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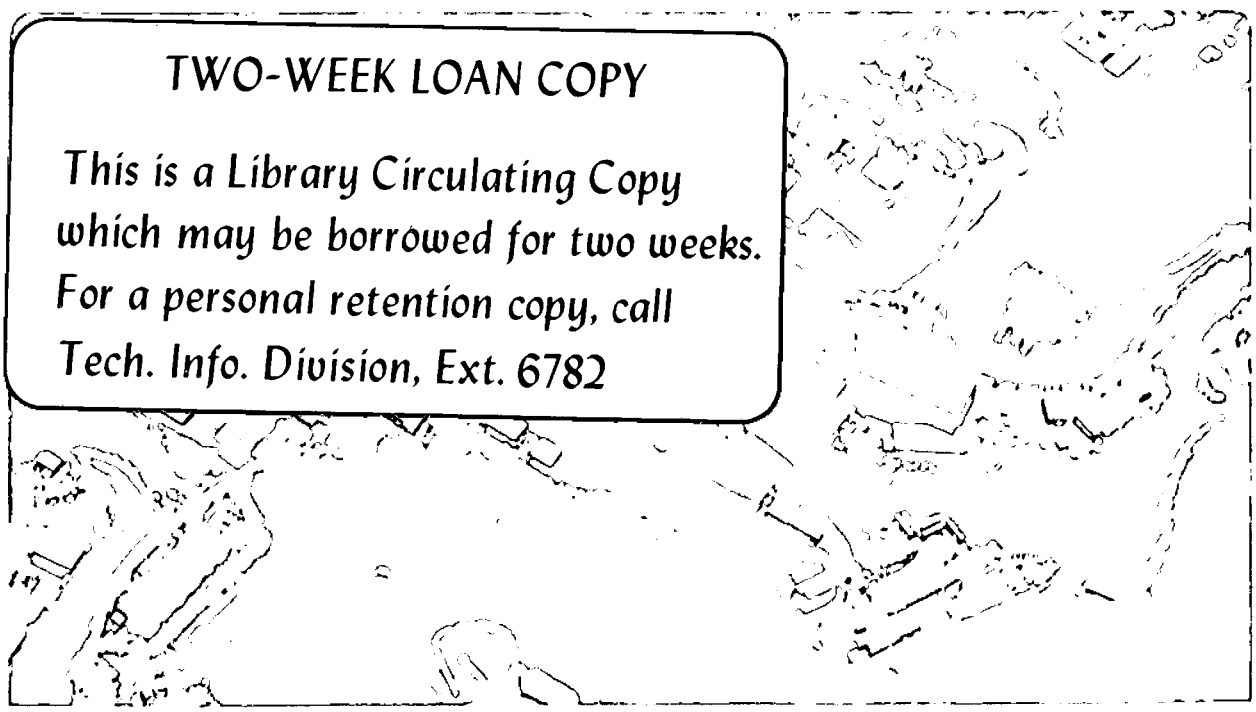

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TOMOGRAPHIC VISUALIZATION OF BREAST CALCIFICATIONS BY ULTRASOUND SCATTERING

Victor Perez-Mendez*, Douglas Ortendahl*, Graham Sommer**, John Baker* and Pamela Wiedenbeck*

Abstract

Various types of malignant and benign breast tumors are associated with clusters of calcifications with grain sizes 0.1 to 1 mm spread out over volumes of a few cm^3. These clusters have shapes ranging from spherical to elongated chains. A series of phantoms was made and the ultrasound scattering pattern from calcium carbonate grains embedded in a gelatin mixture was measured with 2.25 and 5 MHz transducers. A single send transducer with a few receive transducers placed at angles of 120° to 160° relative to the forward direction was used. Tomographic images of these distributions were obtained by a combination of transit time recording and positioning of the transducer array. Measurements have been done on grain sizes as small as 0.2 mm and show a clean signal above tissue scattering background.

Introduction

Various types of malignant and benign breast tumors are associated with clusters of calcifications with grain sizes ranging from 0.1 to 1 mm or larger (1). These clusters contain, in some cases, as few as five or six grains and can contain many tens of grains. The sizes and shapes of these clusters vary from spherical distributions of 1 cm size to elongated distributions spread out over a few cms. The correlation between the existence of a microcalcification cluster and some form of carcinoma is believed to be greater than 80%.

The standard method for the detection of these calcifications is mammography with a fine x-ray tube. Since the dose to the patient is appreciable, we undertook this study in order to determine whether these calcifications could be detected and their spatial distribution mapped out by use of ultrasound techniques on the assumption that such an approach does not contribute any known hazard to the patient and could be used as a routine screening process.

Experimental Method

Phantom Measurements

The initial objectives of this study were the following: (a) to demonstrate that the signals from clusters of grains ranging in size from 0.1 to 1 mm could be detected adequately above background noise; (b) to show that it is possible to distinguish the signals from the grain clusters from tissue interface back-scattering; (c) to select the frequency of ultrasound that is optimal for this project.

In order to carry out these objectives, we made measurements on a series of phantoms which contained calcium carbonate grains embedded in gelatin containing tissue simulating additives, e.g. Solkafloc (2). We also made measurements on excised breast tissue samples into which we introduced $CaCO_3$ grains.

The prototype ultrasound equipment we used consists of a pulsed emitter transducer operating at a mean frequency of 2.25 MHz surrounded by an array of four receive transducers placed around the send transducer to detect the scattered ultrasound at angles ranging from 120° to 160° as shown in Fig. 1. The gelatin-Solkafloc sample in a plastic container is mounted on a movable platform whose position can be varied over a few cms in the x, y and z directions in order to provide a 3-D scan of the cluster region.

