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NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA
SIX-FOOT LINE TRANSDUCER CALIBRATION PROCEDURE. EXPLAINS THEORY--ETC(U)
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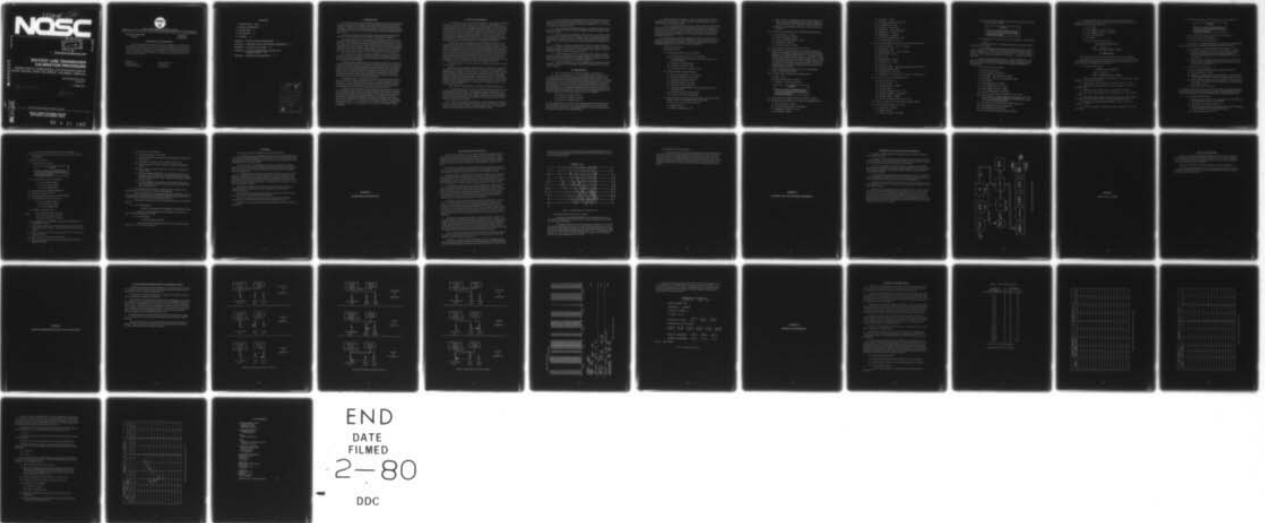
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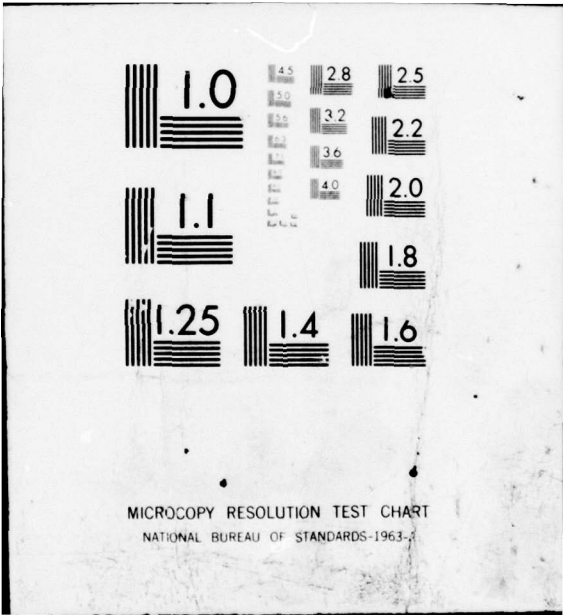
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SIX-FOOT LINE TRANSDUCER CALIBRATION PROCEDURE.

Explains theory, methodology, and procedures used at Sensor Accuracy Check Site (SACS), Long Beach, California.

SACS/FORACS Group
(Code 47)

17 October 1979

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A N A C T I V I T Y O F T H E N A V A L M A T E R I A L C O M M A N D

SL GUILLE, CAPT, USN

Commander

HL BLOOD

Technical Director

ADMINISTRATIVE INFORMATION

This Technical Document presents a procedure for calibration of the SACS 6-foot line transducer at Long Beach, CA. Data will be collected by NO SC, Code 47, during the use of this procedure as a basis for further improving the repeatability measurement quality of the line transducer. Mr. DA Smith of the Applied Research Laboratory, University of Texas is to be acknowledged for his efforts in preparing this calibration procedure, under contract N66001-78C-0329.

Released by
FD Durrett, Head
SACS/FORACS Group

Under Authority of
Dr. RW Sarvis,
Support Director

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I. INTRODUCTION

This technical document concerns the theory, method, and procedures by which the 6-foot line transducer in the moveable carriage at the Sensor Accuracy Check Site (SACS), Long Beach, California is to be calibrated. The equipment, physical and electronic setup, detailed data acquisition procedure, data quality assurance, and data reporting requirements are included. The procedure results in a measurement-to-measurement repeatability better than +0.7 dB

This procedure supersedes any previously used method of calibrating the SACS transducer including the procedure documented in the SACS Operator's Manual.

The principal ship sensor testing capability at SACS depends upon an accurate, repeatable acoustic calibration of the 6-foot line transducer, mounted in a 90° corner reflector, which is in turn mounted on the movable carriage and which can be positioned in depth and azimuth around a ship under test. This transducer, called the line transducer, comprises 39 individual electroacoustic elements which are wired to form three separate, independent transducer sections. They are called the Long, Medium, and Short sections. The operator must select the appropriate transducer section for calibration for an upcoming ship test.

The selected section of the line transducer is calibrated by a reciprocity technique. Reciprocity calibrations are used by acoustical laboratories to yield primary standards. In so far as the reciprocity assumptions are obeyed, the SACS line transducer should be equivalent to a primary acoustic standard.

