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The Evaluation of Search Units Used for Ultrasonic Reference Block Calibrations

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CONTENTS

Abstract

The effects of using different (nominally identical) quartz search units in the evaluation of ASTM-type standard reference blocks are determined. Various characteristics of the search units are measured and correlated with the amplitude of the ultrasonic response from reference blocks to determine which characteristics must be specified if reproducible results are to be obtained. It is shown by a series of experiments that the exact shape of the distance-amplitude curve in water (axial profile) is a primary characteristic that must be considered. When operational corrections for differences in axial profiles are made, the variability in ultrasonic responses from reference blocks, measured with different search units, is reduced from about 25 percent to 4 percent.

Key Words: ASTM standards; calibration; nondestructive evaluation; reference blocks; search units; specifications; transducers; ultrasonics

1.0 Introduction

What characteristics of an ultrasonic search unit* must I specify, and furthermore, what values for these characteristics are appropriate, in order to assure reproducible results from an ultrasonic test? These are the general questions being asked by the consensus standards organizations representing the two largest groups in this country using ultrasonics for diagnosis--the nondestructive testing community (through the American Society for Testing and Materials Subcommittee E7.06 on Ultrasonic Nondestructive Testing) and the medical diagnostic community (through, for example, the American Institute of Ultrasound in Medicine, Transducer Characterization Subcommittee).

In the long term, it appears that at least two standards documents will be necessary. One document should consider the search unit as part of the total system and specify various system characteristics such as axial profiles, front and back surface resolution, center frequency and bandwidth, etc. that reflect the nature of the pulser, cable, search unit, receiver, display, etc. These measurements are necessary to define the operating characteristics of a complete system being used for a specific test and are similar to those described in ASTM E 317 [10]. The other document should specify the characteristics of the search unit alone when excited by a "standard" or easily reproducible waveform such as a spike pulse (broadband) or continuous sine wave or gated (burst) sine wave. These measurements

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*For the purposes of this paper, the ASTM E 500 (Standard Definitions of Terms Relating to Ultrasonic Testing) definitions for transducer and search unit are implied. Transducer refers to the piezoelectric crystal and electrical connections only. Search unit includes the transducer, case, backing material, wear plate, etc.

could be used to characterize the search unit alone. This type of standard would be extremely useful in purchasing a search unit to replace one proven useful for a particular application. These measurements should be repeatable in different laboratories on different, though similar, equipments. In either case, the goal of the characterization measurements is to determine definitively that two search units that appear to be identical, based on the measured quantities, will indeed yield the same results in an ultrasonic test. This is necessary for quantitative flaw definition, either in materials inspection or in medical diagnosis. Without this assurance, the comparison of successive inspection data on a flawed structure, be it a crack in a reactor pressure vessel or a brain tumor, to determine flaw growth over some time period, is not fully meaningful.

Of particular interest to the authors, as well as many others in NDE, are the search units used to "calibrate" or "evaluate" ASTM-type ultrasonic reference blocks [1-3]. Earlier studies at this laboratory [4] have shown that the readings obtained from a particular aluminum reference block exhibited a spread as high as 17 percent when measured with five nominally identical quartz search units. The current ASTM document for checking aluminum blocks [1] has a search unit specification written into it, but the working section on aluminum blocks (E 7.06.02) recognizes that this specification is not suffic and is currently investigating a revision. The aluminum block working section has set a target of ± 1 dB (down from the current ± 2dB) variability in blocks as the acceptance limit. Obviously, if search unit variability now can contribute as much as 17 percent (about ± .75 dB) to the variability in one block's reading, the goal of ± 1 dB spread for all blocks is not attainable with the presently specified measurement procedures. The data presented herein were taken in support of that effort. Of equal importance to the authors is the system used in our reference block calibration service[3]. The objective of this program is to expand this service into a Measurement Assurance Program (MAP) wherein a measurement process (algorithm) is carefully specified and the accuracy of field measurements using the same algorithm is assessed. Obviously, a well characterized search unit is an important part of the measurement algorithm.

The objectives of this study were to re-evaluate the extent of the variability among reference block readings using different search units (more thoroughly and carefully than reported in [4]), to measure as many pertinent characteristics of the search units as possible, to correlate the results to determine the important parameters, and to specify, if possible, appropriate tolerances on the parameters that would allow the ± 1dB acceptance criteria to be met.

