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INDICE

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AN ULTRASONIC BASED SYSTEM USED FOR NON-DESTRUCTIVE IMAGING OF ARCHAEOLOGICAL SITES

Introduction

Upon the approval of the permanent committee of the Egyptian Archaeology Organization for the joint team from Cairo University (Headed by Professor Fathi Saleh) and the California State University-Sacramento (Headed by professor Robert Cribbs) to extend the work already started few years ago which was to use the microwave technology for imaging the second boat pit south to the great pyramid. The team was authorized to carry non-distructive archaeological sites imaging in the area of Saqqara using ultrasonic technique.

After investigation on the nature of the ground at Saqqara area, it was concluded that the area of the Giza plateau has more solid limestone formations than the Saqqara area.

Because the solid limestone is more favourable for the propagation of ultrasound waves, the team has demanded from the Organization to start their experiements at Giza area instead of Saqqara area.

The Work Team

The team is composed of:

Team Leaders:
Prof. Robert Cribbs (California State University).
Prof. Fathi Saleh (Cairo University)

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1. Robert Cribbs (California State University, Sacramento), Fathi Saleh (Faculty of Engineering, Cairo University).

Assistants:
Dr. Ahmed Darwish (Cairo University)
Eng. Hany Mohamed Fahmy (Cairo University)
Eng. Hatem El-Kadi (Cairo University)
Eng. Mohamed El-Hadi (Cairo University)

The Work Program

It was planned to work for about two weeks on the project, but due to unforseen delays the team could not start working as scheduled. This left the team with only four days of work. The team then decided to proceed, as much as time allows, with the first part of the program which is to examine on a test site "the ability of the system designed to detect known chambers".

The Equipment

The equipment used, consisted of a computer belonging to the Cairo University which was modified by the addition of some specialised cards and programs that were donated by California State University in order that the two universities would have identical equipment and that the team of Cairo University would be able in the future to continue the work in other areas.

Fig. 1 shows a simplified diagram of the equipment used, which is composed of an ultrasound source (three different types of sources were available to test the system) which produces an ultrasound pulsewave. This pulse is transmitted into the rock and propagates till it is reflected back by the end surface of the rock. The reflected pulse is received by an ultrasound transducer. The transmitted and received signals are electronically connected to the computer via an amplifier and A/D converters which convert the analogue received signals into digital ones, that can be processed by the computer.

Three different types of ultrasound sources and three different types of transducers were used, each one of the ultrasound sources and transducers covers certain frequency range, which corresponds to certain range of wavelengths (and consequently suitable for certain rock thicknesses).

When an ultrasound pulsewave is transmitted, the transducer will receive an echo after certain time interval (equivalent to the time travelled by the sound wave from the source, across the rock slab, to the other surface of the slab and return back to the transducer). Knowing the sound propagation velocity in the limestone (as calculated by the team of the Stanford Research Institute),[2] one can calculate the distance of the reflecting surface. Also, moving the ultrasound source across a grid of points and by applying a special imaging algorithm, the shape of the cavity or chamber can be recomposed by the computer.

The Sites

The site chosen for testing the methodology is the rock-cut tomb of Iasen (G 2196) in the western necropole of the Giza plateau. The reason for this selection is that the team found this tomb having two levels separated by a slab of a solid piece of limestone in good condition for testing the system. The main problem was that the width of the slab was about one meter which is not suitable for the ultrasound sources used (we were hoping to find greater depth in another site but due to the time limit, the team decided to work in this tomb).

Fig. 2 shows the plan view of this tomb indicating the test area.

The Experiment

Three ultrasound sources were used: a low, a medium and a

2. As result of a project about «Application of Modern Sensing Techniques to Egyptology» developed by the Standford Research Institute in collaboration with the Ain Shams University (Cairo) in May 1975.

high frequency range one. The three transducers have three equivalent frequency ranges for detection. Each ultrasound source was tried with every transducer separately, which results in nine different experiments, the results of the main two experimets are analysed in the following part.

