AD-766 310

PROTOTYPE PORTABLE ULTRASONIC SPECTROSCOPE

Kenneth A. Fowler, et al

Panametrics, Incorporated

Prepared for:

Army Materials and Mechanics Research Center

May 1973

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AMMRC CTR-73-17

PROTOTYPE PORTABLE ULTRASONIC SPECTROSCOPE

MAY 1973

KENNETH A. FOWLER, GERALD M. ELFBAUM,
BRIAN J. SPENCER and JEAN L. HUNERWADEL

PANAMETRICS, INC.
Waltham, Massachusetts 02154

Final Report - Contract DAAG46-73-C-0096

Approved for public release; distribution unlimited.

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classif

1. ORIGINATING ACTIVITY (Corporate author) PANAMETRICS, INC. 221 Crescent Street Waltham, Massachusetts 02154	2a. REPORT SECURITY CLASSIFICATI UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

PROTOTYPE PORTABLE ULTRASONIC SPECTROSCOPE

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - January 26, 1972 to May 26, 1973

5. AUTHOR(S) (First name, middle initial, last name)

Kenneth A. Fowler, Gerald M. Elfbaum, Brian J. Spencer and Jean L. Hunerwadel

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1973	~~35~~ 29	12

8a. CONTRACT OR GRANT NO. DAAG46-73-C-0096 b. PROJECT NO. PEMA c. AMCMS Code 4931.OM.6350 d.	9a. ORIGINATOR'S REPORT NUMBER(S) AMMRC CTR-73-17 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172

13. ABSTRACT

A portable ultrasonic system designated as the Model 5030 Ultrasonic Spectroscope, has been completed. This system displays both the time-domain rf signal and the spectral content of selected portions of the signal on a single CRT. This advancement significantly reduces the complexity of operation with no loss in system capability. Typical uses of the system include thickness gaging, attenuation measurements, flaw characterization, and transducer evaluation. The characteristics and specifications of the system are summarized. The report also contains oscillograms of typical CRT displays and a bibliography of papers covering a variety of applications.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nondestructive Tests						
Ultrasonic Frequencies						
Spectroscopy Instruments						
Thickness Gages						
Sound Transducers						

AMMRC CTR 73-17

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Technical Report by

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D/A Project PEMA
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FOREWORD

This work was performed with the cooperation and guidance of O. R. Gericke, of AMMRC, under Contract No. DAAG46-73-C-0096, Project PEMA, AMCMS Code 4931.OM.6350.

This project has been accomplished as part of the 'J. S. Army Materials Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures or prototype equipment (in mechanical, chemical, or nondestructive testing) to insure efficient inspection methods for materiel/material procured or maintained by AMC.

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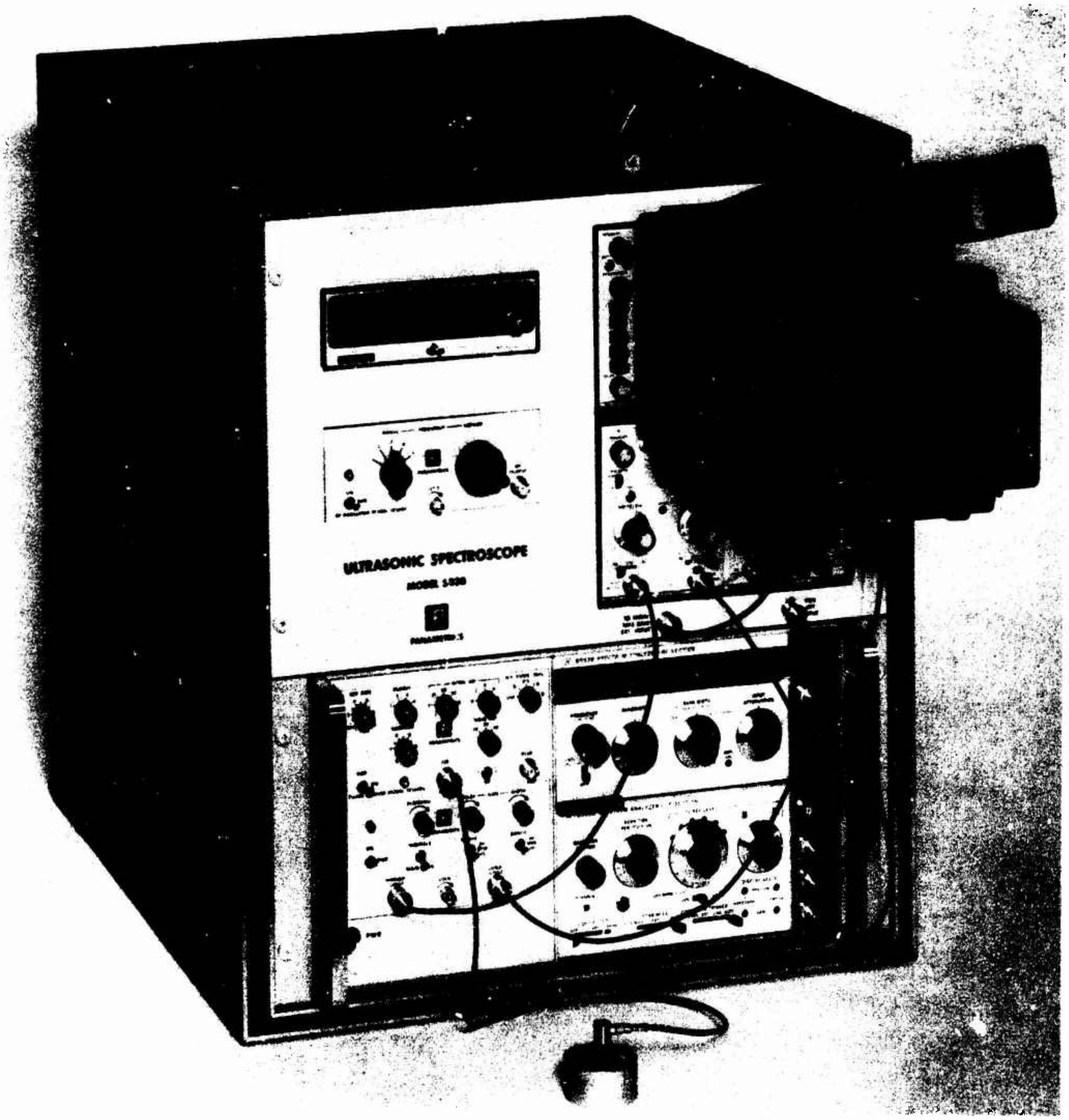
ULTRASONIC SPECTROSCOPE