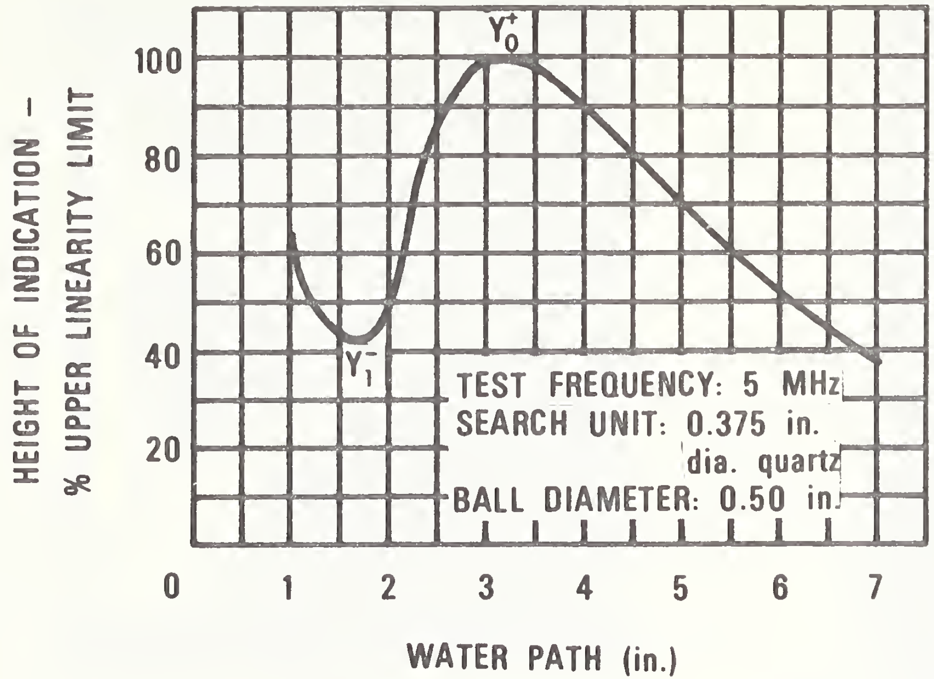
2.0 Ultrasonic Search Units

Most ultrasonic inspections today are performed with search units incorporating ceramic transducers. The advantages of these ceramic materials, such as lead-zinconate-titanate, barium titanate, and lead meta-niobate, include cost, availability, high sensitivity, and low Q (broadband response). The primary disadvantages, as compared to quartz, are difficulty of <u>exact</u> reproducibility, and depolarization caused by aging of the transducer material. Because of these two disadvantages, ASTM E 7.06.02 has chosen, for the near term, to specify that search units used for checking aluminum reference blocks incorporate quartz transducers. A future goal is to develop a search unit specification that will allow the use of ceramic transducers for checking reference blocks.

The search units specified in E 127 [1] are nominal 5-MHz, 0.375-in (9.52-mm) effective diameter quartz units. The characteristics of acceptable search units, per E 127, include center frequency (5.0 $\pm$ 0.5 MHz), location of Y_o^+ point in water (3.2 to 3.5 in, 8.1 to 8.9 cm), general shape of the axial profile (fig. 1), Y_o^+ beam symmetry (minimum 0.75:1 ratio of - 6dB beam diameters from four scans), and Y_1^- beam symmetry (peak amplitudes vary by less than 15 percent among four scans). Other quantities not specified in E 127, but sometimes shown in other search unit specifications, include sensitivity, resolution, frequency bandwidth, damping factor, waveform distortion, and absolute output power (especially in the medical field). Characteristics that are rarely specified include the exact shape of the pressure field (either axial or lateral profiles) and electrical impedance. The details of procedures for measuring these parameters are fairly well documented in the literature [5-9].

3.0 Equipment

Six nominally identical search units were used in the study, all reportedly 5-MHz, 0.375-in (9.52-mm) quartz. These consisted of three different styles from two different manufacturers. Two pairs (LS-1 and LS-2, and LS-3 and LS-4) were purchased in pairs and had sequential serial numbers. The other two (LS-5, LS-6) were loners. For the reference block measurements a commercial flaw detector with a tuned pulser/receiver was used. This is the type specified in E 127 and used in our calibration service for the blocks.