The line transducer is calibrated by the three transducer, spherical wave reciprocity method, where all three transducers are assumed to be reciprocal (that is, linear, passive, and reversible) and that all measurements are made in the farfield and freefield. Two auxiliary transducers (units A and B) are suspended from a boom in the field of the line transducer (unit C), which is the object transducer in the calibration. The minimum test range used (from unit C to unit A) is chosen to be in the farfield at all frequencies of interest. The test depth and the choice of receive gate settings assure the measurement is freefield (no surface or bottom reflections can corrupt the measurement).

An important property of the reciprocity technique is that all computations involve ratios of measurements, thus, the absolute accuracy of a voltage measurement is of no importance. It is only required that the measurement system be linear, not absolutely accurate. Measurements of current must be accurate. Therefore, a precise and accurate current probe, used to convert current to voltage measurements, is required.

A standard reciprocal calibration requires only three measurements (a measurement is defined as driving current I into one unit and measuring the output voltage E on another unit). Sometimes a fourth measurement is obtained to support (not prove) the assumption of reciprocity invoked against some single transducer unit. At SACS, all three units are assumed to be reciprocal, and all six possible measurements are obtained. From these six measurements, the calibration constants for each of the three transducers may be computed at least eight separate ways. The average of these calibration estimates is equivalent to computing once with averaged measurements, which is what the TRCAL2 program accomplishes.

II. GENERAL DESCRIPTION

Each calibration measurement at SACS (for example, A → B) is actually accomplished many times. The system is setup to drive the A unit and receive with the B unit. The computer then proceeds to pulse A and sample the voltage from B at a specified time. This sampled voltage is a root mean square (RMS) sample of the voltage over a 2 msec interval. The voltage in dB, as well as other qualities, are printed on the Statos printer. After a short delay, set by the repetition rate control on the DRU panel, the operation is repeated and recorded on Statos. After a predetermined number of samples have been taken, the program computes an RMS average and sample variance. The average sample is presented on the CRT screen. If the average value, variance, and samples are judged good, then the operator selects another setup, for example, A → C, and repeats the procedure.

Checks of the method, including local acoustical conditions and operator care in performing the measurements, are indicated by operator inspections of the data, and by quality control inspections of the data at a later time. These inspections include: (1) checking the list of samples on Statos for outliers or data trending (tending to rise or fall with time), (2) checking that the variance is less than a predetermined limit. If the measurement fails this inspection, the measurement must be repeated. After all six measurements have been successfully completed, the measurement average values will be presented in pairs on the CRT. The pairs (for example, A → B and B → A) must be equal, or not more than 0.5 dB apart. This equality supports the reciprocity assumptions, supports the free acoustic path assumption, and checks the operator's drive current adjustment and setup.

If the pair averages are unequal by more than 0.5 dB both measurements of the pair must be repeated.

After successfully obtaining the three equal pairs of measurements, a calibration computation can be requested from the keyboard. The results of the computation are calibration values for all three transducer units. A final check can then be made by comparing the microphone sensitivity of units A and B to their historical values. These should be within ± 0.7 dB of their historical averages. Unit C (the line transducer section being calibrated) can then be assumed to be within ± 0.7 dB of its true value. If A, B, or C do not compare favorably with historical values, the entire calibration must be executed again. Finally, the operator must determine if some transducer has changed properties, or if the procedure has been misapplied.

A line calibration is accomplished by performing the following detailed actions:

A. Select the line transducer section to be calibrated and the frequencies at which the calibrations are to be performed. The information required to make the selection is obtained by determining the sonars to be calibrated, their depth below ship waterline, and the height of the array which must be insonified. Appendix A describes the SACS line transducer, and indicates which line section should be used to calibrate sonars of various frequencies, depths, and array heights.

B. Rig the boom and auxiliary transducers. The line transducer and reflector should be cleaned, and the auxiliary transducer cleaned and wet with detergent. Weights are attached below each auxiliary transducer. Depths are adjusted to the 22 foot mark, the carriage set to the required depth, and the time and tide level recorded.

C. Record ancillary data. Items required are state of tide (tide level and ebb or flow), wind speed and direction, general weather (sunny, warm, cloudy, etc.) and air temperature. The sound velocity should be measured and recorded at 17, 22, and 27 feet. The velocimeter is to be left at 22 feet.

D. Setup console and load calibration program. Appendix B contains a block diagram of the equipment needed to measure voltage and the equipment needed to drive and measure current.

E. Acquire data and make judgements. Select a frequency. Set the filter. Select a measurement, for example A → B, drive A, adjust current, receive with B, set gate delay and gate open time, instruct computer to take data. Inspect data printed on Status and decide to keep or repeat. When complete, select another measurement, acquire data, and judge.

F. Calibrate and compare to historical data. When all six measurements at a frequency have been successfully obtained, request the program to calibrate. Compare the microphone response of each transducer to the recorded average. Accept or reject the calibration. Continue calibrations for other frequencies.

G. Comply with data requirements. Data requirements are listed in detail in Section V, Records, of this instruction. In summary, data must be included in the historical set, data must be formatted and sent to NOSC for quality control purposes, and data must be entered into the computer for ship calibration purposes.

H. Unrig boom and transducers. At the completion of the last frequency and/or transducer section, the boom and auxiliary transducers and weights must be retrieved, cleaned, and stored.

