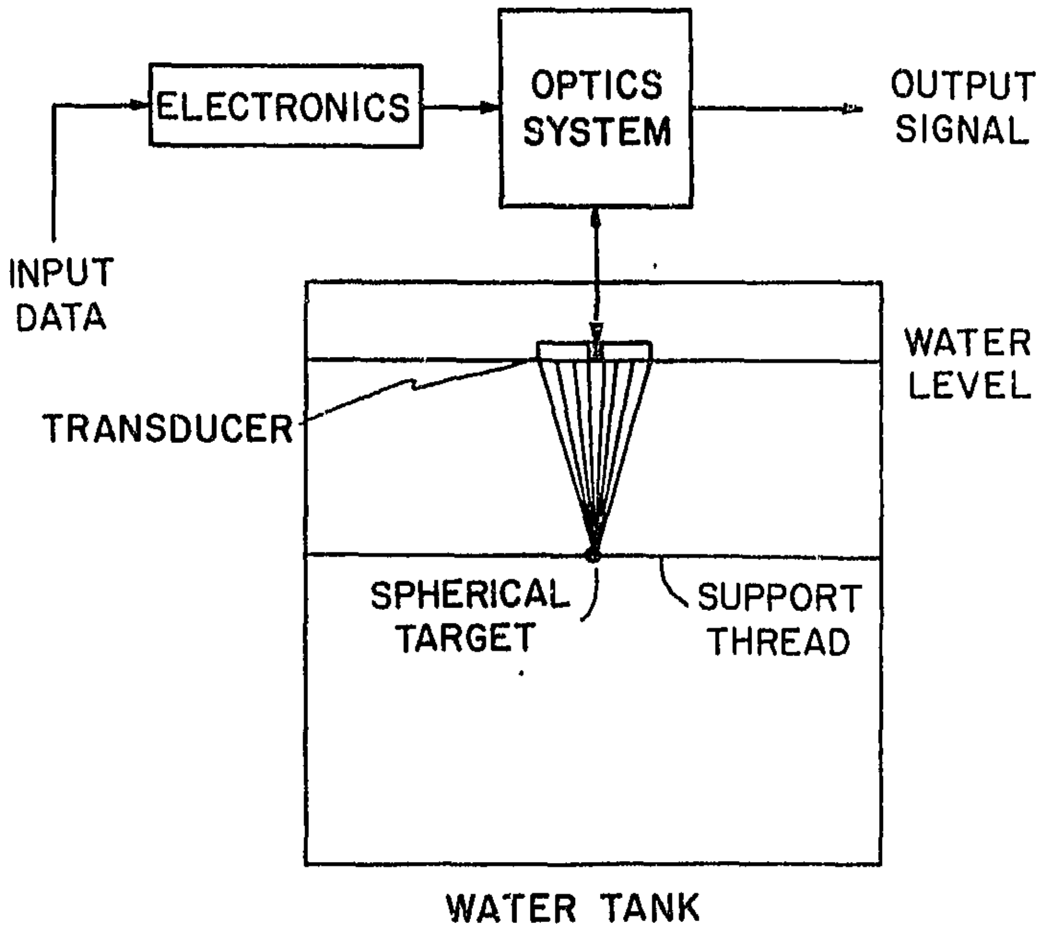
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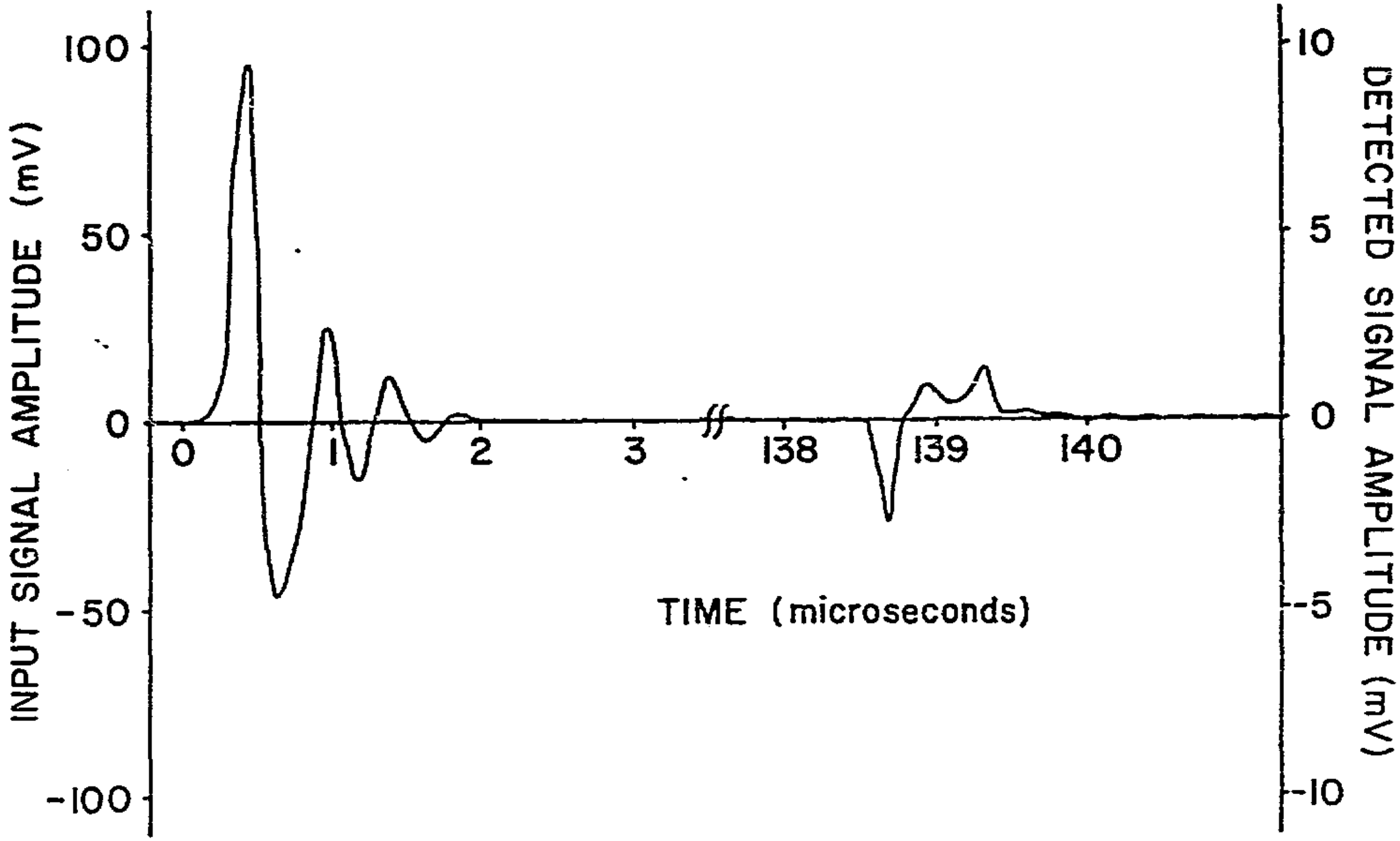