1 in. = 25.4 mm

FIGURE 1 – AXIAL PROFILE OF AN "ACCEPTABLE" SEARCH UNIT PER ASTM E 127-75. REPRINTED BY PERMISSION OF THE AMERICAN SOCIETY FOR TESTING AND MATERIALS, COPYRIGHTED.

The vertical linearity of this flaw detector was checked with all six search units per ASTM E 317 [10] and was determined to be better than 5 percent over the range of interest in all cases. For the search unit characterization, either the commercial flaw detector or a broadband pulser/receiver was used as noted below. The output pulse waveform and frequency spectra for these two pulser/receivers are shown in figures 2 and 3. The reference blocks were all ASTM E 127 aluminum reference blocks, with hole diameters of 3/64, 5/64, and 8/64 in (1.2, 2.0 and 3.2mm) and metal travel distances of 0.5, 1.0, and 2.25 in (13, 25, and 57 mm).

4.0 Reference Block Readings

Initially the nine reference blocks were read in accordance with the procedures outlined in ASTM E 127-75. That is, the sensitivity was set such that the signal from the appropriate size ball, at 3.5-in (8.9-cm) water distance, read 80 percent of vertical linear limit on the CRT. The blocks were then read, keeping the water distance at 3.5 in (8.9 cm). Three independent readings were taken on each block with each of the six search units. The data are summarized in table 1. Statistical analysis of similar data at this laboratory indicated that the standard deviation of the mean of three readings is about 0.8 units.

The data are very interesting in some respects. The extent of the variability is much larger than reported earlier [4]. However, all the earlier data were taken on 0.5-in (13-mm) metal distance blocks. The data shown in table 1 for 0050 blocks agree well with the earlier data.