III. PREPARATION

A. Select the line transducer section to be calibrated. (See Appendix A.)

B. Rig the calibration boom. The TR-225/WQM auxiliary transducers are to be weighted with about 15-pound weights attached 20 feet below the transducers; The TR-225 transducers must be cleaned and wet with detergent before immersion. The weights and transducers are put over the side and the boom rotated perpendicular to the rail and pinned into place. The transducers are lowered until reaching the large white mark on the cable, indicating 22 feet deep. The carriage is positioned so that the corner reflector is directly below the boom. A triangular red mark on top of the carriage reel gear box marks the reflector and line transducer center. The line transducer carriage is then lowered to the set depth, depending upon which line transducer section is to be calibrated.

For section L, set carriage to 22 feet.

For section M, set carriage to 23.25 feet.

For section S, set carriage to 20.5 feet.

The water tight junction box to the left of the carriage manual controls contains the transducer select switch. Select the line section to be calibrated by the rotary switch in the upper left hand corner of the box. The carriage should be in local control mode, selected by a switch to the right of the carriage control box.

C. Record ancillary data. Appendix C contains a form that must be filled in at the completion of boom setup. The form contains data that will help discover causes of calibration scatter encountered in the future.

One item of ancillary data is sound velocity at three depths. These data should be taken after boom rigging and before acoustical data is acquired. The velocimeter is lowered to 17 feet, 22 feet, and 27 feet. The sound velocity is recorded at each level, and finally, the velocimeter is to be parked at 22 feet deep. Sound velocity measurement at that depth will be recorded automatically on the computer output as each acoustical measurement is acquired.

D. Setup console for calibration. Appendix B contains an equipment block diagram and describes the general setup. Following is a list of patch panel connections and equipment settings required for calibration. The TR-225 transducer leads are routed through Distribution Box B, patch 3. The connections should be:

TR-225A (138) to J-4, and

TR-225B (139) to J-8.

- (1) At the patch panel PP-1, patch the following:
 - (a.) S/A signal + gate to Scope 1, Ch. A, with a plug.
 - (b.) Current Monitor to Filter In with a cable long enough to reach over the patch panel.
 - (c.) Filter Out to 463 In with a plug.
 - (d.) 463 Out to S/A In with a cable.
 - (e.) Enable Gate to Scope 1, Ch B with a cable.
- (2) At Patch Panel PP-2, patch the following:
 - (a.) Scope 1 Trig to DRU Preset 1 with a plug.
 - (b.) OSC Trig to DRU Preset 2 with a plug.
 - (c.) Synth Out to PA-50 In with a plug.
 - (d.) PA-50 Out to Elgar In with a plug.
 - (e.) Elgar Out to Tuner In with a plug.
 - (f.) Tuner HI to Carriage HI with a cable long enough to reach the entire patch panel.
 - (g.) Carriage Low shorted with shorting plug.
 - (h.) Tuner Low shorted with shorting plug.
- (3) Connect Scope 2, Ch A in Unit 4 to array transducer tuner in Unit 5, BNC labeled V output. Use a long BNC-to-BNC external cable.
On Scope 2, Unit 4, set the following controls.
 - (a.) Display channel A.
 - (b.) Channel A volt/division to 20.

- (c.) Rotate calibrate control Channel A fully counter clockwise. The scope should now read RMS volts, thus, number of centimeters peak-to-peak times 20 gives transducer drive voltage in RMS volts.
 - (d.) Adjust sweep and trigger to display wave form when driving any transducer.
- (4) At the Frequency Synthesizer, Unit 1, position the following switches:
- (a.) Operate/Standby – Operate.
 - (b.) Frequency Standard – Internal.
 - (c.) Frequency Select Push Buttons – all zero.
 - (d.) Lock/Operate – Operate.
 - (e.) Frequency Selection – Remote.
- (5) At the Synthesizer Attenuator, Unit 1, set in 5.5 dB.
- (6) At the 3202 Filter (Krohn Hite), Unit 1, set the left side multiplier to High Pass, and the right side multiplier to Low Pass. Set the left dial multiplier to the calibration frequency times 0.7. Set the right dial and multiplier to the calibration frequency times 1.4. An example: if calibration is to be made at 5 kHz, set the left dial and multiplier to $0.7 \times 5 \text{ kHz} = 3.5 \text{ kHz}$, and the right dial to $1.4 \times 5 \text{ kHz} = 7.0 \text{ kHz}$. Consistently setting the filter in this way yields a one octave bandwidth centered at the operating frequency, keeping out-of-band noise at a minimum and yet allowing ample pulse rise time.
- (7) At the carriage control panel, bottom Unit 1, set the Depth Mode Control – Auto/Manual to Manual.
- (8) At the Elgar Power Amplifier set the following controls:
- (a.) Power – ON.
 - (b.) Input Internal/External – External.
 - (c.) Amplitude – Fully Counterclockwise.

CAUTION

Failure to comply with detailed directions
may result in overdriving and thus damaging
the selected transducer.

- (9) At the Velocimeter Control Unit, in Unit 2, select Ft for display.
- (10) At Digital Range Unit (DRU), Unit 2, position the following switches:
- (a.) Zero Time Polarity – positive.
 - (b.) Internal Stop/External Stop – Internal Stop.
 - (c.) Range/Distance Selector – 9.0 yds.
 - (d.) Auto/Manual – Manual.

