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A COMPUTER-AIDED ULTRASONIC IMAGING SYSTEM

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ABSTRACT

A preliminary version of an ultrasonic imaging system with capability of two dimensional coherent data processing and computer image processing has been built and tested. The system consists of two parts: data acquisition, and computer processing and display. The data acquisition system detects and records the coherent ultrasonic diffraction pattern emitted from or reflected by an object. This pattern is then quantized and entered into the computer memory. The computer portion processes the data and displays the resulting image on a high resolution computer controlled graphics terminal. The use of coherent detection offers advantages in that coherent processing techniques as well as incoherent techniques can be used to obtain an optimal image. Such operations as matched filtering, removal of the receiver transducer's directivity pattern, edge enhancement, etc. are easily performed. Applications of the system to ultrasonic imaging, acoustic transducer calibration and studies of scalar wave propagation will be discussed.

INTRODUCTION

Inverse diffraction[1-3] was suggested as an imaging technique about ten years ago. In this technique, an

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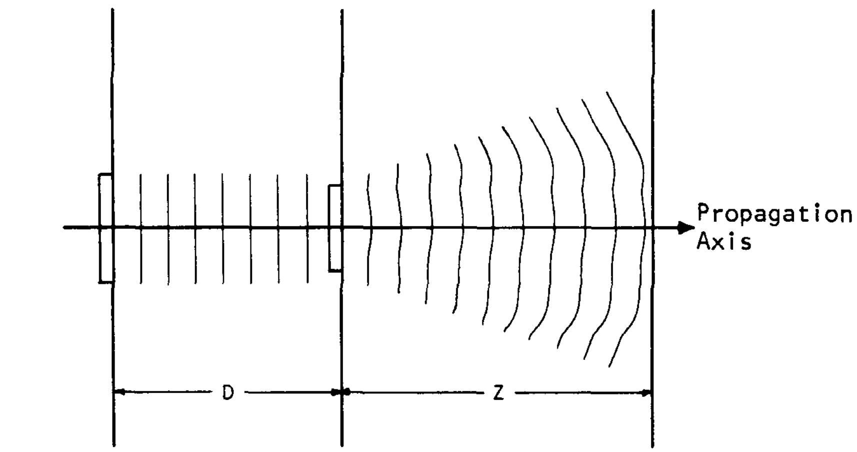


Fig. 1 Relative locations of the transducer, object and diffraction planes for a transmission system.

object (Fig. 1) is insonified by a transducer and the transmitted (or reflected) wave is detected coherently (i.e., both amplitude and phase) in some portion of a diffraction plane located an arbitrary distance Z away from the object. Detection of the complex wave by a linear detector can be accomplished in a variety of ways: a two-dimensional matrix of detector elements, a sweep of a linear array of elements, or a raster scan of a single receiver. Piezoelectric receiving elements offer an ideal combination of linearity and sensitivity[4] for this application. After wave detection, the amplitude and phase of the wave can be sampled, digitized and placed in a computer memory. By programming the inverse diffraction equations[5], the computer can 'propagate' the waves backward in space and at the distance Z from input plane an image of the object will be found. Such a computer aided technique combines the advantages of acoustic linear detection with the rapidly expanding technology of computer memory, manipulation (such as array processors) and display. Because of the relatively long acoustic wavelengths, a meaningful image can be produced from an amount of data that is relatively manageable in terms of storage and processing. Recent advances in solid state memory and fast processing hardware and software also will further alleviate this data handling requirement. Computer aided acoustic imaging also allows one to simultaneously apply many of the recent advances in image processing to the acoustic images. Such techniques can improve signal-to-noise ratios, improve resolution, or help recognize features, for example.