The physics principle that we utilize in requiring that the signal be detected simultaneously in more than one transducer is that the scattering of sound by particles whose mean diameter is comparable to the wave length of the sound extends over 2π scattering angle and in general has an appreciable intensity over the range of angles used here (3). Since the scattered intensity for a given θ angle of the receive transducer is independent of the azimuthal angle, all of the receive transducers should receive comparable signals modified only by different tissue absorption, depending on the particular path from scatterer to transducer. The effectiveness of this approach in enabling the transducer array to distinguish the smaller scattered signals from larger interface back reflections is seen in Fig. 2. The 6 mm Lucite sheet scattered strongly at 0° (backward direction); the scattered intensity from the 0.1 mm copper wire is larger than the Lucite signal at angles greater than $\pm 7°$ from the back direction. An interface oriented at the appropriate angle for specular reflection to any of the receive transducers can occur. In that case, one receive transducer only will detect a large signal, and the event can be eliminated by the requirement that all transducers receive comparable signals.

Transducer Frequency

The criterion for selection of transducer freqquency is that the intensity of the scattered signal be maximum relative to the tissue scatter noise. Other factors that have to be considered are the amplitude of the scatter signal from the grains as a function of their diameter and the average attenuation in the breast tissue. From acoustic scattering theory, it is known that, in the short wave length limit when the wave length of the sound becomes smaller than the mean diameter of the scattering object, the scattered intensity approaches a constant magnitude independent of the diameter (3). In Fig. 3 we show calculated and measured values of the amplitude of the scattered signal at 180° (backward direction) from a series of wires, in a water bath, whose diameter ranges from 0.1 to 1.0 mm for transducer frequencies of 2.25, 3.5 and 5.0 MHz. These measurements indicate that at 5 MHz, for objects as small as 0.2 mm, we are almost in the asymptotic limit for scattering, and hence the detection of grain scatter is reliable down to this diameter.

Since the total path length in breast tissue is not too large, the additional attenuation of the 5 MHz compared to the 2.25 MHz is acceptable. Furthermore, as shown below, the signal/noise of the scattered amplitude from grain clusters is slightly better for the 5 MHz. Unless we have indications from clinical investigations that it is important to look for calcification grains smaller than 0.2 mm, we would rule out the use of frequencies higher than 5 MHz.

The scattered signals and B-scan displays shown in the figures below were done using calcium carbonate grains of various diameters and cluster sizes embedded in gelatin-Solkafloc phantoms, in samples of human

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breast tissue, and in beef liver. These were all done in the set-up shown in Fig. 1, and the signals were recorded from a single receive transducer. In Fig. 4 we show the signals from a ten-grain cluster (grain diameter 0.2 - 0.4 mm) in a gelatin-Solkafloc phantom using transducer frequencies of 5 and 2.25 MHz. In Fig. 5 we show the signals from calcium carbonate grains embedded in (a) breast tissue and in (b) beef liver, using 2.25 MHz transducers. As can be seen from the figures, the background scatter from the breast tissue and the liver medium is only slightly higher than that of the gelatin-Solkafloc phantoms and is still appreciably smaller than the scattered signal from the grain clusters.

Tomographical Displays

B-scan displays are inherently tomographic displays for any given plane within the object. Thus the entire breast volume can ultimately be displayed in a series of planes 4 to 6 mm apart. We generated some B-scans of clusters in the gelatin-Solkafloc phantoms using a computer-controlled Tektronix 4012 oscilloscope display. In Fig. 6 we show (a) an x-ray photograph of a spherical cluster of 24 grains, 1 mm diameter embedded in the gelatin-Solkafloc phantom. Fig. 6b shown one plane of the corresponding B-scan tomogram of the cluster generated by our computer display. In Fig. 7(a) and (b) we show corresponding x-ray and B-scan tomograms of an elongated cluster of 24 grains in a similar phantom. Fig. 8 shows schematically the electronics and computer-controlled display that were used. The B-scan tomogram was created by moving the sample through its median plane by the positioning screws shown in Fig. 1. In a clinical situation, of course, the transducer array would be moved mechanically to provide a full tomographic coverage of the breast region in a series of parallel planes.

It should be noted that the number of dots in the B-scan displays need not equal the number of scattering grains. This is due to the following reasons: (1) although the Picker and Aerotech transducers that we used had some damping, their response to a single grain scatter is approximately 3 to 4 oscillations; (2) depending on the nearest-neighbors distance distribution between the grains in the clusters, destructive interference effects can occur which decrease the amplitude of some oscillations; (3) more dots can result if the cluster is over-scanned by recording receive signals from the cluster for transducer positions closer than the width of the incident beam at the cluster position. Factors (1) and (3) can be programmed a priori into the computer display and a correction for (2) can be made after the initial scan.

In any case, our initial objective is to be able to detect and display the position, approximate shape and size of the cluster by the ultrasound technique. After such a cluster is identified more precise details can be obtained from a subsequent x-ray mammogram.

The linear amplifiers, timing discriminators and other recording electronics that we used have been optimized for this particular project in order to search for calcification clusters of unknown size and position within the phantom. We were curious to see whether the conventional diagnostic machines were capable of mapping out the clusters in our phantoms. For this purpose we tried out the Rohe and the Varian electronically steered heart scanner machines on our samples. The results are shown in Fig. 9.

The gain controls and other features had to be set precisely in order to see the grain clusters without flooding the scan with extraneous reflections. Furthermore, neither of these machines has provisions for systematic volume scans and signal correlations; hence, it is unlikely that such clusters could be detected reliably by conventional means in clinical situations, without a priori knowledge of their existence.