- (e.) Yards/Meters -- Yards.
 - (f.) Test Select -- RS (receiver sensitivity).
 - (g.) Gates/SDVM On -- Gated.
 - (h.) Test Switch -- OFF (not lit).
 - (i.) SDVM Delay -- Full Counterclockwise.
 - (j.) RS Rep Rate -- Set about 1/sec.
 - (k.) SDVM Window -- mid-range.
 - (l.) Counter Preset thumbwheels -- Zero.
 - (m.) Zero time Pulse Delay -- Zero.
- (11) At the Sampling Digital Voltmeter, Unit 2, set the following controls:
- (a.) Sample Gate Width -- 1 msec \times 2 multiplier.
 - (b.) Sample Delay -- OFF.
 - (c.) Internal Sample Rate -- 1 Hz \times 5 multiplier.
 - (d.) Offset Switches -- Set zero.
 - (e.) Scale -- Log.
 - (f.) High-Pass Filter -- 1 kHz.
 - (g.) Low-Pass Filter -- 100 kHz.
 - (h.) Attenuator -- XI.
 - (i.) Measurement Trigger -- Press Input Signal and One Shot together.
 - (j.) Measurement Mode -- RMS.
 - (k.) Per Integral Sync -- Prec/Nom.
 - (l.) Input Selector -- Rear 75 Ω (in fact, this selects a 1 M Ω input Z).
- (12) At Scope 1, Unit 2, set the following controls:
- (a.) Chan A, Volts/Div -- 0.5.
 - (b.) Chan B, Volts/Div -- 5.0.
 - (c.) Time Base, B source -- RIGHT.
 - (d.) Time Base, Mode -- A.
 - (e.) Time Base, Triggering, A source -- EXT.
 - (f.) Time Base, Triggering -- + slope, both.
 - (g.) Time Base, Display -- CHOP.
 - (h.) Time Base, Seconds/Div, Main sweep 2 msec.
- (13) At the 463 Amplifier, Unit 3, set the gain to X100 or +40 dB.
- (14) At the Configuration Panel, Unit 3, select:
- (a.) Velocimeter -- ON (Up).
 - (b.) SDVM -- ON (Up).
 - (c.) All other switches -- OFF (Down).

- (15) At the top McIntosh Amplifier in Unit 5, set the array gain control about 3/8 turns (about 10 o'clock).

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- (16) At the Array Transducer Tuner, Unit 5, set the Q select – 3rd mark from full ccw.

E. Load TRCAL2 Program. The calibration program is on the current disk and on mag tape as a core image.

In the following paragraphs, quotation marks identify the teletype or CRT keyboard operation to be performed. Everything within the quotes should be input exactly as shown. Nonprint keys, such as carriage return, will be set in <>. Thus "C, <CR>" means press C, then comma, then carriage return. Only the "C," will shown on the CRT or TTY output.

To load from the disk, type on the TTY: "/U,TRCAL2,MAP <CR>". The disk will be searched, the program will be loaded, and executed. The operation requires about 2 to 3 minutes. When ready, the operator CRT will display TRANSDUCER CALIBRATION.

To load from mag tape (core image)

- (1) Power up the tape deck.
- (2) Mount mag tape with TRCAL2.
- (3) Press LOAD – tape tension will be applied.
- (4) Press LOAD – tape will run to begin-to-tape mark.
- (5) Press ON-LINE.
- (6) On computer panel, press STEP.
- (7) Load "000000" octal in "U" register.
- (8) Load "076000" octal in "P" register.
- (9) Press "SYSTEM RESET", then "RUN".
- (10) After TTY "dings", type, in capital letters: "F1,0 <CR>".
- (11) TYPE "R0 <CR>" (The tape will be read, loaded, and executed. The operator's CRT will display TRANSDUCER CALIBRATION. Ignore TTY output (R0,LP00 NOT READY).
- (12) On tape deck, press ON LINE (On-line light should go out).
- (13) Press REWIND (Tape will go to begin point).
- (14) Press REWIND (Tape will unload).
- (15) Remove tape from machine and replace in canister.

F. Program Restart Procedure. Some errors made at the keyboard during a calibration run are fatal, and the program will have to be restarted at the top. The restart procedure is, from the computer front panel:

- (1) Press "STEP".
- (2) Load "000000" octal in the "U" register.
- (3) Load "000002" octal in the "P" register.
- (4) Press "SYSTEM RESET".
- (5) Press "RUN".

The operator CRT should display

TRANSDUCER CALIBRATION

DATE: XX XXX XX

INPUT STARTING SAMPLE NUMBER

IV. PROCEDURES

This section assumes that all setup described in Section 3 has been completed.

Appendix D contains a descriptive outline or summary of the actions required in this procedures section. The appendix also contains example output from Statos and the TTY with a description of the meaning of output numbers.

- A. The operator CRT contains

TRANSDUCER CALIBRATION

DATE: XX YYY ZZ

INPUT STARTING SAMPLE NUMBER

Type in the time, for example, 0745 followed by a comma, and then a carriage return CR. Thus, type "0745, <CR>".

- B. CRT requests number of frequencies. The answer must be "1, <CR>".
- C. CRT requests the operation frequency in kHz. Example is "5.0, <CR>", to calibrate at 5 kHz.
- D. CRT requests pulse length in msec. Answer should be "30, <CR>".
- E. CRT request number of pings to delay to stabilize current. Answer must be "1, <CR>".
- F. CRT requests driving current. The answer must be the set current in dB plus 20. Normally, the set current is +10 dB, so the answer is normally "30, <CR>".
- G. CRT requests carriage element being calibrated. Answer L, or M, or S. Example "M, <CR>".
- H. CRT request numbers of samples to be averaged. Usual answer is 20. Thus, "20, <CR>".

- I. The CRT will now display a list of operation codes for use during the run.

CAUTION

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the selected transducer.**

- (1) Check that Elgar amplitude control is full counter clockwise.
- (2) Press "CU, <CR>" to begin pinging.
- (3) Press space bar to stop Status printing.

- J. To set Unit C drive current, see that patch from TUNER HI to CARRIAGE HI is in place, and that patch from CURRENT MONITOR to FILTER IN is in place.