Having previously demonstrated some of the concepts of inverse diffraction imaging with computer simulated objects[6], we have built a system that can provide real acoustic data to test the technique. It is the purpose of this paper to present this system and our first results. The scope of the imaging system work at the Naval Postgraduate School (NPS) is to provide a research vehicle to investigate a variety of computer aided imaging techniques rather than building a prototype of a working system. The NPS system consists of two parts: a data acquisition section and the computer processing and display section. The computer section uses the large scale computing facilities at NPS as well as some of the graphic display systems of the Computer Science Laboratory. No special attempt has been made to maximize the speed or efficiency of the system or to build a dedicated system. Emphasis instead has been placed on operational flexibility to investigate various geometries and processing techniques.

DATA ACQUISITION

The purpose of the data acquisition section is to record (on an instrumentation tape recorder) the amplitude, phase and receiver X-Y position information for subsequent digitization and formatting for entry in a computer. Figure 2 shows a block diagram of the system. An insonifying transducer, object and receiving probe are placed in an echo-free test tank. Figure 3 shows a typical source (and mounting) and a receiving point transducer. The source is a 2" x 2" (5.08 cm x 5.08 cm) gold coated quartz transducer operating at 1 MHz; the receiver is a .04" (1.01 mm) diameter PZT-5 ceramic receiver with a fundamental frequency of 1.014 MHz. The position of the receiving element is controlled by a precision X-Y screw system under electronic control that generates the X-Y raster sweep. (Modification of this control allows variation in the sweep geometry.) The position of the receiver in the raster is recorded by the generation of position marks every half wavelength. Electronics have been designed and added to system to count the number of

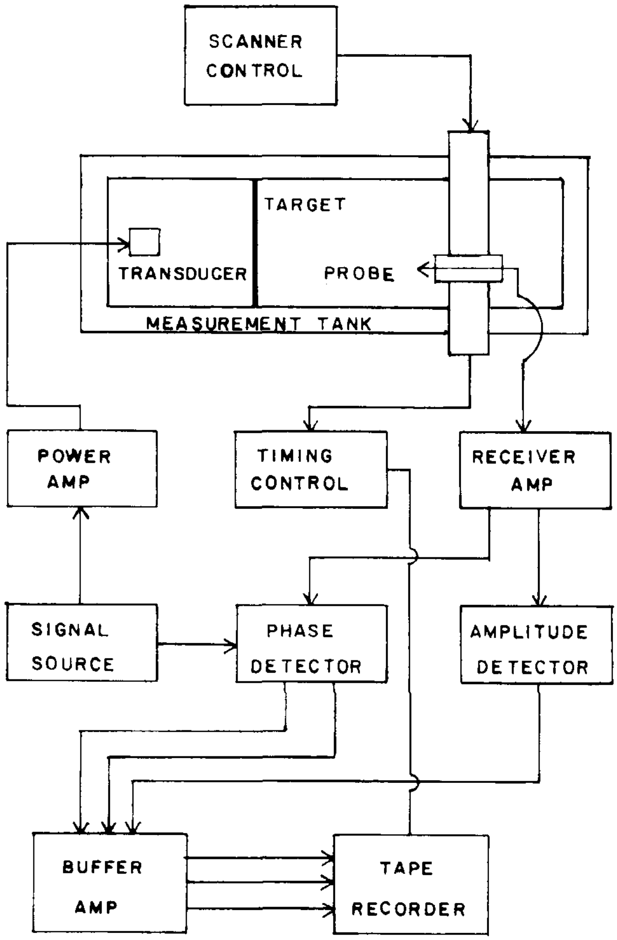


Fig. 2 Acquisition system block diagram.