Summary and Conclusions

Using 2.25 and 5 MHz transducer arrays we have shown that it is possible to detect the scatter signals from clusters of calcium carbonate grains embedded in phantoms consisting of plastic containers filled with gelatin-Solkafloc media. Measurements on breast tissue samples and beef liver samples in which calcium carbonate grain clusters were embedded show that the interfering scatter signal from normal tissue is appreciably smaller than the grain cluster signals, and hence can easily be distinguished electronically. In normal and abnormal breasts there can be large tissue interface scattering signals. These signals will be discriminated against by correlating in the computer the signals from the various receive transducers. The assumption we make is that a tissue interface or other structure capable of giving a large reflected signal is unlikely to project it back onto more than one receiver at any given measuring position.

A series of clinical measurements in which we will compare the results of mammograms with our ultrasound scatter tomograms will be used in order to optimize the design of a clinical machine.

Acknowledgements

We would like to thank Drs. E. Sickles, P. Davis and R. Snyder of the Radiology and Pediatric Cardiology Depts., University of California, San Francisco for their assistance in taking the x-ray photographs and B-scans with the clinical machines.

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References

1. W. A. Murphy and K. DeSchryver-Kecskemeti, "Isolated Clustered Microcalcifications in the Breast: Radiologic-Pathologic Correlation," Radiology 127, 335-341 (1978). This paper has a comprehensive bibliography on calcifications in breast tissue.

2. Solkafloc: an additive developed by the Picker Corp. to simulate liver and breast tissue in gelatin media. Made by Brown Co., Berlin-Gorham Div., Berlin, NH, 03570.

3. T.F. Hueter and R.H. Bolt, Sonics, John Wiley and Sons, New York (1955), pp. 83-85.

Figures

Fig. 1: Ultrasound sample scanning configuration.
1. Solkafloc-gelatin sample with cluster.
2. Send transducer position.
3. Two of four possible receive transducer positions

x,y,z: phantom positioning mechanism.

Fig. 2: Comparison of wire signal and Lucite plane boundary signal as a function of scatter angle in water bath. At 10° from the back scatter direction, the specular reflection signals are appreciably smaller than those from the wire.

Fig. 3: Signal amplitude vs. wire diameter for three ultrasonic frequencies. At 5 MHz we are almost in the high frequency constant scatter amplitude for objects down to 0.2 mm diameter.

Fig. 4: Signals from a cluster of 10 grains, 0.2 - 0.4 mm diameter, in a gelatin-Solkafloc medium.

4a: 5 MHz transducer.
Scale: horizontal: 1μsec/cm
vertical: 1 V/cm

4b: 2.25 MHz transducer.

Scale: horizontal: 2 μsec/cm
vertical: 0.5 V/cm

Fig. 5: a: 2.25 MHz transducer received signals from a cluster embedded in human breast tissue.
Scale: horizontal: 2 μsec/cm
vertical: 1 V/cm

b: 2.25 MHz transducer received signals from a cluster of 25 grains, 0.4 - 0.6 mm diameter embedded in beef liver.
Scale: horizontal: 2 μsec/cm
vertical: 0.1 V/cm

Fig. 6: a: x-ray photograph of spherical cluster of 24 grains, 1 mm in size, in a gelatin-Solkafloc medium.

b: computer tomograph of cluster in 'a'.

Fig. 7: a: x-ray of photograph of elongated cluster of 24 grains, 1 mm in size, in a gelatin-Solkafloc medium.

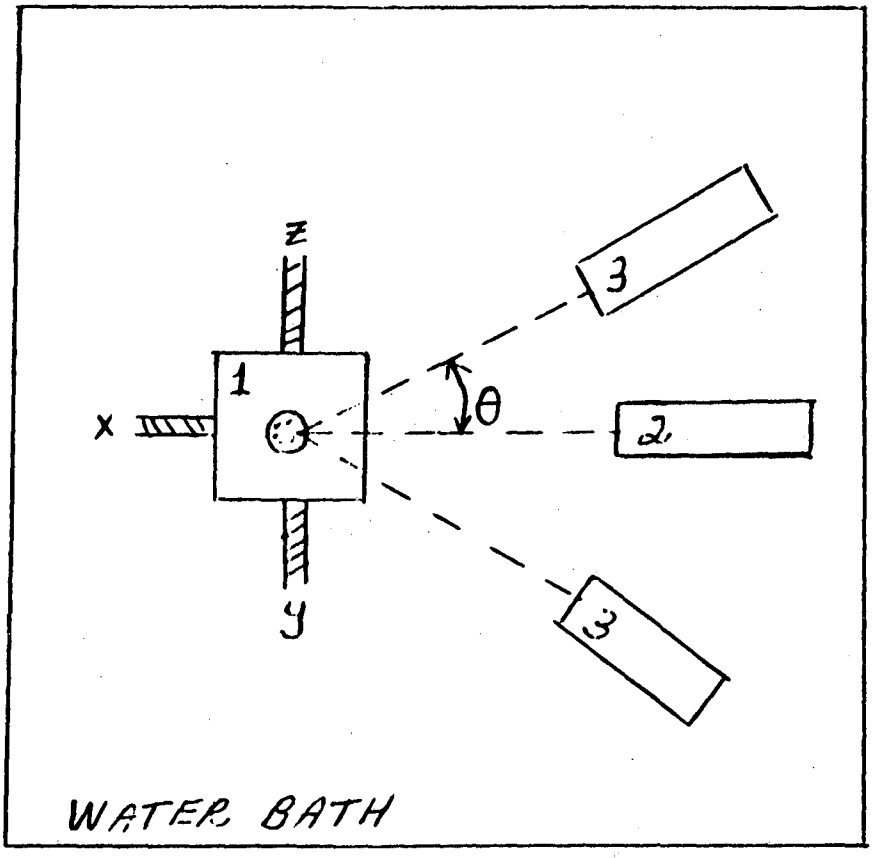
b: computer tomograph of cluster in 'a'.