MODEL 5030



ABSTRACT

A portable ultrasonic system designated as the Model 5030 Ultrasonic Spectroscope, has been completed. This system displays both the time-domain rf signal and the spectral content of selected portions of the signal on a single CRT. This advancement significantly reduces the complexity of operation with no loss in system capability. Typical uses of the system include thickness gaging, attenuation measurements, flaw characterization, and transducer evaluation. The characteristics and specifications of the system are summarized. The report also contains oscillograms of typical CRT displays and a bibliography of papers covering a variety of applications.

INTRODUCTION

Spectrum analysis of ultrasonic pulse-echo signals was pioneered by O. R. Gericke of AMMRC in the early 1960's and several papers resulted from that early work.[1-8] In the interim refinements have been made in the instrumentation and several applications have been found for which real-time spectral analysis can be employed to advantage.[9-12] One of the major impediments to field utilization of the spectrum analysis technique has been the size and complexity of the instrumentation required to make the measurements. This has now been largely overcome with the Model 5030 Ultrasonic Spectroscope. It is anticipated that this system will permit field utilization of ultrasonic spectrum analysis techniques in a variety of applications.

CHARACTERISTICS

General

The Model 5030 Ultrasonic Spectroscope is a general purpose instrument that provides accurate measurements of waveform and spectral content of ultrasonic signals. A high-energy broadband ultrasonic pulser-receiver is combined with a precision stepless gate, high frequency oscilloscope, and spectrum analyzer to permit measurements over the frequency range of 100 kHz to 50 MHz. A variable frequency rf oscillator and frequency counter are also provided for accurate calibration of the spectrum analyzer. The entire system is packaged in a relatively small single mainframe to allow reasonable portability.

Pulser-Receiver

The pulser-receiver module generates the electrical pulse that is transformed to a mechanical pulse by the transducer. The pulse repetition rate is variable from an internal generator. The signals produced by the transducer as a result of echo returns are amplified by the receiver portion of the pulser-receiver and are then available for display on the oscilloscope and for gating and spectrum analysis. Internal, high-pass filters are also available for improved baseline recovery when low frequency transducers are used.

The following describes the controls and input and output connectors that are found on the pulser-receiver module.

A. Front Panel

1. Rep Rate Control: The Rep Rate control permits adjustment of a number of excitation pulses applied to the transducer per second from the internal repetition rate generator. Range: 100 to 5000 Hz.

2. Energy: The pulse energy control has four detent switch positions which govern the amplitude and width of the negative voltage spike applied to the transducer. Normally, the low energy positions are used for high frequency transducers while the high energy positions are utilized for low frequency transducers.

		Load	
		50 ohm	250 ohm
Pulse Amplitude	-	200V	350V

3. Damping Control: The damping control adjusts the value of the load resistor across the transducer at the input to the receiver preamplifier. The optimum setting of this control depends on the electrical impedance of transducer being used. For transducers with relatively high electrical impedance the damping control should be adjusted toward zero while for low impedance transducers a value of 8 or 9 should be used. Range: 5 to 250 ohms linear potentiometer.

4. Gain Control: The gain control is a three position detent switch which adjusts the amplifier gain to 20, 30 or 40 dB (10X, 32X, or 100X).