The Results

Experiments ran under different conditions in order to investigate the different output of these tests. These tests are as follows:

Test No.	Source	Detector
1	High frequency	High frequency
2	Medium frequency	High frequency
3	Low frequency	High frequency
4	High frequency	Medium frequency
5	Medium frequency	Medium frequency
6	Low frequency	Medium frequency
7	High frequency	Low frequency
8	Medium frequency	Low frequency
9	Low frequency	Low frequency

The first and last experiment gave the most spectacular results:

Experiment no. 1 (Using a low frequency source and a low frequency transducer)

Under this condition and since the wavelength (in the order of 20 meters) is much greater than the width of the slab (in the order of one meter), the source looks as a D.C. high energy source, the wave generated bounces back and forth between the surfaces of the slab producing an almost pure sinusoidal wave resonance signal. The time difference between every two peaks corresponds to twice the width of the slab divided by the sound propagation velocity through the slab.

Fig. 3a shows a computer graphic output of the signal produced by the ultrasound source, while Fig. 3b shows the signal detected by the transducer.

Fig. 3c gives the spectrum of the detected signal. From fig. 3c one can detect the frequency of the received echo corresponding to f=976.5 hz. Assuming that the sound propagation velocity in the limestone is v=2430 m/s, the thickness of the rock is given by

$$d = v / (2 * f) = 1.24 \text{ meters.}$$

Comments on Experiment no. 1

Using a low frequency source is very suitable in case of parallel surfaces since it allows the bouncing of the wave between the two surfaces. It is also suitable for the detection of targets far away from the source, since low frequency sound waves will penetrate deeply in the rock, as the attenuation is inversly proportional to the wave frequency.

Using low frequency transducer, allows large dynamic range, which means that the system could discriminate between strong echoes and week echoes, and thus better resolution in the constructed image.

Experiment no. 9 (Using a high frequency ultrasound source and a high frequency detector).

In this experiment, since the source wavelength is in the order of magnitude of the width of the slab, the received echo will be wave packets that will bounce back and forth between the two surfaces of the slab. These packets will have a repetition frequency indicating the width of the slab. Investigating the detected waves in this case (Fig. 4) reveals the presence of a shear wave. It is expected that this shear wave effect will cancel out when applying the imaging algorithm over several number of points.

Comments on Experiment no. 9

Using a high frequency source will result in wave packets in the received echoes, it will also produce a clear shear wave, the waveform looking more complicated than in the case of experiment no. 1.

This source is suitable for the detection of irregular shapes.

Conclusions

An experiment was designed to determine the suitability of different ultrasound sources for the detection of the candidate object. It was found that when using a source having wavelength much greater than the distance between the source and the cavity, this condition produces a pure detectable sinusoidal wave in case of single limestone rock with parallel surfaces. On the other hand, a source of wavelength comparable to the distance between the source and the cavity will produce cyclic wavepackets and is more suitable for detecting irregular surfaces and can be used to produce images easily.

The methodology was able to detect clearly the presence of the limestone slab between the higher and lower chamber in the tomb of Iasen

The conclusion is that there is not a single answer for the question: Which frequency is more favourable to use? It is as the English proverb says «Horses for courses» meaning that every specific site condition needs a proper methodology for detection.

Future Work

As stated at the beginning of this paper, the time constraint in this phase of the research limited the work to the testing of the suitability of the different methodologies. The results of this phase have to be followed by two further steps:
- Applying an imaging algorithm to form a three dimensional image.
- Applying the method to candidate sites that have preferably the following conditions: solid limestone environment and deep suspected cavities or chambers.

Two candidate areas are recommended: the area around the great pyramid and the tomb of Sety I in the Valley of Kings.