Fig. 8: Scanning set-up for the ultrasound experiment.

Fig. 9: Scans of calcification cluster. Ten grains (0.2 - 0.4 mm in diameter) embedded in a gelatin-Solkafloc medium.

a: Rohe compound B-scanner.

b: Varian heart sector scanner.



ULTRASOUND SAMPLE SCANNING CONFIGURATION

FIG. 1

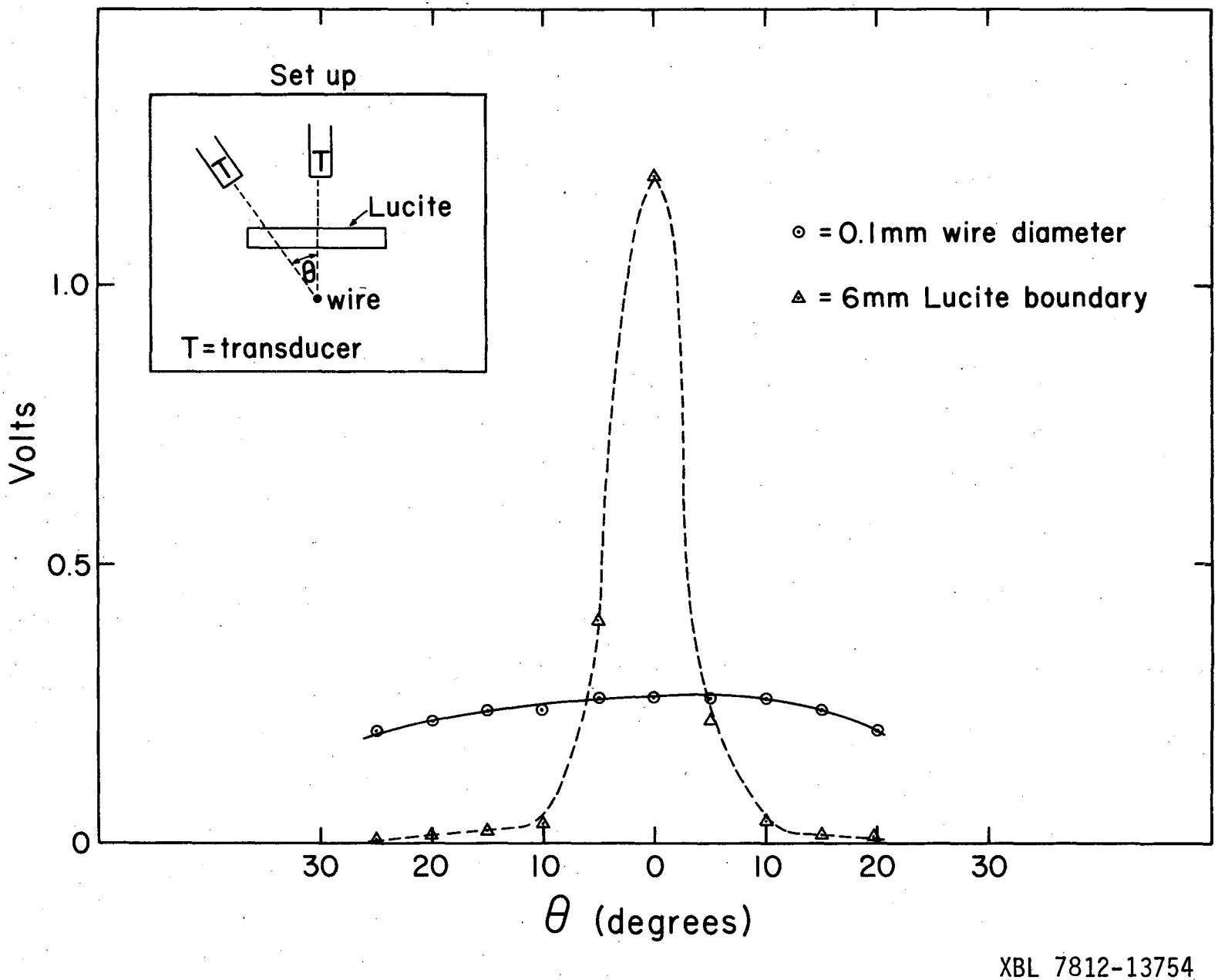

Set up
T
T
Lucite
θ
wire
T=transducer
⊙ = 0.1mm wire diameter
△ = 6mm Lucite boundary
Volts
1.0
0.5
0
30
20
10
0
10
20
30
θ (degrees)
XBL 7812-13754