5. Attenuator Control: The attenuator control is a pair of detent switches which give a total of 68 dB of attenuation in 2 dB increments. The coarse control increases the attenuation in 10 dB steps from 0 to 60 while the fine control adds attenuation to the value showing on the coarse control in 2 dB increments.

6. H. P. Filter: This five position detent switch permits high pass filters to be added with 0.1, 0.5, 1.0, and 2.0 MHz cut-off frequencies. For full bandwidth operation this control should be in the "out" position. The roll-off of these filters below the cut-off frequency is 6 or 12 dB per octave.

7. T/R Connector: For single transducer, pulse-echo operation, the transducer cable should be connected to T/R connector with the toggle switch located between the T/R and RCVR connectors in the "1" position.

8. RCVR Connector: For dual transducer operation the transmitting transducer should be connected to the T/R connector and the receiving transducer to the RCVR connector. For dual transducer operation, the toggle switch between these connectors should be in the "2" position.

B. Rear Panel

1. Signal Output Connector: The amplified rf signal is available here for input to the gate module.

2. Sync Output Connectors: The sync pulse from the repetition rate generator is available from two connectors. One is applied to the sync input of the gate module - the other is connected to the Pulser/Receiver sync input on the rear panel of the oscilloscope.

Gate

The gate module provides a "stepiess" gate capability for selecting the part of the signal train to be analyzed for spectral content. The "stepless" nature of the gate is derived from a double-balanced mixer (DBM) circuit and permits a small segment from the time-domain signal train to be passed by the DBM during the time the gate pulse is on. The gate pulse position and width are easily controlled to cover a wide range of values.

The A-scan or time-domain presentation on the oscilloscope is taken from the marked output connector on the gate module. This signal is the output from the pulser-receiver with a pedestal superimposed on the signal that corresponds to the position and width of the gate pulse. This enables the operator to note the position of the gate from the time-domain waveform and follow it as the controls are adjusted.

An additional feature of the gate module is the ability to select the reference signal from which the gate delay time is initiated. The gate delay may be referenced to the main bang which is common for contact measurements or it may be referenced to a selected interface echo. Unwanted interface echoes may be eliminated by adjustment of a "blank" pulse which eliminates signals for up to 100 μ sec after the main bang. The interface gating mode is most useful for immersion measurements where the water-path may vary and it is desirable that the gate position remain fixed with respect to specific distance within the part being measured.

The following describes the controls and input and output connectors that are found on the gate module.

A. Front Panel

1. Gate Delay: The gate delay is controlled by a ten-turn potentiometer and a three position toggle switch located directly beneath the potentiometer knob. This gives continuously variable control of delay time from ~200 ns to ~200μ s.

Range Switch Position	Width Range
LO	< 100 ns to 680 ns
MED	650 ns to 20 μ s
HI	10 μ s to 280 μ s

2. Gate Width: The gate width is controlled by a ten-turn potentiometer and a three position toggle switch located directly beneath it. This gives continuously variable control of the gate width from ~200 ns to ~200μ s.

Range Switch Position	Width Range
LO	50 ns to 700 ns
MED	600 ns to 20 μ s
HI	10 μ s to 300 μ s

3. Interface/Main Bang Switch: The gate delay is timed from either the main bang or a selected interface echo. When this switch is in the "main bang" position, the delay is timed from the main bang and a single pedestal is observed on the marked output indicating the gate position. If this switch is placed in the "interface" position the gate delay is timed from the selected interface echo. Further, a "blank" is activated in this mode which may be used to eliminate noise from up to 100 μ seconds after the main bang. The blank and its width are indicated by a second pedestal on the marked output signal immediately following the main bang. Commonly, main bang gating is used for contact measurements while interface gating is used for immersion measurements or measurements with a delay line or buffer transducer.

4. Blanking Control: The blanking control adjusts the width of the blanking pulse. Any signals occurring before the end of the blanking pulse cannot initiate interface triggering of the gate delay. This is particularly useful if the transducer has internal

noise, after the main bang, that is comparable in amplitude to the interface echo.
Blanking Range: 3 to 100 μs.

5. Marked Output Connector: The signal at this connector is connected to the A-channel input on the oscilloscope vertical amplifier. Pedestals of +25 mV are superimposed on the signal to indicate the position of the gate and the width of the blanking pulse if in the "interface" triggering mode.

6. Gated Output Connector: The signal at the gated output connector is the only portion of the rf signal falling in the gate window. This signal is applied to the input of the spectrum analyzer for spectral analysis.