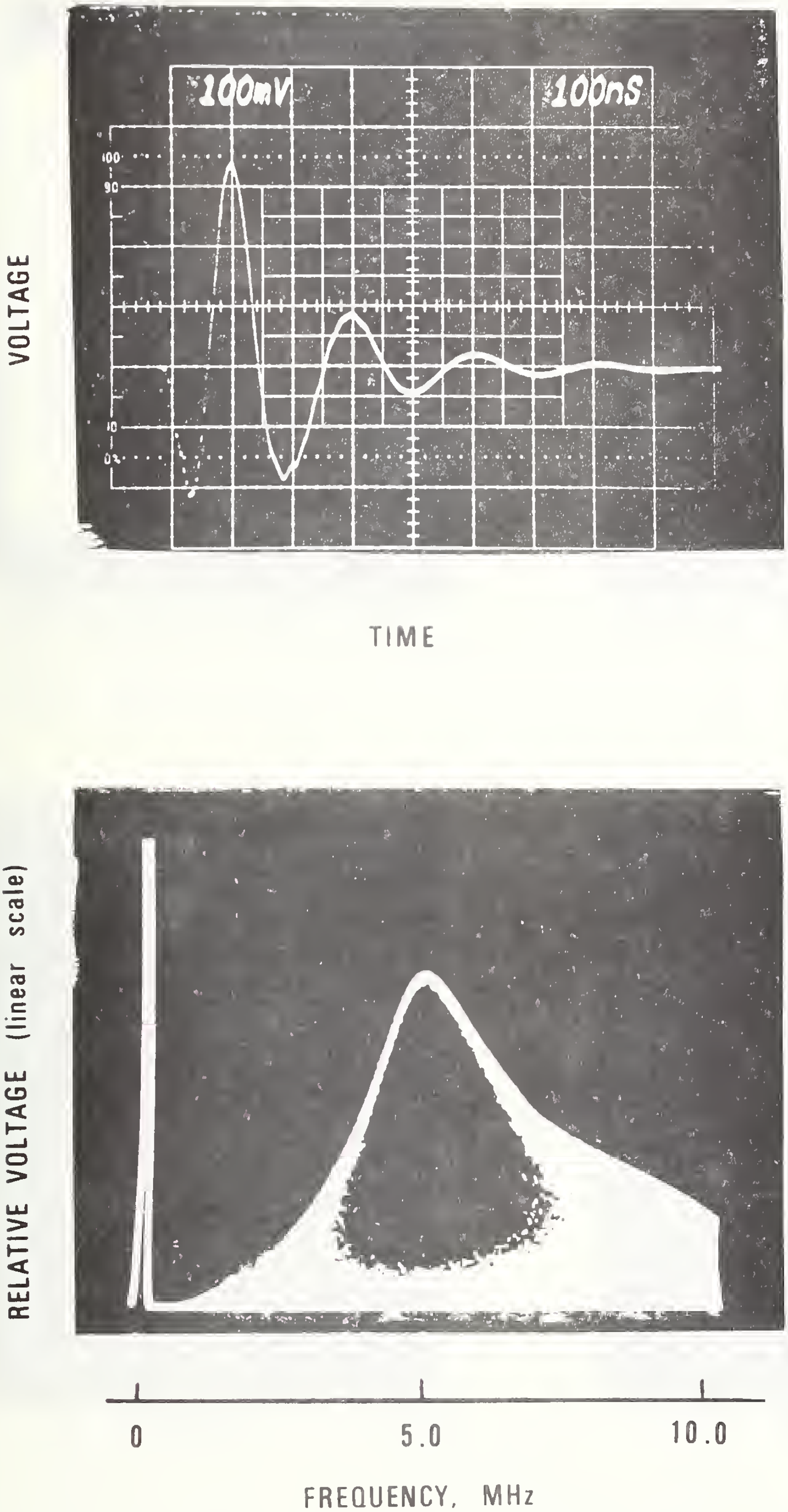


FIGURE 2 – OUTPUT PULSE WAVEFORM AND FREQUENCY SPECTRUM FOR TUNED PULSER/RECEIVER. TAKEN FROM CENTER PIN OF "RECEIVE" JACK, NORMAL MODE, 5 MHz, NO SEARCH UNIT, ATTENUATED BY 36dB.