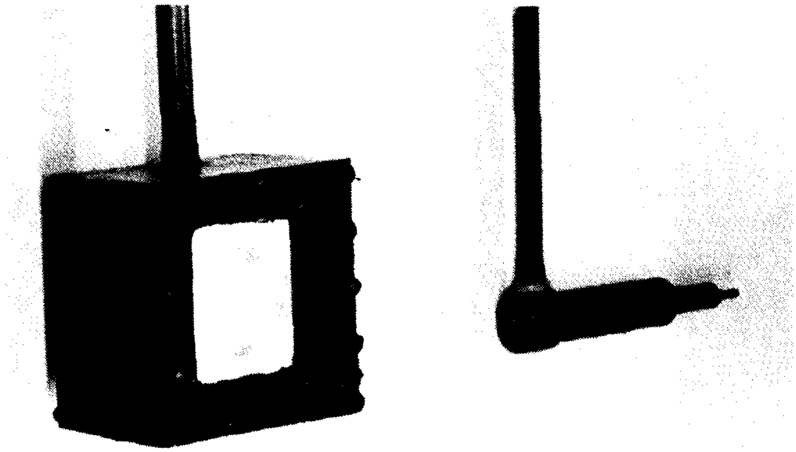


Fig. 3 Source (A) and receiving transducer (B)

samples per row, the number of rows, and automatically ensure precise vertical alignment of the position locations. The position pulses are later used in the digitizing process to trigger the sampling of this amplitude and phase channels so precise alignment of the position locations is crucial to the success of the technique.

The complex signal received by the linear detector is detected, preamplified and split into two: one portion for the amplitude detection circuitry and the other for the phase detection circuits. Following detection, the analog amplitude and phase information and the position location pulses are recorded on an instrumentation tape recorder. The amplitude detector (Figure 4) is primarily two 30 dBV log amps whose combined characteristics cover the 60 dBV dynamic range observed in representative amplitude data. Figure 5 shows the overall characteristics of the amplitude detector with a slight discontinuity in the slope observed between -20 and -30 dBV where the log amp stages transition into each other. Software processing can easily correct for this discontinuity once the data is in the computer.