B. Rear Panel

1. Signal Input Connector: This is connected to the signal output connector of the Pulser/Receiver module.

2. Sync Input Connector: This is connected to one of the sync output connectors of the Pulser/Receiver.

RF Oscillator: The rf oscillator provides a cw signal for checking the calibration of the spectrum analyzer. The output frequency is shown on the counter. The output frequency range for the five ranges of the oscillator are as follows:

Range Setting	Frequency
1	.7- 2.1 MHz
2	2.0- 5.2
3	4.0-10.8
4	8.2-23.3
5	12.0-35.6

Oscilloscope, Spectrum Analyzer, and Counter

A. Oscilloscope

An H. P. 181A storage oscilloscope mainframe with a 1801A dual channel vertical amplifier and a 1825A time base and delay generator were used. The storage feature of this variable persistence oscilloscope is ideal for this application, however in the normal writing mode the intensity is rather low. In future systems a rack mount configuration is recommended since this would be a more efficient front panel layout. At the time the oscilloscope was procured for this prototype system there was an uncertainty as to whether the pulser/receiver and gate would be housed in the CRT well of the 140A mainframe. If this had not been possible, the bench-type mainframe would be the best choice.

The vertical amplifier, time base and mainframe were all modified to permit both waveforms to be displayed simultaneously. Because of the large difference in writing speed between the time-domain and spectral displays, a spectrum intensity control is required that regulates the ratio of time-domain sweep to spectrum sweeps. This control combined with other instrument settings permits adjustment for equal intensity of the two sweeps.

B. Spectrum Analyzer

An H. P. 140B mainframe with a Model 8553B rf section and a Model 8552A rf section make up the spectrum analyzer. The CRT was removed from the 140B mainframe and the position of several components of the power supply changed so that the pulser/receiver and gate would be housed in this mainframe in the CRT well.

C. Counter

A Heath-Schlumberger counter is used to monitor the output of the rf oscillator used to check calibration of the spectrum analyzer.

SPECIFICATIONS

I. System Components

A. Panametrics Model 5052 PRS Pulser-Receiver/Gate Module

B. Panametrics Model 5050 RF CW Oscillator

C. Hewlett-Packard Model 181A Oscilloscope Mainframe (Modified) with

1. Model 1801A Dual Channel Vertical Amplifier (Modified)
2. Model 1825A Time Base and Delay Generator (Modified)

D. Hewlett-Packard Model 140B Oscilloscope Mainframe (Modified) with

1. Model 8553B Spectrum Analyzer RF Section
2. Model 8552A Spectrum Analyzer IF Section

E. **Hewlett-Packard Model 197A Oscilloscope Camera**

F. **Heath-Schlumberger Model SM-104A Solid-State Counter**

User is referred to Original Manufacturers Manuals for specifications on equipment not manufactured by Panametrics.

II. **5052 PRS**

A. **Pulser-Receiver**

(Pulser)

Pulse Amplitude	200 Volts into 50Ω 350 Volts into 250Ω
Repetition Rate	Int - 100-5000 Hz
Damping Range	5 to 250Ω
Rise Time	10 nsec (50Ω damping and #1 energy setting)
Pulse Width	20-1000 nsec (1/2 amplitude points) adjustable in 4 steps
Recovery Time to Baseline	350 nsec min under optimum conditions
Sync Signal Output	> +2 Volts 50Ω, t_r = 200 ns, t_{pw} = 30μs
Ext Trig Requirements	+5 Volts (15V max) into 50Ω, 100 ns min pulse width

(Receiver)

Voltage Gain	100 (open circuit) ± 10%
Input Impedance	500Ω
Output Impedance	50Ω in series with 50 μf
Attenuator	0-68 dB in 2 dB steps
Noise	40 μV rms referred to the input (BW = 35 MHz)

Bandwidths	100 Hz-30 MHz 0:1-30 MHz 0. 5-30 MHz 1. 0-30 MHz 2. 0-30 MHz	Selectable by HP Filter Switch
Maximum Output Voltage	± 1 Volts (open circuit), ± 0. 5 Volts into 50Ω	
Power Requirements	115/230 Volts, 50-60 Hz, 7 Watts	

B. Stepless Gate

Gate Delay Range	< 0. 2 to > 200μ s in three switched ranges. Continuously variable within each range.
Delay Mode	From main bang or selected interface echo.
Gate Width Range	< 0. 2 to > 200μ s in three switched ranges. Continuously variable within each range.
Blanking Delay	100μ s max. Used to select desired echo for interface gating up to 100μ s after main bang. Active only in Interface Gating Mode.
Input Signal Level	1 Volt pk-pk max
Input Impedance	1000Ω
Input Sync Level	+2 to +5V max into 50Ω
Output (Gated) Level	1 V pk-pk max into external 50Ω
Output (Marked) Level	1 V pk-pk (Z_o = 50Ω)
Gate Bandwidth	60 MHz
Switching Transients	< 25 mV
Operating Temperature	20^oF-120^oF
Power	115/230 Volts, 50-60 Hz

OPERATING INSTRUCTIONS

Cable Connections

The following lists the cable connections that must be made prior to operation. Cables are provided for all connections listed.