FIG. 2

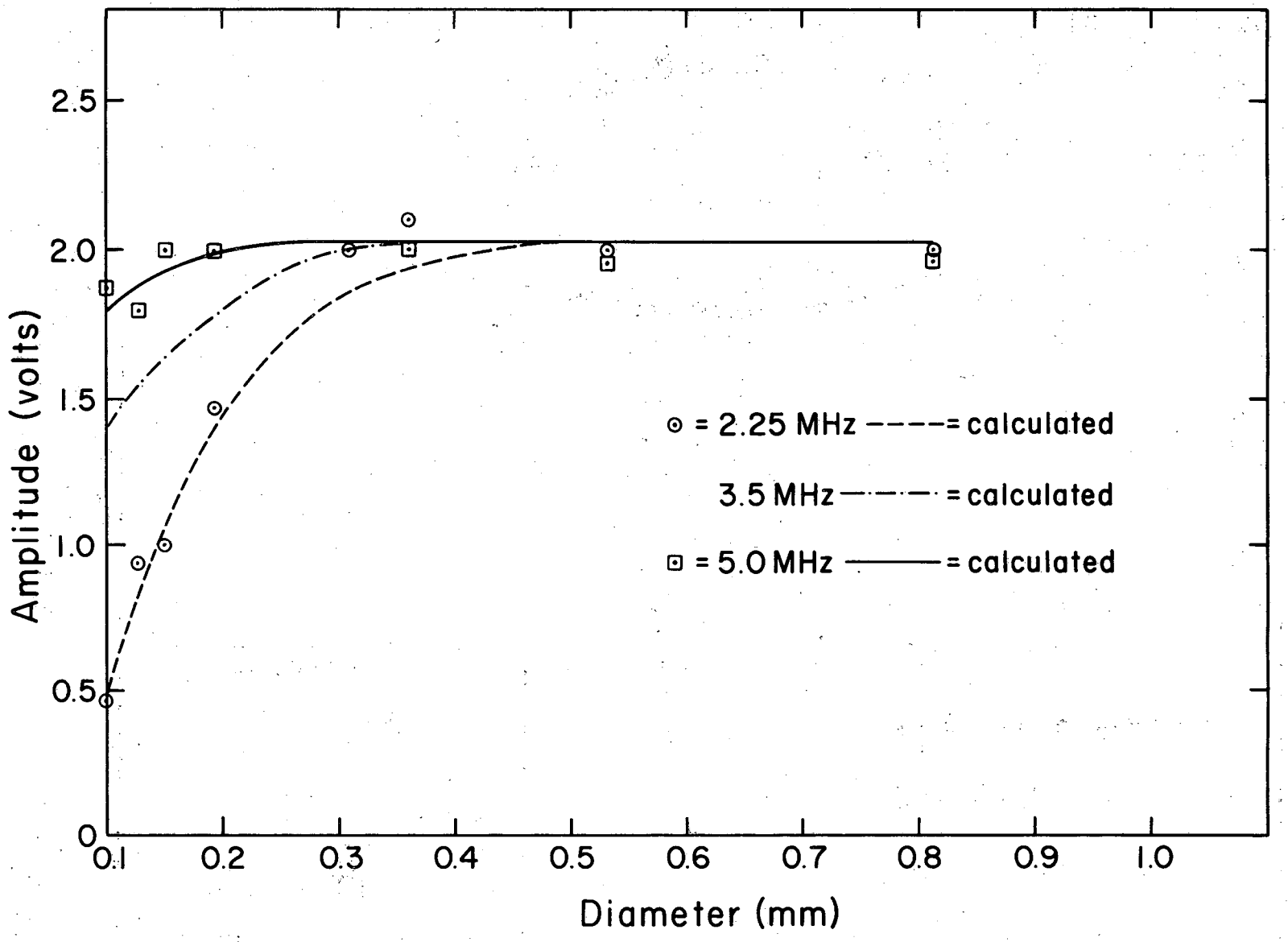


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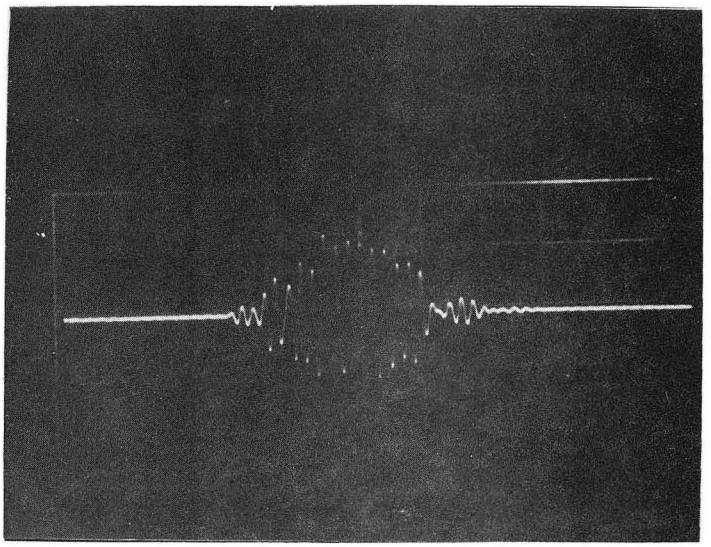
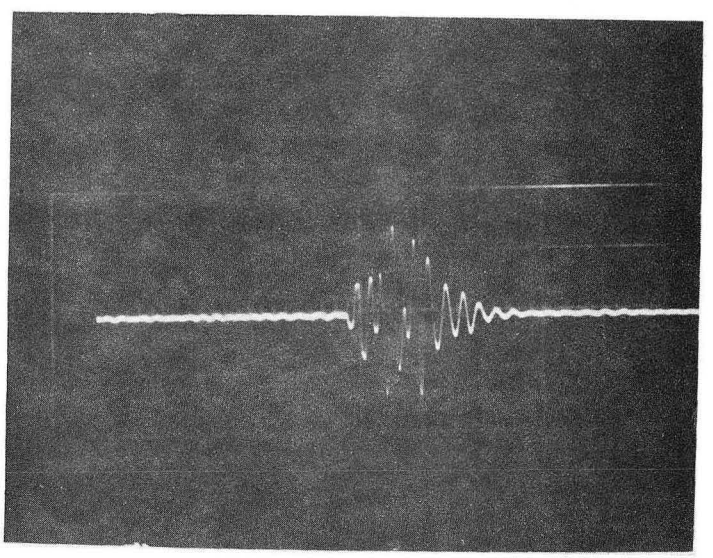
FIG. 3