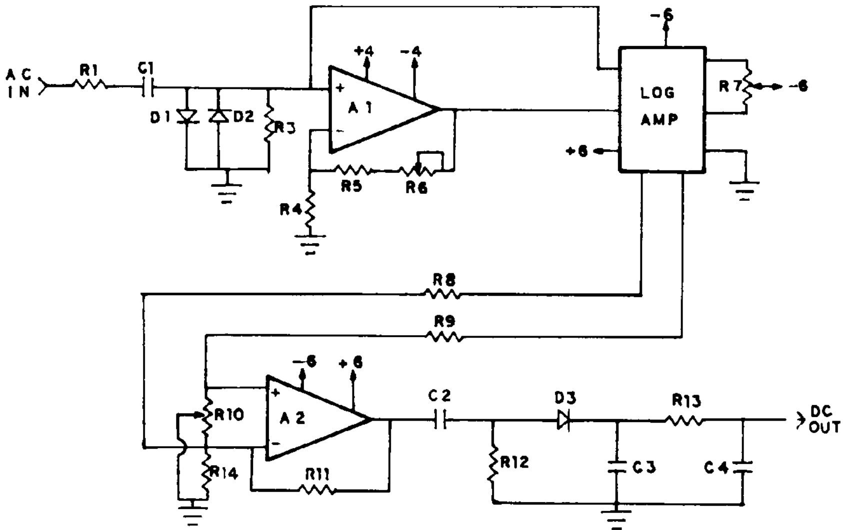


Fig. 4 Amplitude detector circuit

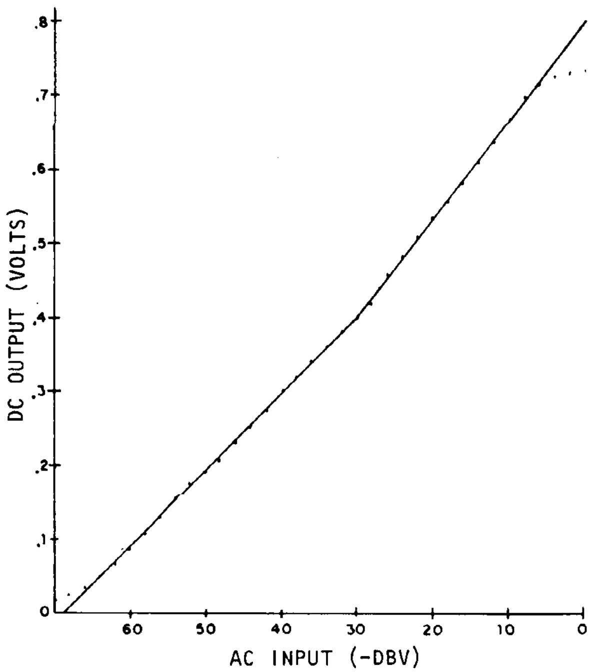


Fig. 5 Transfer characteristic of the amplitude detector

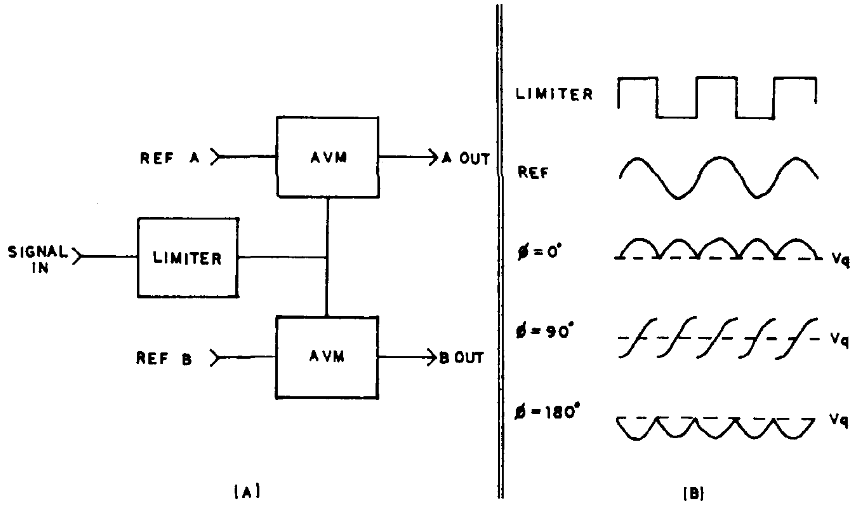


Fig. 6 Phase detector: (A) block diagram; (B) output for various phase relationships

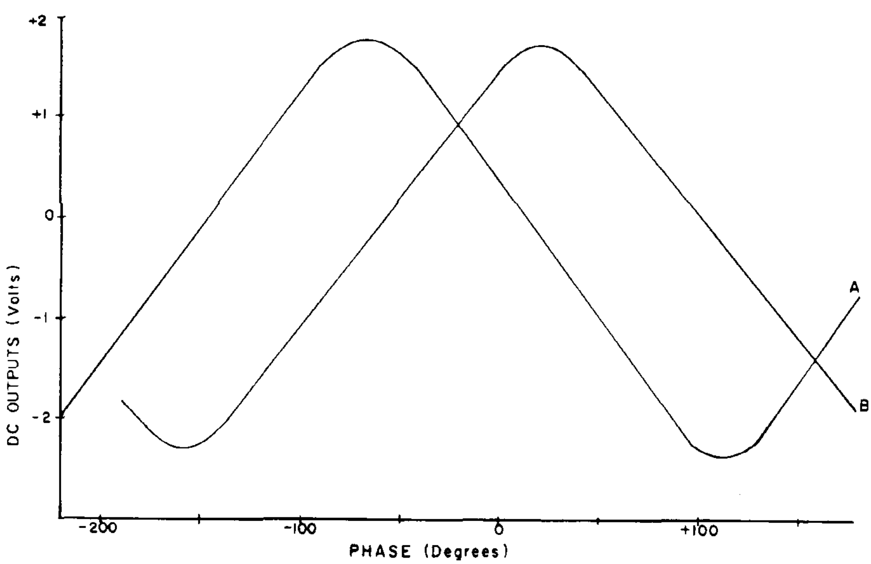


Fig. 7 Experimental phase detector characteristics (channels A and B)