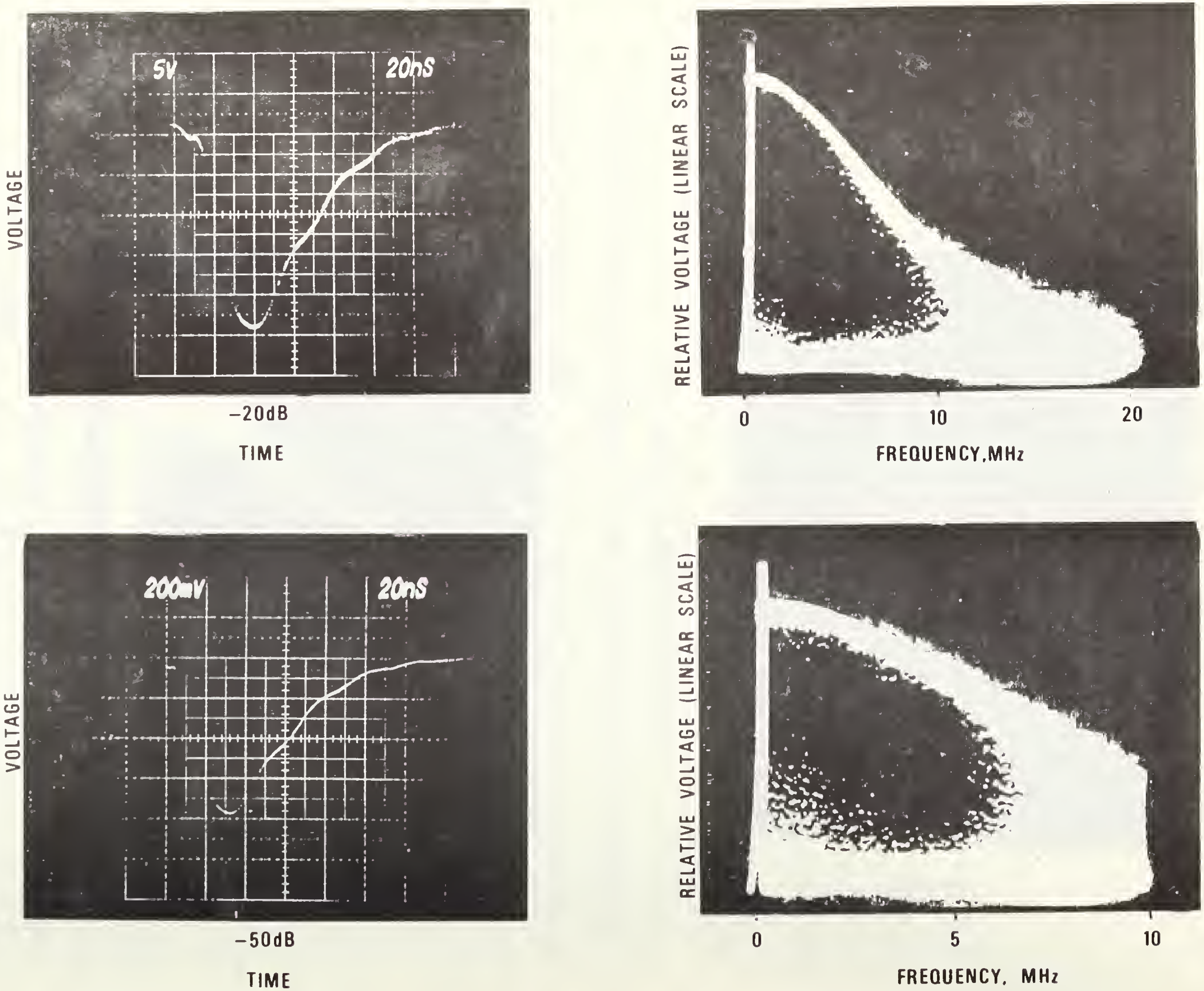


FIGURE 3 – OUTPUT PULSE WAVEFORM AND FREQUENCY SPECTRUM FOR BROADBAND PULSER.
TAKEN FROM "T/R" JACK, MODE 1, NO SEARCH UNIT, ATTENUATED.

Table 1 - Ultrasonic Reference Block Readings
Using Six Nominally Identical Search Units

	LS-1	LS-2	LS-3	LS-4	LS-5	LS-6	Spread/Average Percent
/8-in ball (.2-mm ball)	80	80	80	80	80	80	——
-0050	93.0	82.2	97.7[a]	92.3	91.2[a]	94.8[a]	+ 6.3 -10.5
-0100	49.7	50.0	58.5	54.5	51.7	61.3	+12.9 - 8.4
-0225	20.3	20.2	24.5	23.2	21.7	25.5	+13.0 -10.5
/16-in ball (.9-mm ball)	80	80	80	80	80	80	——
-0050	78.7	74.7	90.8	85.5	78.8	84.5[a]	+10.5 - 9.1
-0100	47.5	48.8	61.3	56.8	50.5	56.8	+14.3 -11.4
-0225	18.2	18.2	24.8	22.3	19.8	22.7	+18.1 -13.3
1/16-in ball (17.5-mm ball)	80	80	80	80	80	80	——
-0050	78.8	77.7	91.0	86.5	80.8	86.0	+ 9.0 - 6.9
-0100	50.3	50.8	63.5	59.0	53.0	59.7	+13.3 -10.3
-0225	20.5	20.2	26.8	24.7	21.2	24.8	+16.3 -12.3

All values are in percent of upper linear limit
All values are averages of three independent readings
(a) Not 100% resolved from front surface echo

Secondly, the variability among readings tends to increase with increasing block length in all three cases. Thirdly, there seems to be no systematic relationship between hole size and variability. These last two trends lead one to believe that the search unit characteristics contributing to the variability are distance related characteristics, such as frequency spectrum (which influences attenuation) or axial pressure distribution, rather than other characteristics such as lateral beam symmetries, sensitivity impedance. However, for completeness, most of the characteristics mentioned earlier were measured for all six search units to show more fully which are the "important" characteristics for this application.*

5.0 Search Unit Characteristics

Using the broadband pulser/receiver, a 100-MHz bandwidth oscilloscope, stepless gate, and spectrum analyzer, we recorded the signals reflected from a flat quartz plate and from a 3-0050 E 127 reference block for each search unit (figs. 4-9). From these, the center frequency, half-power bandwidth, damping, and resolution were determined. Additionally, the center frequency and half-power bandwidth were determined by the modulated radiation force method [11]. Using the tuned pulser/receiver in the commercial flaw detector, we measured the axial profile landmarks Y_o^+ and Y_1^-, -6dB beamwidth at Y_o^+, and checked for beam symmetry. We also carefully measured the values of the axial pressure amplitude (amplitude of the signal reflected from a 0.500-in (12.7-mm) steel ball) at the water distances

*Obviously, if the application is the inspection for small defects near the surface of a thick section of a highly attenuating material, sensitivity, penetration, and resolution are "important". Here we are concerned only with specifying search units for reference block calibration.