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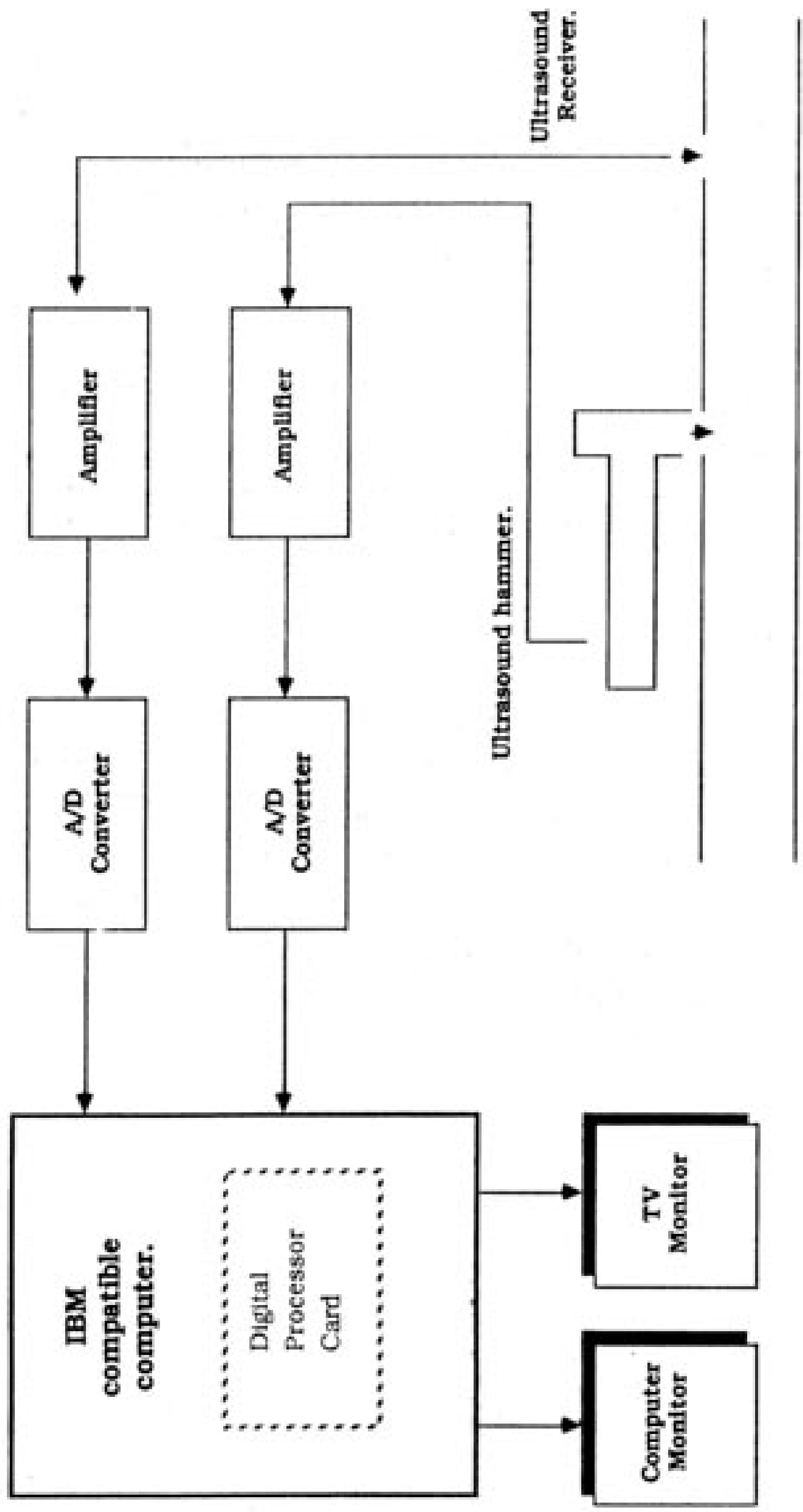

FIGURE - 1 A simplified diagram of the equipment.