A



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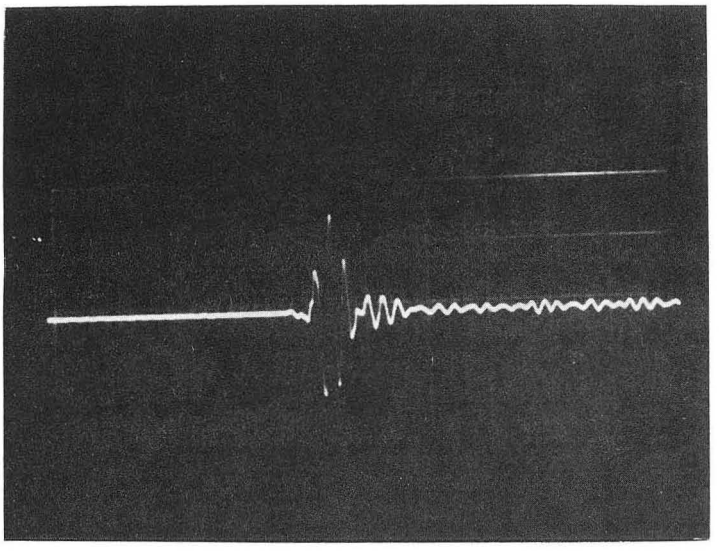
B

FIG. 4



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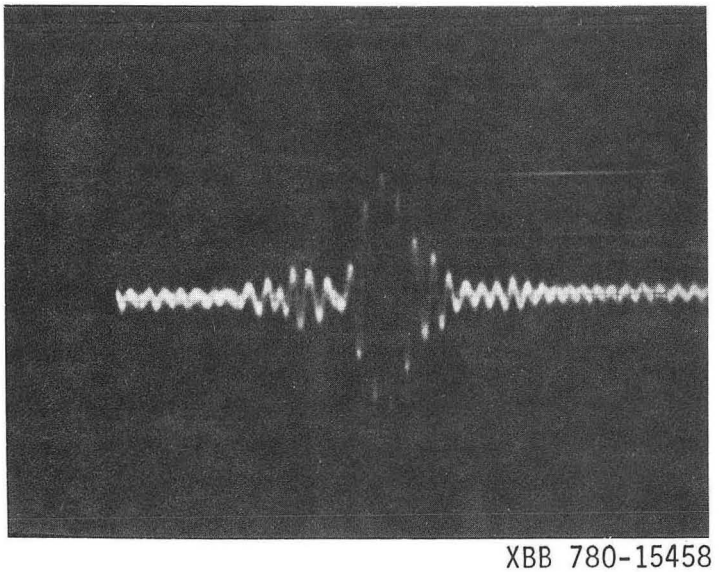

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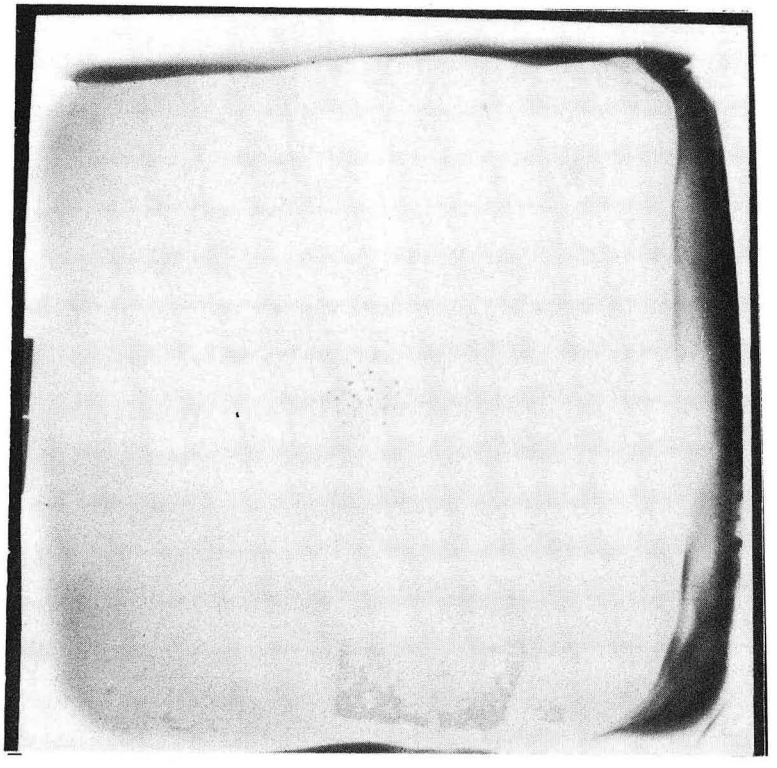
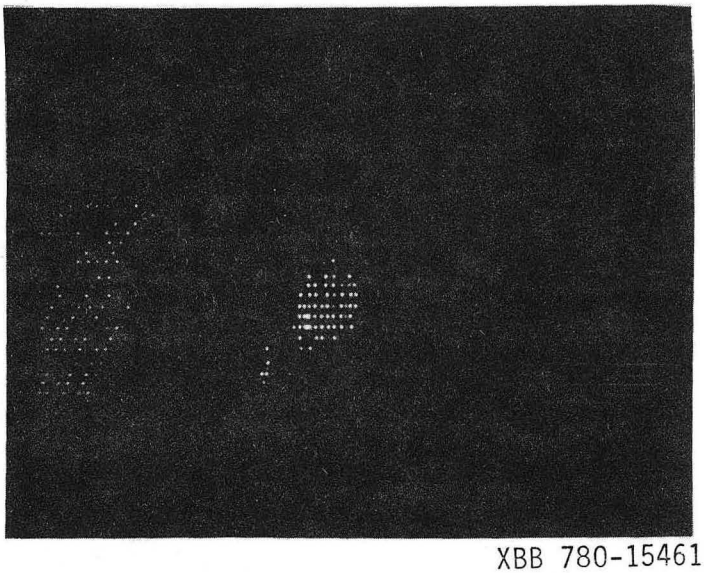
B