A. Front Panel

1. Marked Output to Oscilloscope vertical amplifier A channel
2. Gated Output to Spectrum Analyzer rf input
3. Pen Lift Output (Spectrum Analyzer IF Section) to Pen Lift Input
4. Vertical Output (Spectrum Analyzer IF Section) to Oscilloscope Vertical Amplifier Channel B
5. Scan In/Out to Oscilloscope External Horizontal Input
6. External Input (Oscilloscope Time Base - left side) to "To Main Time Base Ext. Input

B. Rear Panel

1. 5 Volts to Scope
2. Sync Output (PR Module) to P/Rec Sync on Oscilloscope
3. Time Base Ext. Input
4. Scope Z-axis to Z-axis Input
5. Pen Lift Input
6. Signal Output (PR Module) to Signal Input (Gate Module)
7. Sync Output (PR Module) to Sync Input (Gate Module)
8. Connect all power cords to terminal strip. Photographs of the front and back panels are shown in Figs. 1 and 3 in Appendix.

Initial Turn-On Procedure

WARNING: **It is important that the following be read and understood before attempting to run the instrument. Failure to do so may cause serious damage to the oscilloscope.**

A. Control Settings

For initial start-up set the controls as follows:

1. Oscilloscope

a. Mainframe

Intensity: Full counterclockwise (ccw)
Persistence: Full ccw
Mode Selector: Write mode
Horizontal Position: Centered
Spectrum Intensity: Full ccw
Display: Alternate

b. Vertical Amplifier

Channel A: Polarity +, 0.2 V/div, AC coupled position control 2 o/clock
Channel B: Polarity -, 0.2 V/div, DC coupled position control 11 o/clock

c. Time Base

Main Trigger Level: Just CCW of 0 (zero at 10 o'clock)
Holdoff: Full ccw
Display: Left button out, Right button in
Delayed Trig Level: Full ccw
Delay Dial: Full ccw
All Buttons out except the following:
Ext. Trig, Neg. polarity, Normal Trigger Mode
Time per div: 1 μ sec/div

READ MANUAL ON THE OSCILLOSCOPE

2. Spectrum Analyzer

a. RF Section

Range MHz: 0-11
Frequency: 10 MHz
Bandwidth: 100 kHz
Scan per division: 2 MHz
Input Attenuation: 10 dB
Tuning Stabilizer: Off

b. IF Section

Baseline Clipper: Inoperative
Scan time per division: 5 millisec
Linear Sensitivity: 2 mV/div
Multiplier: 0.5
Log-Linear Switch: Linear (blue)
Video Filter: Off
Scan Mode: Int.
Scan Trigger: Auto

3. Pulser-Receiver

Rep Rate: Max
Energy: 2
Atten: 20 +4
H. P. Filter: Out
Damping: 8
Gain: 20 dB
Mode Switch: 1

4. Gate

Blanking: Full ccw
Interface-Main Bang Switch: Main Bang
Delay: 2-1/2 turns cw Range: Med
Width: 1-1/2 turns cw Range: Med

5. RF Oscillator

Range: 4

With the controls set as stipulated above, plug the terminal strip into a 110V, 60 Hz power line. Make sure that the terminal strip is on:

1. Connect an M202 transducer, 10 MHz delay line type, to the T/R jack on the pulser-receiver
2. Push the green power switch on the oscilloscope
3. Wait three minutes and press the erase button
4. Turn on Spectrum Analyzer Mainframe, Pulser/Receiver, Gate, RF Oscillator and Counter
5. Increase intensity, in the write mode, until a trace is observed. Do not increase the intensity beyond about the 12 o'clock position.
6. Increase the persistence to about the 12 o'clock position. The echo from the delay line should be clearly visible. Adjust focus for maximum sharpness of trace.

7. Turn the Horizontal position ccw until the arrow is at about 11 o'clock. The negative going main bang pulse should be at the left of the screen.

8. Make sure that the first back echo is in the gate as evidenced by the 25 mV pedestal. If not, adjust the delay or width control until it is.

9. Increase the Spectrum Intensity until the spectrum trace begins to show. This should be about 4 turns on the Intensity Control knob.

10. Adjust the Vertical position of the B Channel until the baseline of the spectrum sweep is just off the bottom of the screen. If this is not done the lower part of the spectrum will "bloom" and a very unsatisfactory display will result. At this point the display should appear as Fig. 4 in the Appendix.

11. Delay the sweep by turning the delay dial of the oscilloscope so that the first echo is at the left edge of the screen. Then expand the sweep by turning the outer knob on the time/div selector to 0.1 μs/div.

12. Check the calibration of the center frequency by teeing in the output from the RF oscillator into the spectrum analyzer. This will cause a drop in amplitude of the spectrum display due to the loading effect of the RF oscillator, but this can be compensated for by adjusting the display adjust on the IF section.

13. Adjust the RF oscillator frequency to 10 MHz.

14. Adjust the frequency knob on the RF section of the spectrum analyzer so that the 10 MHz marker is exactly at center screen. The resulting display should now look like Fig. 5 in the Appendix.