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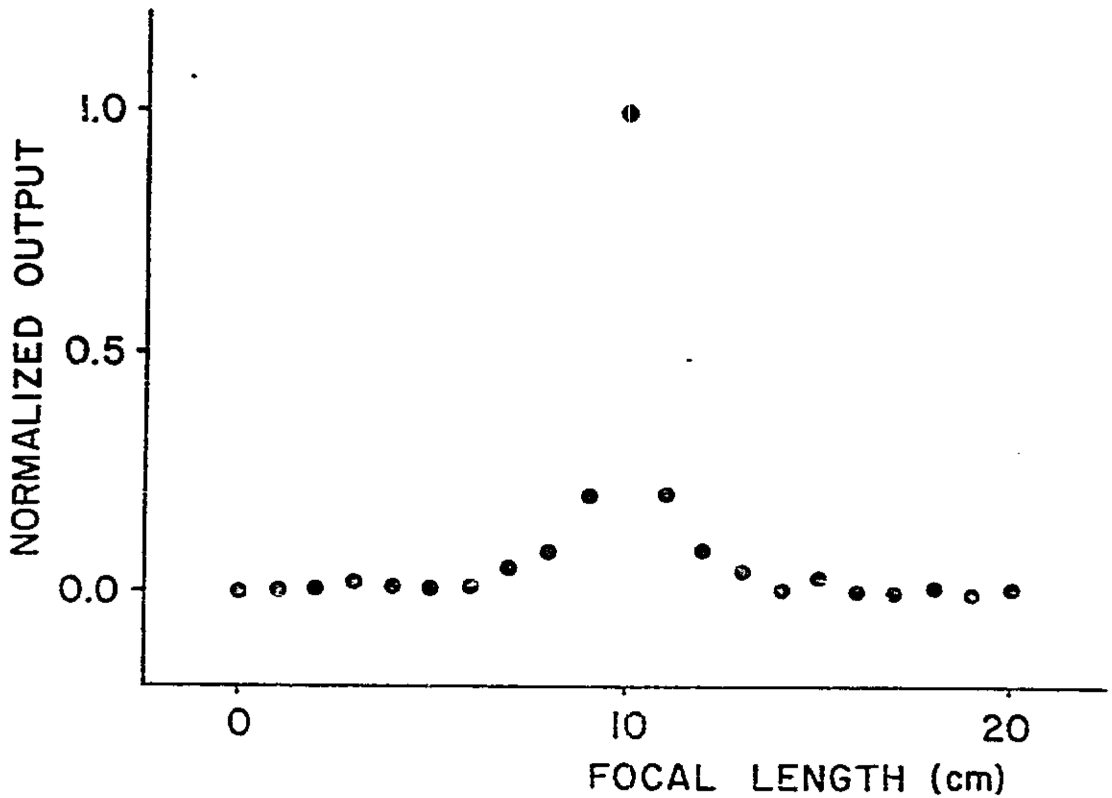
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