FIG. 5



A



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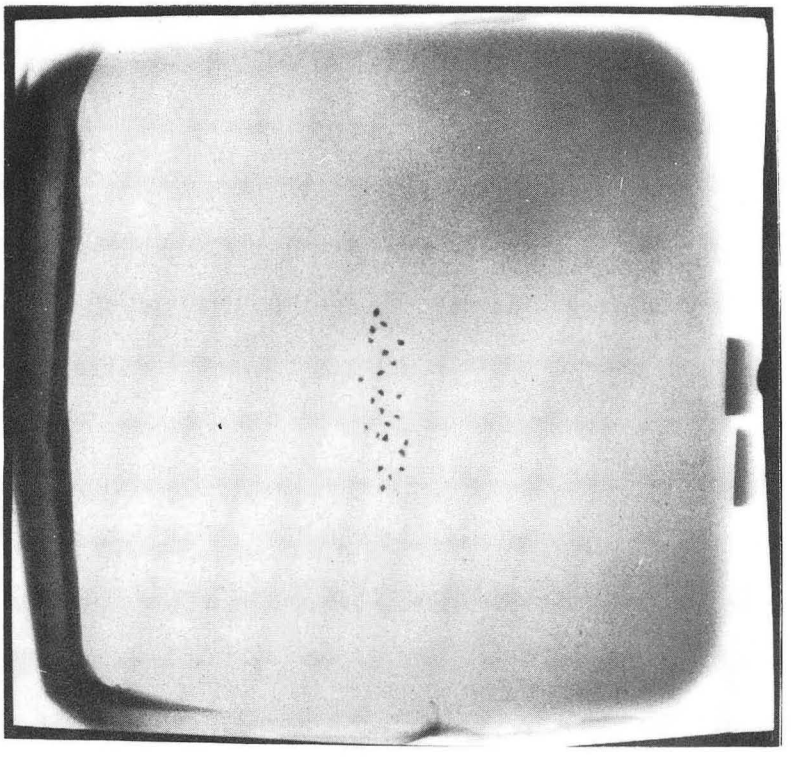
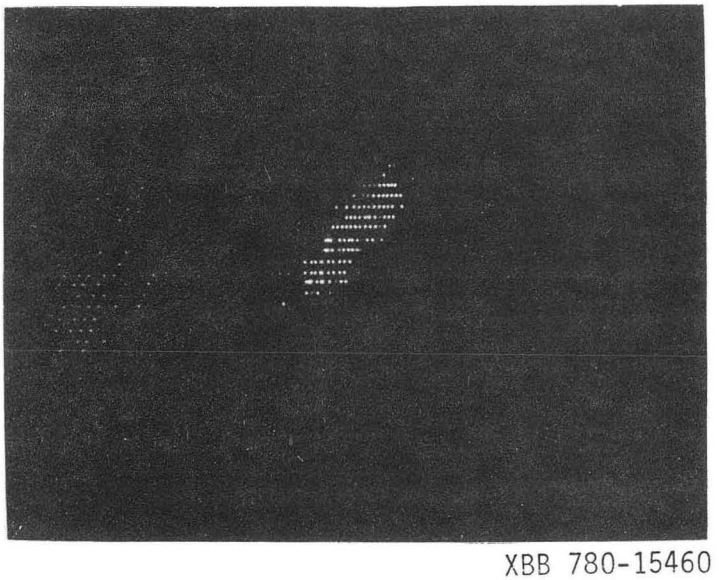