Two forms of phase detector have been built and tested. The first (of lesser accuracy) uses analog voltage multipliers to determine the phase. As shown in Figure 6, two multipliers are required to obtain unambiguous phase information over a full 0 - 360° range. Signals 'REF A' and 'REF B' are quadrature signals obtained from the source.The variable amplitude input signal is limited (in our circuit with a phase lock loop and comparator) to produce a constant amplitude square wave that carries the phase information of the input signal. As shown in the right of Fig. 6, the dc component of the product of the square wave and the reference indicates the relative phase of the input signal. Low pass filtering of the output of the multipliers provides a phase detected signal. Figure 7 gives the experimental transfer characteristics of the phase detectors. Since curves A and B are not quite sin and cos curves (especially in the peaks and troughs and in the fact that they are not exactly 90° out of phase), some phase errors (±3°) were encountered near the peaks and troughs. Consequently, a commercial integrated circuit phase detector with linear characteristics as shown in Figure 8a was used for our second phase detector. Two quadrature phase detector circuits having characteristics as shown in Figure 8b can be combined to produce an overall phase transfer function of Figure 9. This circuitry is presently being implemented. The phase voltage is then also recorded in analog form for subsequent digitizing.

COMPUTER PROCESSING AND DISPLAY

The sampling, A/D conversion, and formatting of the computer compatible tape was done on a XDS 9300 computer combined with a CI 5000 analog computer. Large blocks of data would be processed on the large IBM 360 computer while image display and simple processing are done on a dual PDP-11/50 computer system driving an interactive Ramtek CX-100A color display terminal (Figure 10). Early work has generated a basic interactive display capability, while further work is required to develop more software for processing and display. Additionally, the present display has a limitation of 16 gray scales (although many pseudocolor schemes are possible).

TEST RESULTS

The data acquisition system has been completely electronically tested and calibrated producing the