- (1) On the DRU, set the RANGE/DISTANCE SELECTOR to 2.0 yards.
- (2) Adjust Elgar amplitude control to near +10 dB on SDVM. Synthesizer attenuator can be used for fine control. Adjust until SDVM reads +10.0 dB. (The SDVM will indicate OUT OF RANGE, but the meter is still accurate.)
- (3) Scope 2, in Unit 4, will display transducer drive voltage. Check that the voltage waveform is undistorted, and that the pulse envelop is fast rising and flat after 1 msec from turn on.

- K. To perform the CA measurement:

- (1) Remove CURRENT MONITOR plug and select TR-225 UNIT A.
- (2) Set range on DRU to 9.0 yards.
- (3) On SDVM, press Measurement Trigger "INTERNAL", then press "INPUT SIGNAL" and "ONE SHOT" together (they should remain depressed).
- (4) Inspect the signal on Scope 1 (the waveform should be clean and relatively free of noise – the measurement gate should begin 1 msec from the pulse onset, and last 2 msec).
- (5) On Keyboard, press "CA, <CR>"

The computer will now ping and record received levels on Status. The measurement will be repeated the selected number of times for ping averaging. At the completion of this operation, the TTY will "ding", and the CRT will display ENTER THE OPERATION CODE.

- L. To perform the CB measurement:

- (1) Remove the plug from TR-225 UNIT A and select TR-225 UNIT B (that is, UNIT B should now be patched to FILTER IN).
- (2) On the DRU, set the range to 13.0 yds.
- (3) Observe waveform on Scope 1 (check for gate start 1 msec from beginning – check that pulse is clean with relatively little noise).
- (4) On the Keyboard, press "CB, <CR>"

The data will be printed on Status. At the completion, the TTY will "ding" and the CRT will request another operation code.

M. To set Unit B drive current:

- (1) Adjust Elgar Amplitude control full counter clockwise.

CAUTION

Failure to comply with detailed directions may result in overdriving and thus damaging the selected transducer.

- (2) Patch TUNER HI to TR-225 UNIT B.
- (3) Patch FILTER IN to CURRENT MONITOR.
- (4) On the DRU, set the range to 2.0 yards.
- (5) Adjust Elgar Amplitude control clockwise to near +10 dB on SDVM (Synthesizer attenuator can be used for fine control – adjust until SDVM reads +10.0 dB (out of range indication normal)).
- (6) On Scope 2, Unit 4, inspect the drive voltage waveform.

N. To perform the BA measurement:

- (1) Patch FILTER IN to TR-225 UNIT A.
- (2) On the DRU, set the range to 2.0 yards.
- (3) On the SDVM, press Measurement Trigger "INTERNAL", then press "INPUT SIGNAL" and "ONE SHOT" together.
- (4) Inspect the received signal on Scope 1 – check the gate start and on time.
- (5) On the Keyboard, press "BA, <CR>". When data taking is complete, the TTY will "ding".

O. To perform the BC measurement

- (1) Patch FILTER IN to CARRIAGE HI.
- (2) On the DRU, set the range to 13.0 yards.
- (3) Inspect the signal.
- (4) On the Keyboard, press "BC, <CR>".

P. To set UNIT A drive current:

CAUTION

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- (1) Adjust Elgar Amplitude control full counter clockwise.
- (2) Patch TUNER HI to TR-225 UNIT A.
- (3) Patch FILTER IN to CURRENT MONITOR.
- (4) On the DRU, set the range to 2.0 yards.
- (5) Adjust Elgar Amplitude and Synthesizer attenuator to +10.0 dB on SDVM.
- (6) Observe drive voltage on Scope 2.

Q. To perform the AB measurement:

- (1) Patch FILTER IN to TR-225 UNIT B.
- (2) On the DRU, set range to 2.0 yards.
- (3) On the SDVM, press "INTERNAL", then press "INPUT SIGNAL" and "ONE SHOT" together.
- (4) Inspect the received signal on Scope 1.
- (5) On the Keyboard, press "AB, <CR>".

R. To perform the AC measurement:

- (1) Patch FILTER IN to CARRIAGE HI.
- (2) On the DRU, set the range to 9.0 yards.
- (3) Inspect the signal on Scope 1.
- (4) On the Keyboard, press "AC, <CR>".

All six measurements have now been completed and recorded on Statos.

S. To qualify the data:

- (1) Press "PAGE EJECT" on Statos until all six measurements can be seen.
- (2) Inspect the data for outliers. (Interference from ships in the harbor, impulsive noises, and other sources, cause data values unreasonably large or small compared to the remainder of the set – if most of the set seems scattered by about 1 dB, then a single value of 3 dB difference is probably an outlier, and the data set should be repeated.)
- (3) Inspect the data for trending (note the eyeball average and scatter of the first few pings in a set, and check to see that the same average and scatter occurs for the last few pings).
- (4) Check that the VARIANCE is less than 0.1 (the VARIANCE is a measure of the data scatter – the larger the number, the larger the scatter. Large variance can be caused by high ambient noise levels, low signal levels, or fish moving in or out of the sound field).
- (5) Check for data stationarity. The average value for reverse pairs of data, for example, set AB and BA, should be the same within 0.5 dB. The VARIANCE should also be similar.

If any of the above tests fail, repeat the data. If only one set of a pair has high VARIANCE, it alone can be repeated. If both have about the same variance, both should be repeated.

- (6) If any of the data fail the above listed tests, go to paragraph T.
- (7) If all of the data pass the above listed tests, carry on with the calibration at paragraph U.

T. To repeat any data set XY:

- (1) Turn down drive level at Elgar.