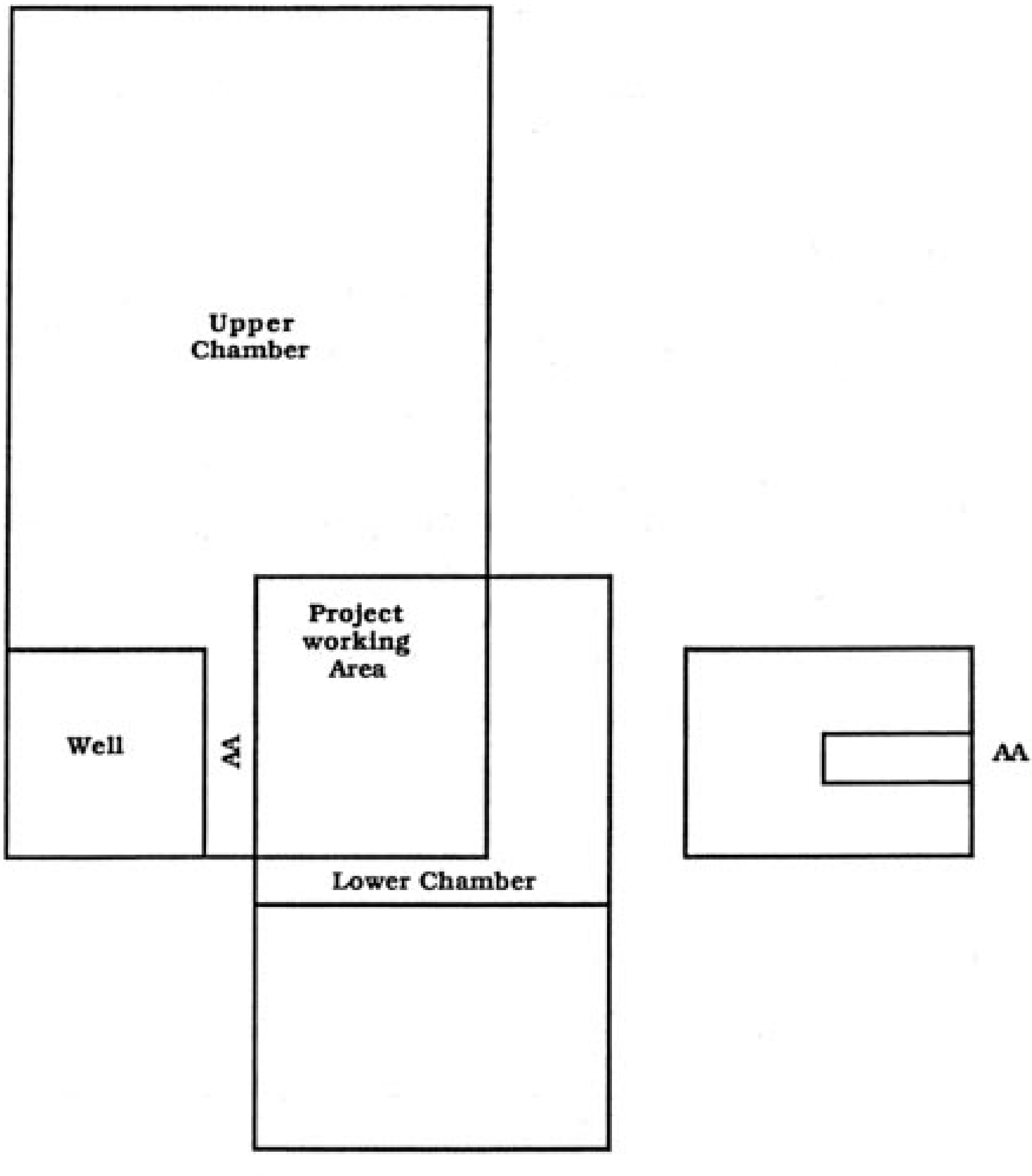

Figure 2 : Plan of the IASEN Tomb

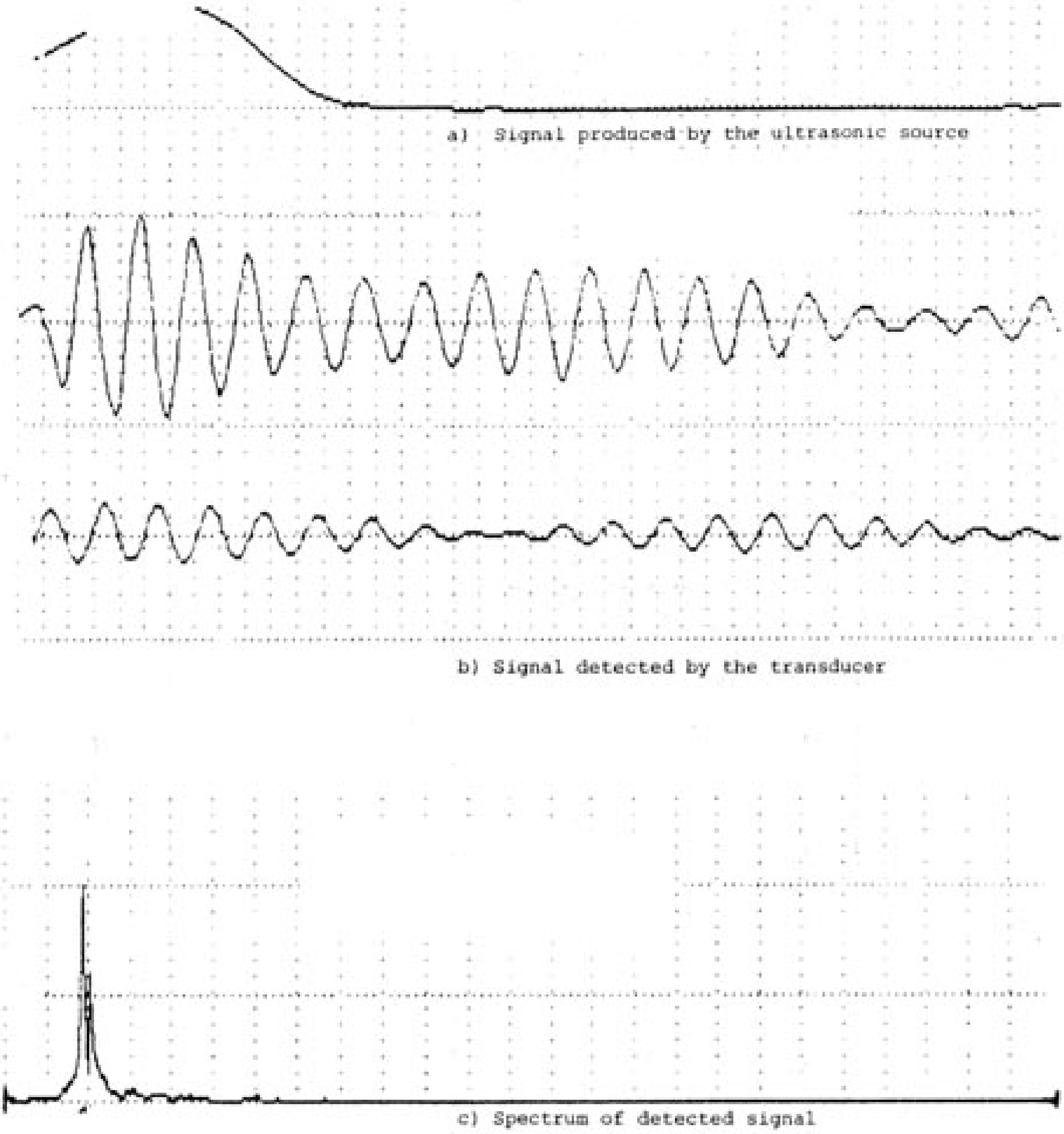