A



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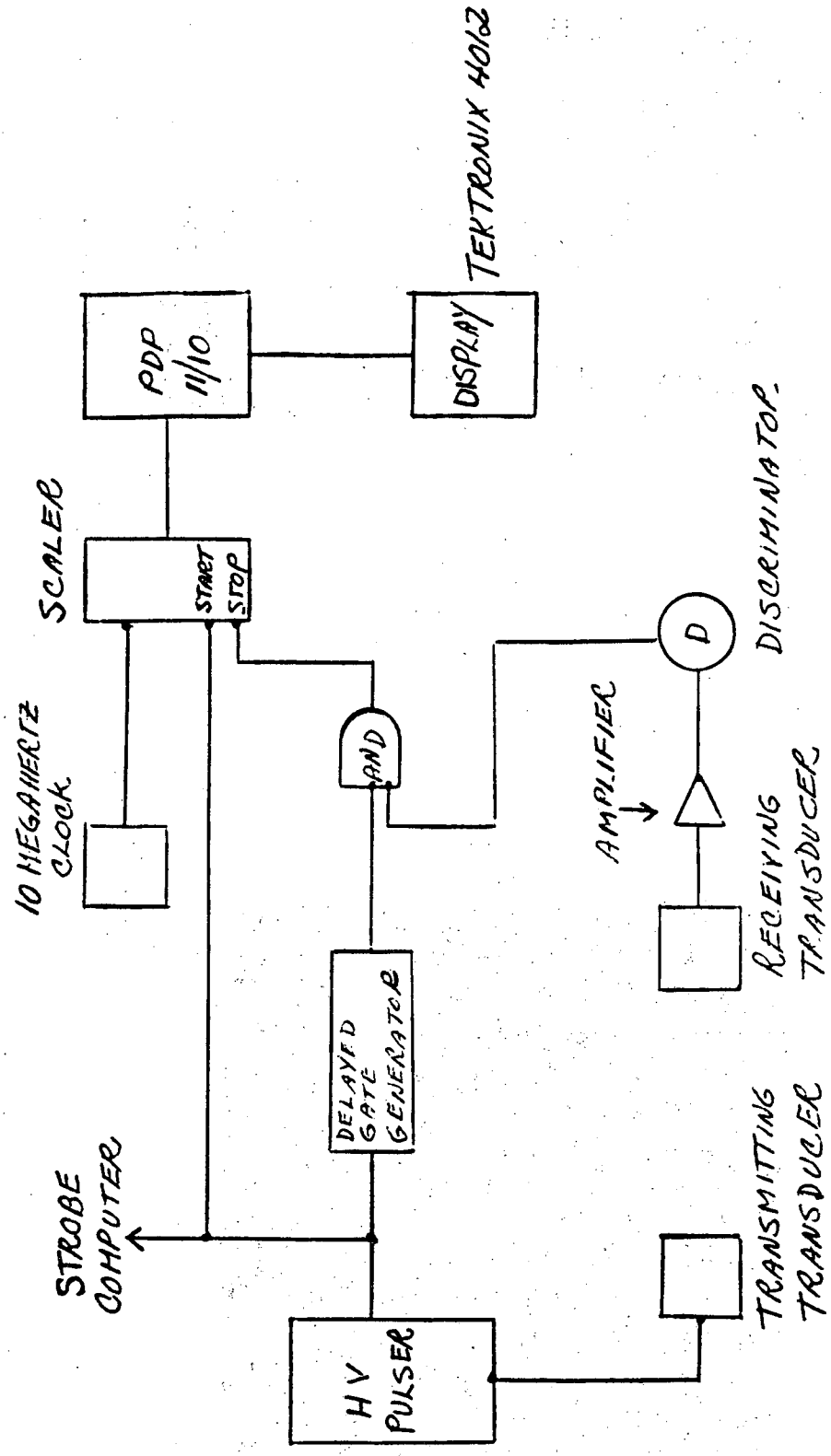
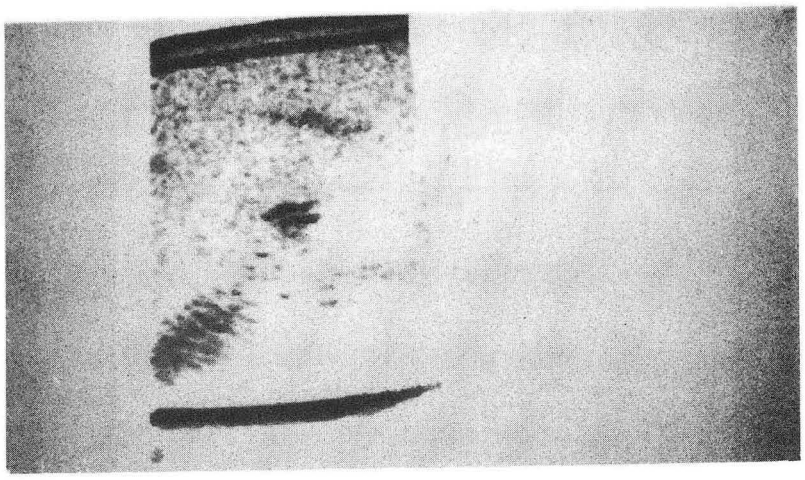
B

FIG. 7

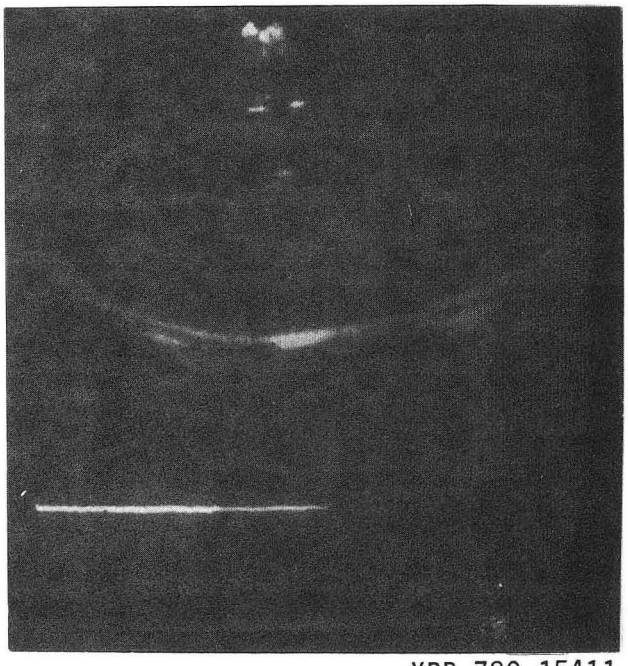


SCANNING SET UP FOR ULTRASOUND EXPERIMENT

FIG. 8



(a) B-scan. Rohe machine.



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(b) B-scan. Varian cardiac machine.

Scans of calcification clusters.
Ten grains each (0.2-0.4 mm dia.)
in gelatin-Solkafloc medium.

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