CAUTION

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the selected transducer.**

- (2) Patch TUNER HI to selected X transducer.
if X = A, select TR-225 UNIT A
X = B, select TR-225 UNIT B
X = C, select CARRIAGE HI,
- (3) Patch FILTER IN to CURRENT MONITOR.
- (4) On DRU, set range to 2.0 yards.
- (5) Adjust Elgar and Attenuator for +10.0 dB on SDVM.
- (6) Patch FILTER IN to selected Y transducer.
if Y = A, select TR-225 UNIT A
Y = B, select TR-225 UNIT B
Y = C, select CARRIAGE HI,
- (7) On DRY, set range to R, where
if XY is AB or BA, then R = 2.0 yards
if XY is AC or CA, then R = 9.0 yards
if XY is BC or CB, then R = 13.0 yards,
- (8) On the SDVM, press "INTERNAL", then press "INPUT SIGNAL" and "ONE SHOT" together.
- (9) Inspect the waveform on Scope 1 (be sure gate is set correctly and that the problem is not in evidence – observe for several pins to be sure data is stable.
- (10) On the Keyboard, press "XY, <CR>" where XY is one of the six combinations of A, B, or C.
- (11) When data set is complete, the TTY will "ding".
- (12) Page eject on Statos, and repeat the data tests at paragraph S above to qualify the new data.

U. If all data pass the visual inspection:

- (1) On the Keyboard, press "DO, <CR>".
- (2) The CRT will display the frequency of operation and the averages for the paired values.
- (3) Check again to see that the pairs are equal to within 0.5 dB.
- (4) If not equal, press "R, <CR>", and pick up procedure at paragraph T above.
- (5) If pairs are equal to within 0.5 dB, press "C, <CR>", to calibrate with these six values.
- (6) The CRT will display PUNCH ON?. (If a punched paper tape copy of calibration values is required, turn on the tape punch and punch a leader, then answer on the keyboard <CR>. Normally, no paper tape is required, so answer <CR>).
- (7) The CRT will display the calibration values, the TTY will print a sheet containing calibration values as well as ancillary data, and the Status will print a calibration record.

V. The calibration values for the three transducers must be compared to their historical values for a final check on the validity of the calibration.

The historical values are the latest updated running average calibration values in the calibration log. If the present values are within ± 0.7 dB of the historical values, they are accepted as valid, and incorporated in the historical average values.

The updated historical values for Unit C (the line transducer) are to be used for ship tests.

W. (1) The CRT displays

ENTER C TO CONTINUE, P TO REPRINT, R TO RETEST A PAIR

P results in one additional copy of the TTY output. R should not be used. The operator should press "C, <CR>".

(2) The CRT displays

T TO TEST AGAIN, E TO END

Use E only if no other calibration is needed. Use T to retest the present frequency or to retest with other frequencies.

V. RECORDS

This section concerns the requirements for data storage and usage.

A. All Status output and one ancillary data sheet for each 2 hours calibration time are to be mailed promptly to NOSC Code 47. These data will be used for calibration quality control purposes and for further research into the cause or causes of calibration data scatter and trending caused by transducer ageing.

B. The TTY copy of the calibration is to be kept in a calibration record book located on-site. The three receiving sensitivity numbers for transducers A, B, and line transducer C are to be recorded by hand onto historical record sheets described in paragraph C, below and in Appendix E.

C. The historical record sheets are of two types. The first type is for the auxiliary transducers A and B, and only one sheet is needed for each transducer, regardless of the frequency of calibration. These transducers (TR-225) have receiving response that is flat and independent of frequency over the range of interest at SACS. The second type record sheet is for use with the carriage line transducer. A separate sheet is necessary for each line section and calibration frequency.

Both type record sheets list the historical receiving sensitivity for the respective transducers with the ± 0.7 dB bound, to be used to qualify new calibration data in Section IV, paragraph V.

A copy of each completed historical record sheet must be sent to NOSC, Code 47, for inclusion in their records for quality control purposes.

The two entries between the double lines on the line transducer record sheet, marked \bar{R}_S and \bar{L}_S , are to be entered into the computer for using during a ship test.

The masters for the record sheets and a further description of their use is contained in Appendix E.

APPENDIX A
THE SIX-FOOT LINE TRANSDUCER

THE SIX-FOOT LINE TRANSDUCER

The six foot line transducer is a rather complex collection of individual elements connected so as to form three separate line transducers. A cable containing three twisted pair connect the transducer to the watertight connection box mounted on the movable transducer carriage. A rotary switch selects one of the three separate transducer configurations to be used and thus connected through the carriage slip rings to the SACS control room.

The transducer comprises 39 individual PZT-4 ceramic cylindrical elements, each 1 inch long. They are arranged along a support rod with various spacing, such that by wiring selected elements together, three separate transducers of various lengths are formed.

The Long transducer section (L) contains 14 elements equally spaced 5 inches apart. The series-parallel wiring is such that the three end elements on each end (six in all) are shaded down to 0.5. The center eight elements have a relative strength factor of 1.0. The overall acoustic length of the Long section is 65 inches. The center of the section coincides with the physical center of the line (centered about the middle line-to-reflector clamp).

The Medium section (M) contains 14 elements equally spaced 2.5 inches apart. The wiring is such that the three end elements (six in all) are shaded to 0.5, while the center eight are of strength 1.0. The overall acoustic length of the Medium section is 32.5 inches. The center of the section is 15 inches above the physical center of the line (the middle line-to-reflector clamp). When the Medium section is used, the carriage depth indicator reads too deep by 15 inches (1.25 feet). That is, if the Medium section center is to be adjusted to 22 feet, the depth indicator must be set to 23.25 feet.