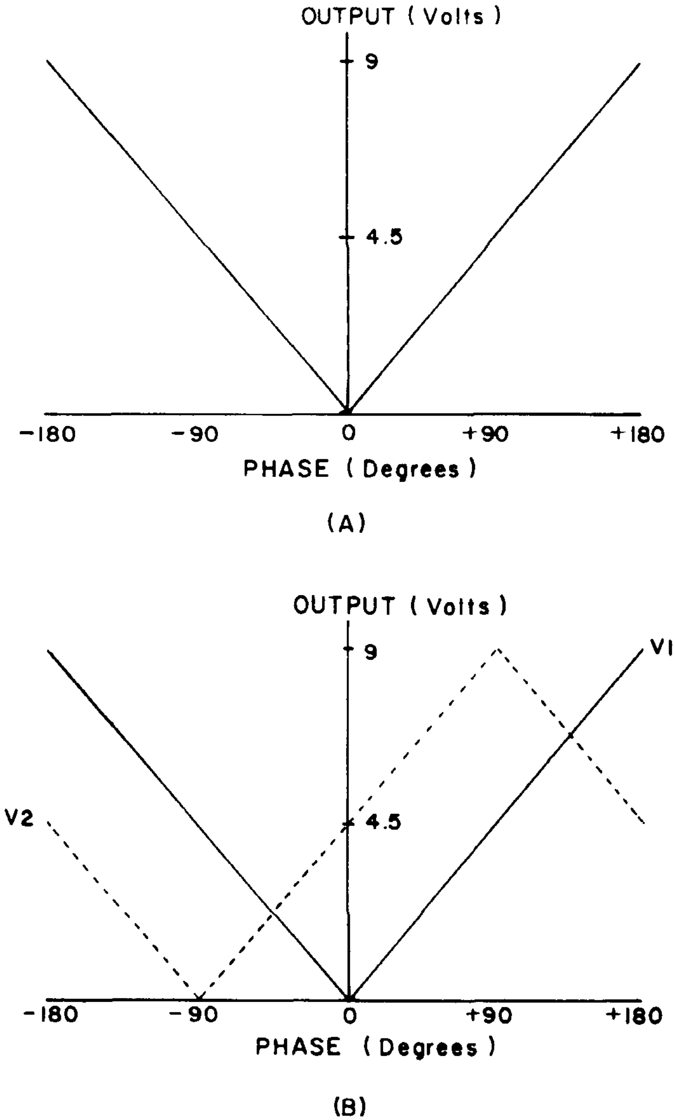


Fig. 8 (A) Transfer characteristics of commercial integrated circuit phase detector;
(B) Quadrature outputs from two channels