This is the general procedure that must be followed in turning the unit on and setting up the display. Although the normal mode of the oscilloscope is useful in setting up because of the instant response, the trace intensity is quite low and care must be taken not to turn the intensity up beyond that required in the "write" mode.

APPLICATIONS

One of the potential applications for this system that is of considerable interest is thickness gaging. The spectrum analysis approach offers considerable advantages in gaging thin materials where "impulse induced resonance" occurs[9,12] or in other situations where pulse reverberations occur but the signal-to-noise is too low for automatic gages to make reliable measurements. Figure 5 in the Appendix illustrates the use of the spectrum analyzer as a thickness gage. Additional examples are given in the literature.[9] The thickness measurement is derived from the fact that the reciprocal of the reverberation period and all the multiples thereof that fall within the useful bandwidth of the transducer show up as amplitude peaks in the frequency domain of the spectrum analyzer. Therefore, the fundamental (lowest) frequency peak

$$f_1 = \frac{V_L}{2t}$$

or

$$\Delta f = f_1$$

where V_L is the longitudinal wave velocity and t is the thickness. The spacing between frequency Δf peaks is equal to the fundamental frequency. As the thickness increases the spacing between frequency peaks decreases.

Other applications are well documented in the literature.

ACKNOWLEDGMENTS

The authors wish to acknowledge the helpful comments and suggestions of L. C. Lynnworth, E. P. Papadakis and F. Capobianco during the course of this program.

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APPENDIX

Figures

Fig. 1. Photograph of front panel showing cable connections.

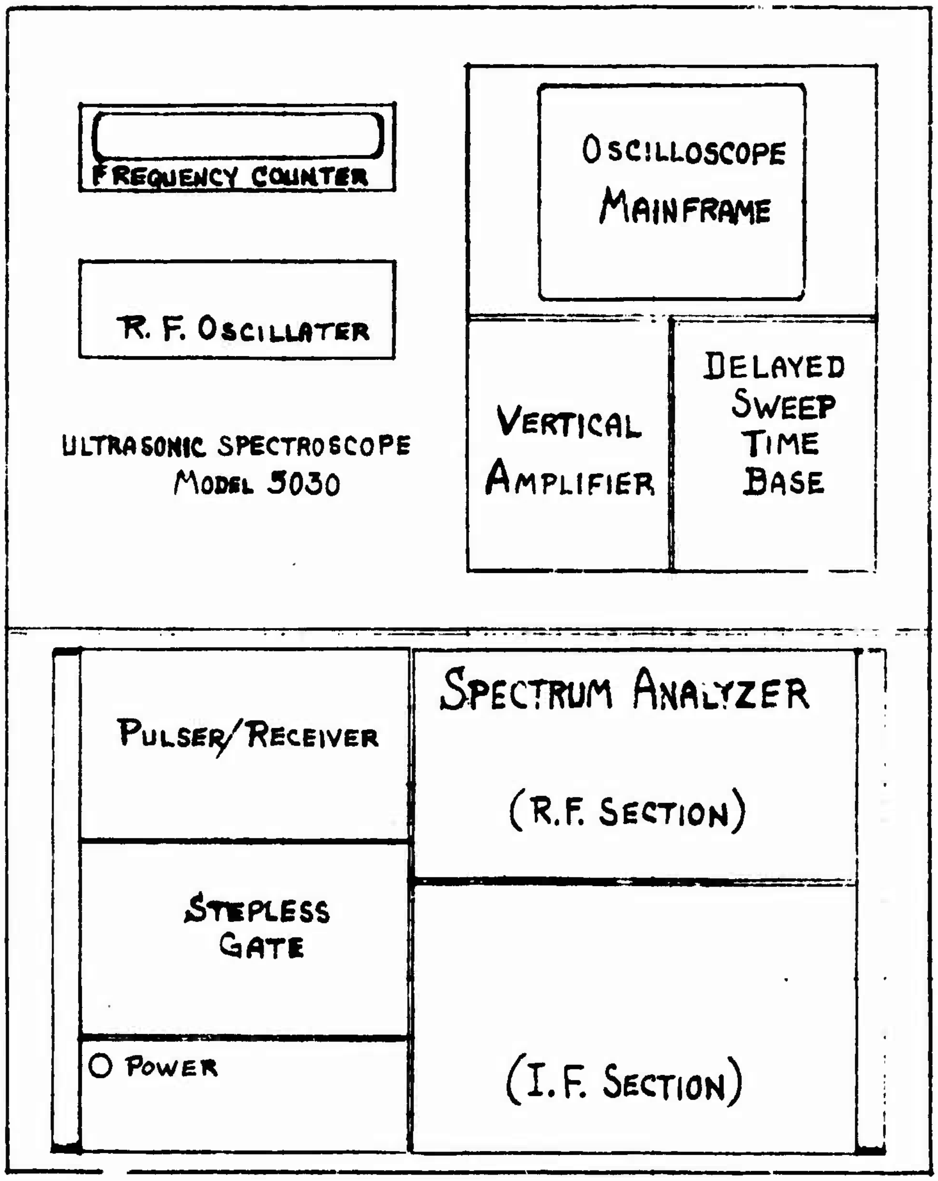


Fig. 2. Schematic of system front panel.