The Short transducer section (S) contains 11 elements, equally spaced 2.5 inches apart. The wiring is such that the two end elements (four in all) are shaded to 0.33, the next one (two in all) is shaded to 0.67, and the remaining middle five elements are of strength 1.0. The overall acoustic length of the Short section is 25 inches. The center of the section is 18.75 inches below the physical center of the line. When the Short section is used, the carriage depth indicator reads too shallow by 18.75 inches (1.56 feet). That is, if the Short section center is to be adjusted to 22 feet, the depth indicator must be set to 20.44 feet.

The purpose of having three line transducer sections is to allow the operator to choose the transducer configuration best suited to a particular sonar test. All three sections are shaded so that side lobes in the vertical beam pattern of the line array are suppressed 20 dB or more below the level of the major lobe. The length of the sections control the beamwidth of the transducer's major lobe. It cannot be too large, otherwise reflection interference from the water surface will cause ship calibration errors, nor can the beamwidth be too small, as the sonar array under test will not be adequately insonified.

To select the proper transducer section one must know (1) the frequency range of the sonars to be tested, (2) the depth to the center of the sonar transducer below ships waterline, and (3) the height of the sonar array.

Figure A-1 is a plot of the range of applicability of the three transducer sections. The curves sloping downward to the right on the left-hand portion of the graph, represent the lowest frequency usable, and that depends upon the depth of the test, as shown on the

left-hand scale. The curves to the right, sloping up and to the right including the vertical lines, represent the highest frequency usable, and it depends upon the height of the array, as shown on the right-hand scale.

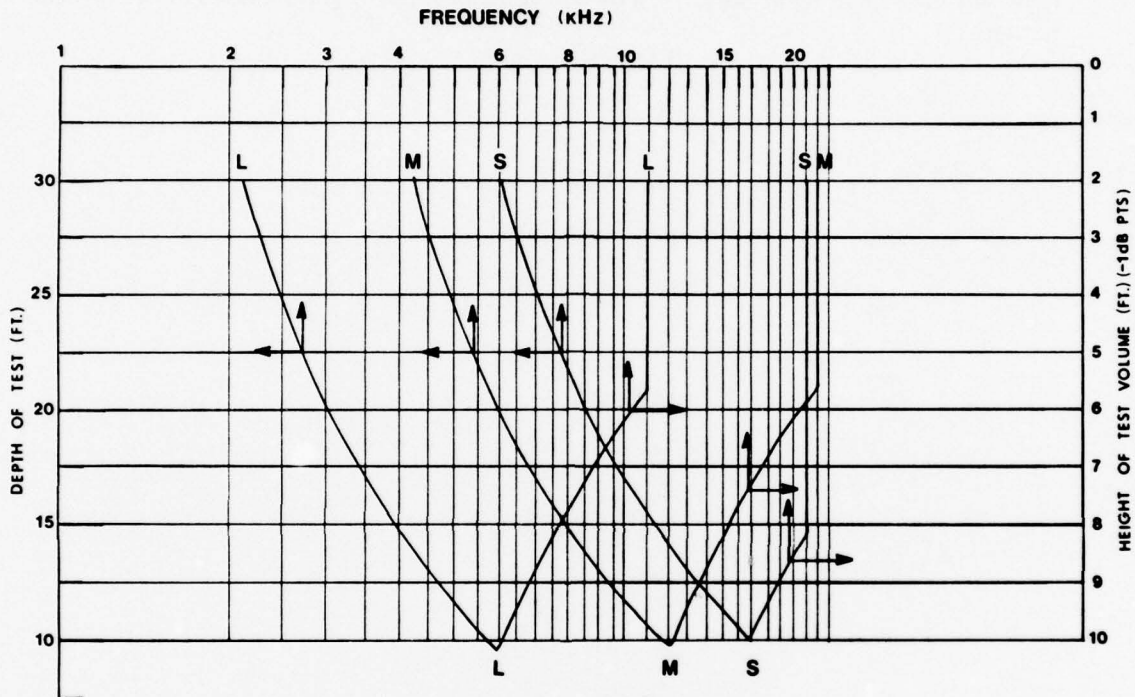


Figure A-1. Frequency limits for line transducer sections.

An example of the use of the curves is as follows:

The sonar to be tested is an AN/SQS-23. The operating frequencies are 4.5, 5.0, 5.5 kHz. The height of the 23 array is 6 feet. The sonar is mounted on a ship so that the array center is 25 feet deep.

The maximum frequency curves are read at the array height of 6 feet. We find the maximum usable frequency of section L is about 10 kHz and section M and S are both about 21 kHz. The minimum frequency curves are entered along the left scale at test depth of 25 feet. We find the minimum usable frequencies to be L min = 2.5 kHz, M min = 5 kHz, and S min = 7.1 kHz. Thus, it is clear that section L with range from 2.5 to 10 kHz adequately covers the operating of 4.5 to 5.5 kHz.

The meaning of the curves is as follows:

If a section is used at a frequency below its low limit, the side of the major lobe will strike the surface and reflection interference errors will exceed ± 1 dB. If a section is used at a frequency above its upper limit, the beam will become so narrow that the array being tested will not be uniformly illuminated. The maximum frequency line represents an illumination uniformity of ± 0.5 dB. The straight line segments on the upper limit curves represent the beginning of the growth of repeat major lobes or grating lobes in the vertical pattern.

APPENDIX B
EQUIPMENT LINE-UP AND GENERAL DESCRIPTION

EQUIPMENT LINE-UP AND GENERAL DESCRIPTION

Figure B-1 is a block diagram of the equipment needed to perform a calibration. It also shows the signal flow.