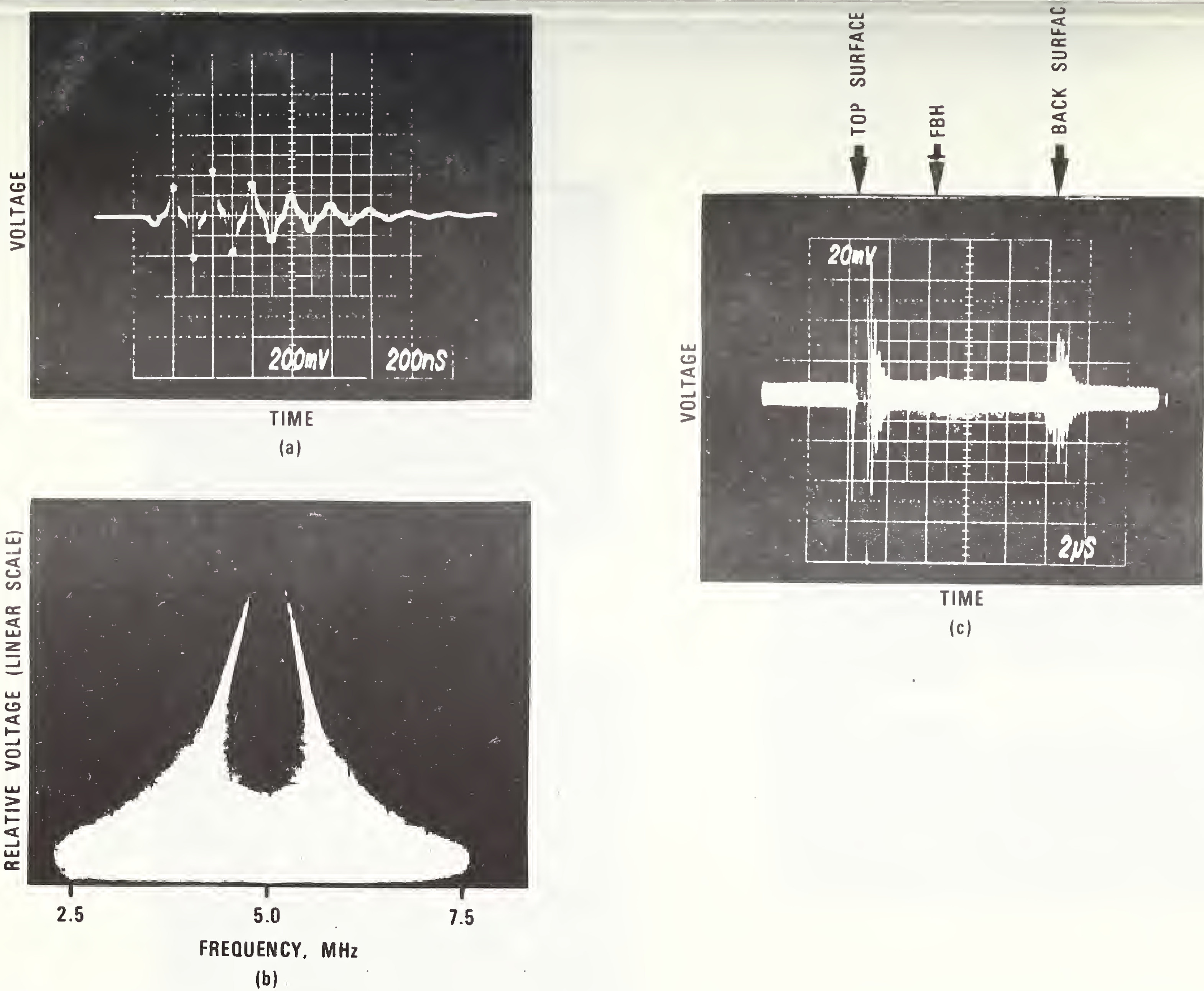


FIGURE 4 – SEARCH UNIT LS-1. (a) WAVEFORM AND (b) FREQUENCY SPECTRUM OF PULSE REFLECTED FROM FLAT QUARTZ PLATE. (c) REFLECTIONS FROM 3-0050 REFERENCE BLOCK. BROADBAND PULSER.