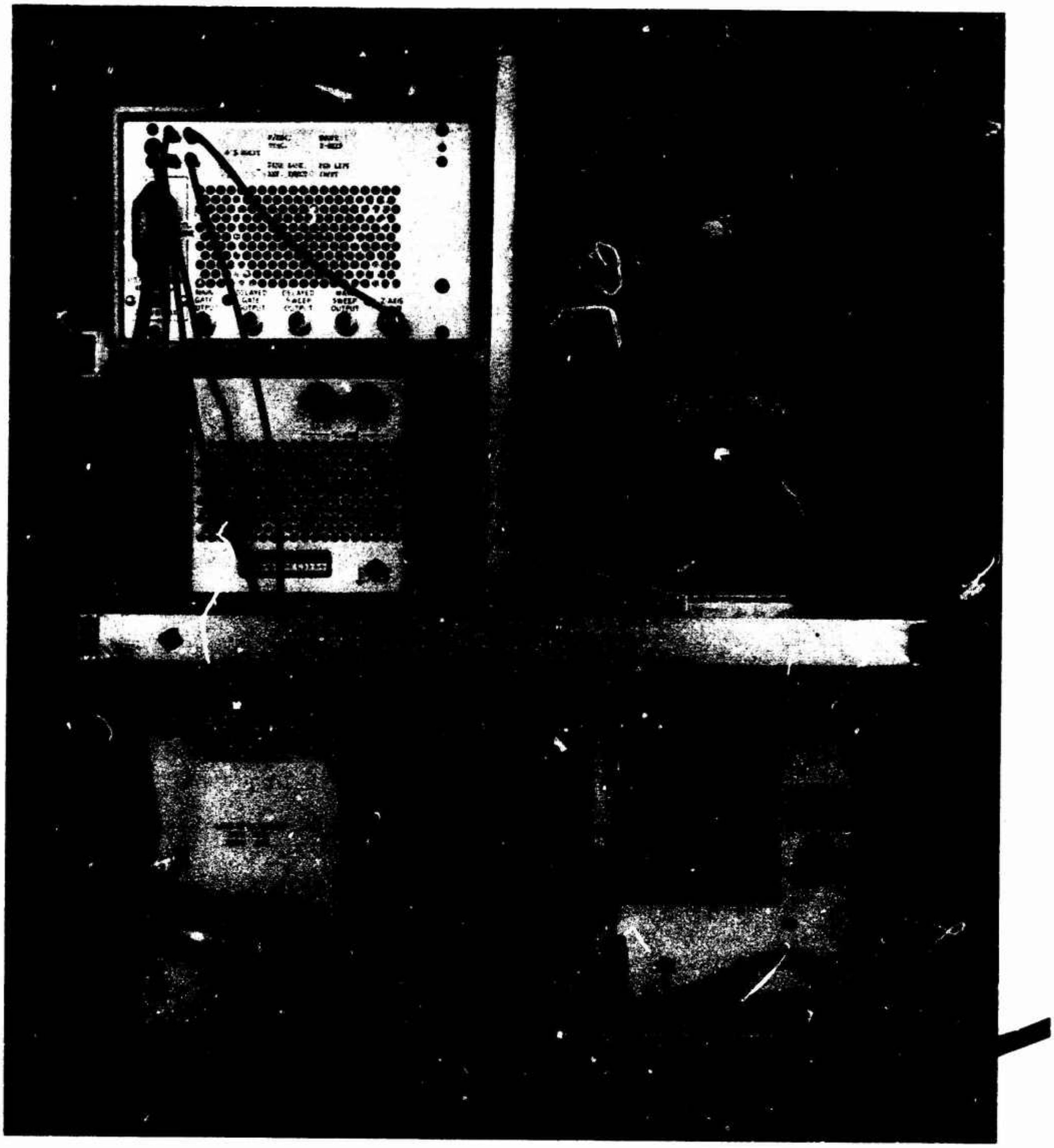
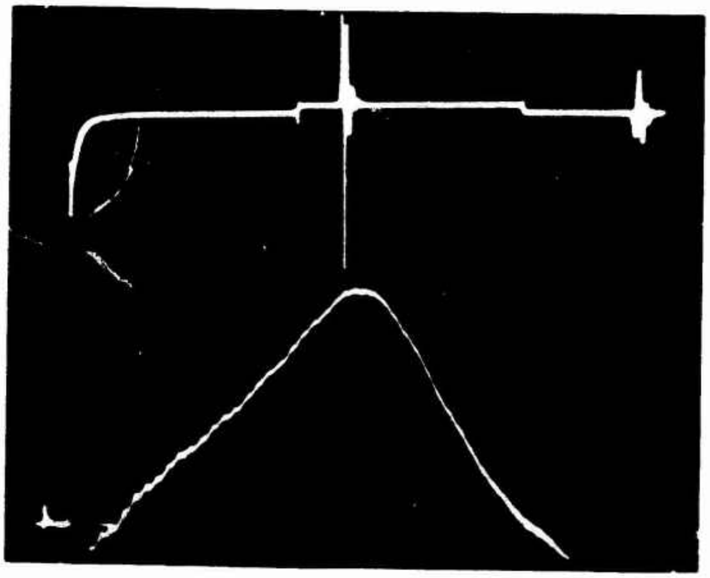