Figure 3 : Experimental No. 1 : Low Frequency Source/
Low frequency detector

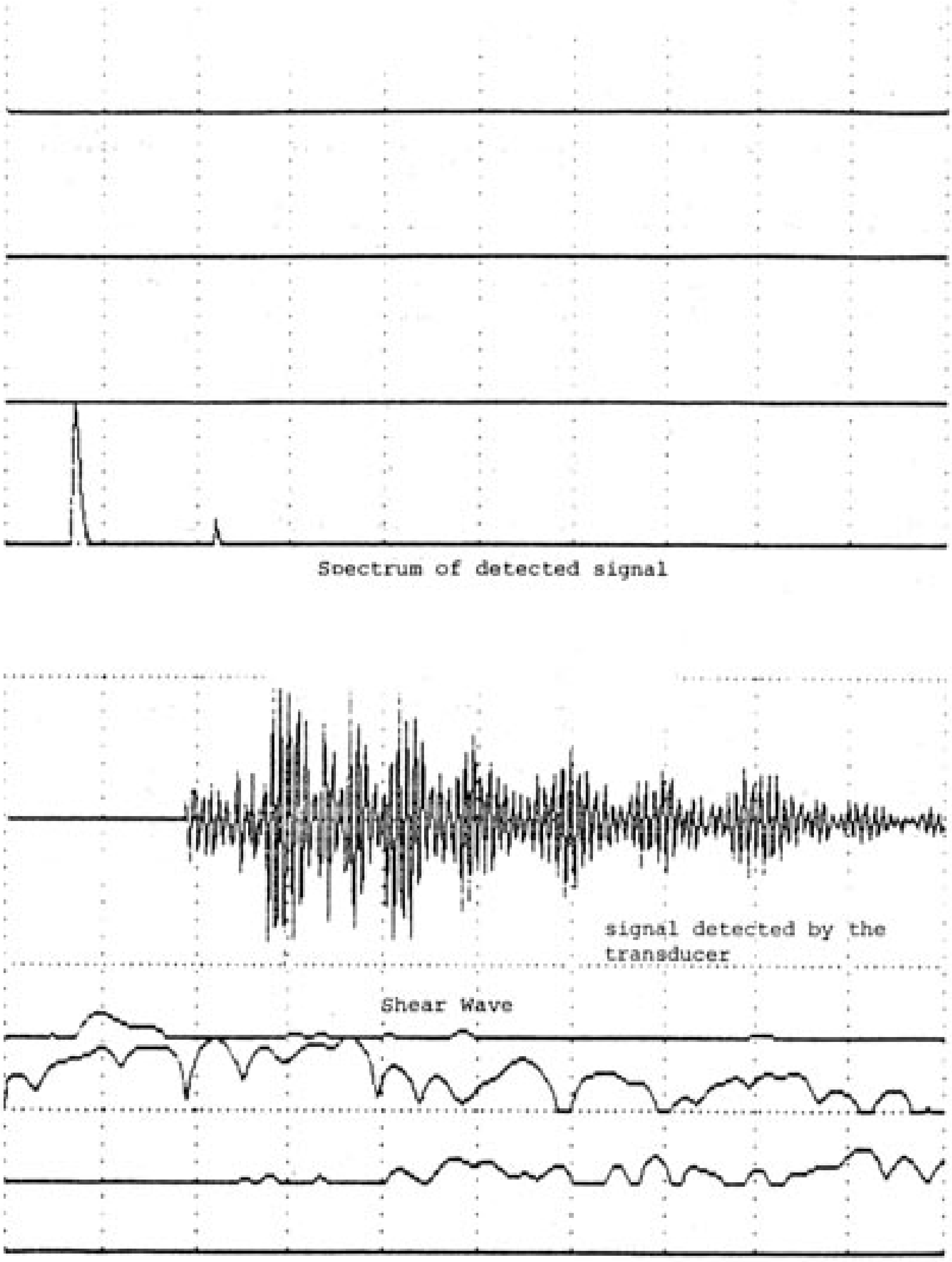

Figure 4 : Experiment No. 9 High frequency source/ high frequency detector