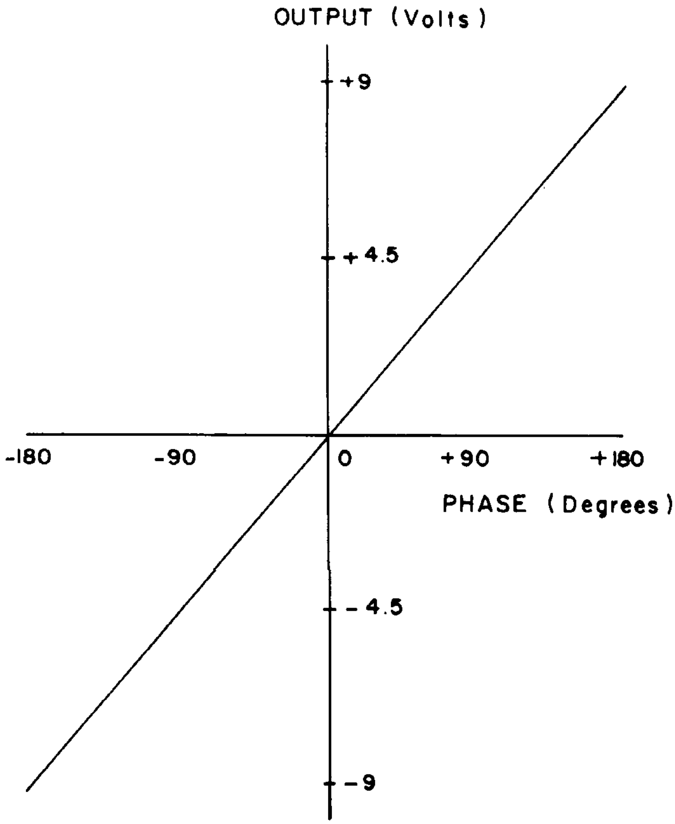


Fig. 9 Phase transfer function after combination of quadrature outputs

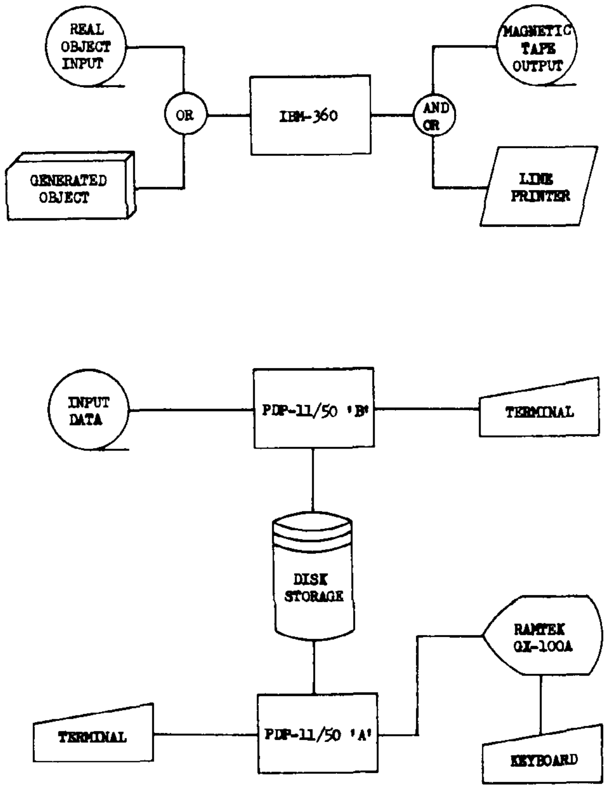


Fig. 10 Block diagram of computer processing system

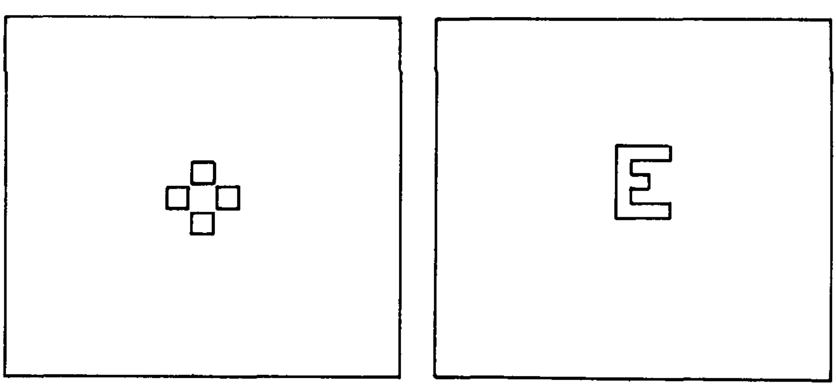
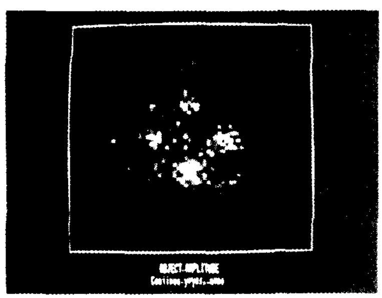


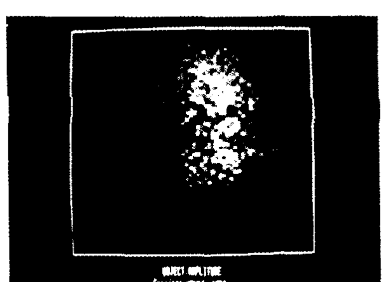
Fig. 11 Test object shapes

transfer characteristics of Figures 5 and 7. Calibration points were provided by HP 3575A gain-phase meter. The data was also found to be reproducible. Building vibrations were found to be an important source of phase noise while the tape recorder also produced noise (20-50 mV) which is bothersome in detecting some of the weaker value of signals although still within the specifications of the tape recorder used. Attenuation measurements of various materials have helped in the design of the test tank lining; phase information has helped in aligning the source transducer parallel to the data plane. The data acquisition system has also proven useful in finding dead elements in transducer arrays or phasing reversal between array elements. These applications use the raw data before display.

To test the display characteristics, two objects (Figure 11) were used: a cruciform of four rectangles holes (5 x 6 mm on a side) and a letter 'E' (total size: 15 mm x 20 mm, stroke width: 5 mm). The forms were cut



(A)



(B)

Fig. 12 Computer displayed images of test objects out of 5 mm thick cork. Data was sampled (64 x 64 points) at half wavelength vertical and horizontal spacings. The object-receiver spacings were only 4 and 6 wavelengths respectively making the images 'shadowgrams' and requiring no inverse diffraction. The first images of these objects from the computer display are shown in Figure 12. Sixteen gray scales are used with 64 x 64 data cells. The letter 'E' image exhibits a large amount of noise (of unknown origin) in the upper left corner. Further refinements and experimentation are obviously required.

SUMMARY

The primitive images shown here are the first obtained with the system. Further areas of interest for future work include refinement of the data acquisition system to remove some of the 'bugs' observed, much more work on the computer display system to enhance the interactive capability between user and machine, more test examples while increasing the data field to 128 x 128, and finally implementation of a broad range of image processing procedures to enhance the images.

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