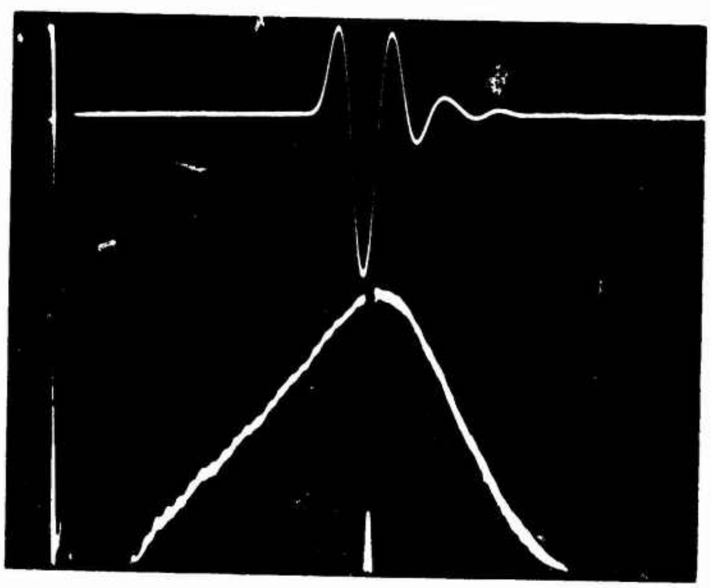
Fig. 3. Photograph of back panel showing cable connections.



0. 2 V/div
1. 0 μs/div

10 MHz Center
2 MHz/div
100 kHz BW

Fig. 4. Oscillogram showing CRT presentation that should be observed during setup procedure.



0. 2 V/div
0. 01 μs/div

10 MHz Center
2 MHz/div
100 kHz BW

Fig. 5. Oscillogram showing CRT presentation that should be observed after setup procedure with markes superimposed on spectrum display.

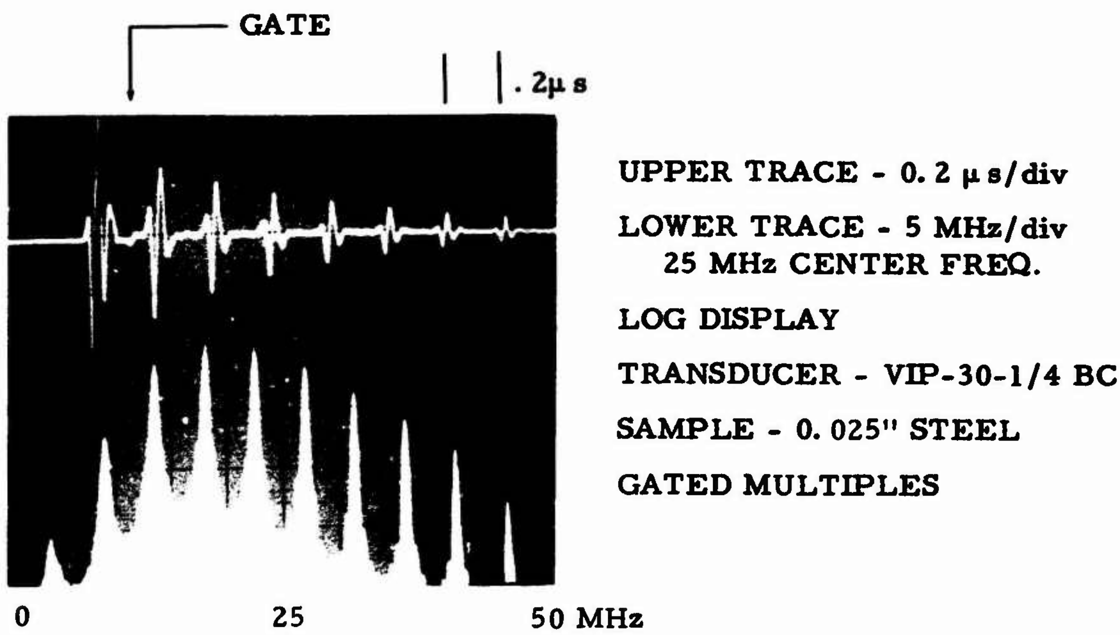


Fig. 6. Oscillograms of stored time and frequency domain displays for thickness gaging application.