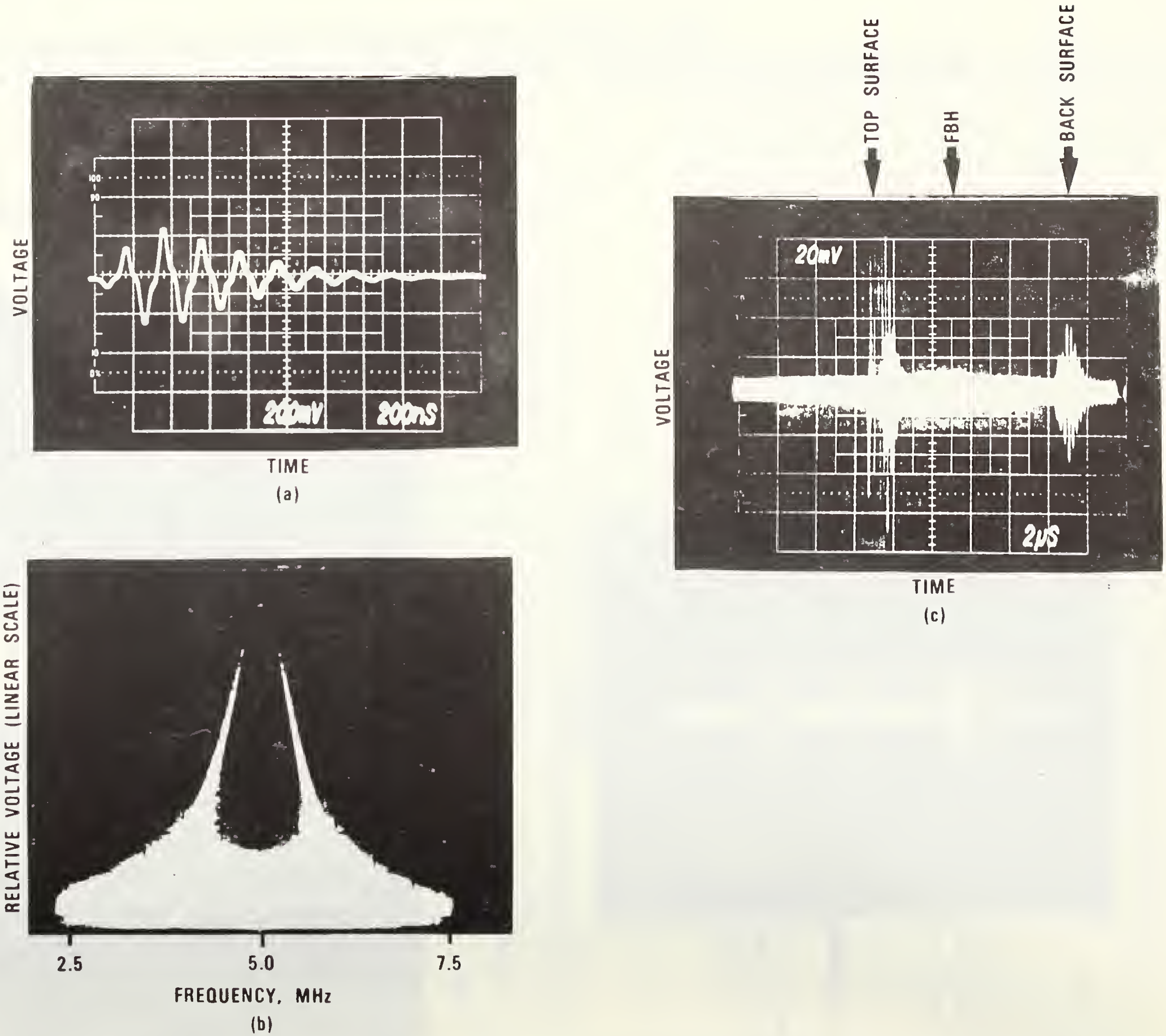


FIGURE 5 – SEARCH UNIT LS-2. (a) WAVEFORM AND (b) FREQUENCY SPECTRUM OF PULSE REFLECTED FROM FLAT QUARTZ PLATE. (c) REFLECTIONS FROM 3-0050 REFERENCE BLOCK. BROADBAND PULSER.