The bottom row of equipment is required to drive a selected transducer. The time at which a transducer is driven is determined by the DRU. The pulse length and frequency is determined by the computer input to the frequency synthesizer.

The top row of equipment comprises the receiving equipment. The SA-SDVM digitizes the receive voltage from a selected transducer and sends the data to the computer. The receive gate time delay is determined by the DRU, and the receive gate on-time is determined by the SDVM.

The particular equipment organization is determined by two patch panels near the center of equipment rack number three (unit three). The equipment shown in Figure B-1 are patched together during console setup phase (Section III, paragraph D).

Throughout the data acquisition phase of the procedure section (Section IV), the patch panel will be used to select the transducer to be driven and which transducer's output voltage will be measured.

During the data acquisition phase, depicted in Figures D-1, D-2, and D-3, the first step involves measuring and adjusting the selected transducer drive level. The receiving system is patched to the current monitor to accomplish the current measurement. The current monitor is a toroidal current transformer with a one turn primary (carrying the transducer current) and a secondary which yields 0.1 volts per amp of drive current. This turns ratio (an equivalent gain of -20 dB) is the reason that 20 dB is added to the proposed SDVM reading in Section IV, paragraph F.

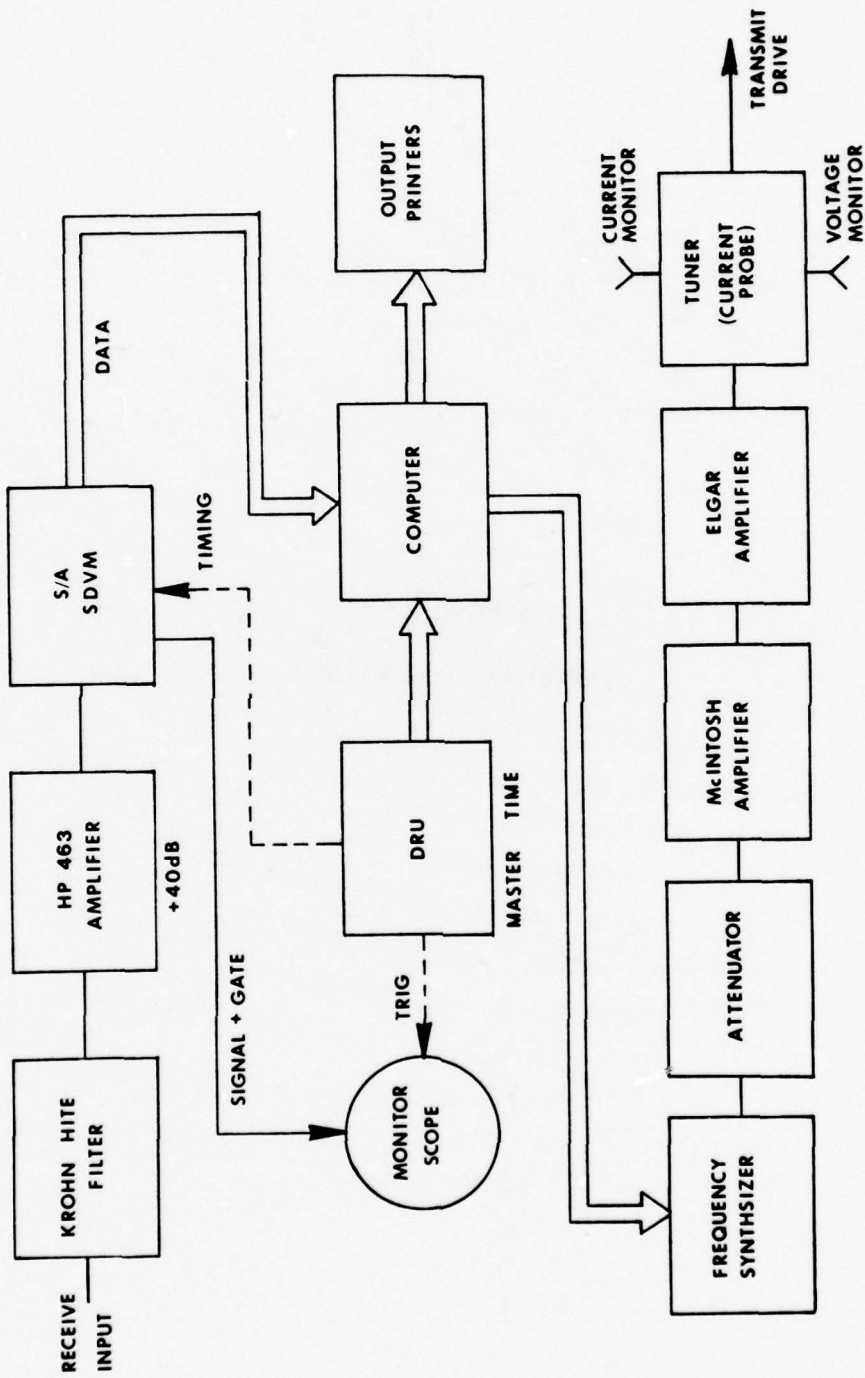


Figure B-1. Calibration equipment block diagram.

APPENDIX C
ANCILLARY DATA FORM

ANCILLARY DATA FORM

Figure C-1 is a master of the ancillary data sheet which is to be filled in at the time of boom rigging, or when transducer depths are changed, or once each 2 hours of calibrate test time. The form should be copied, filled in, and sent with Status output to NOSC as per the records requirement in Section V, Records.

An example form filled in is included for guidance and is shown in Figure C-2.

The tide level data requested is to be read from the predicted tide levels. The charts are plotted with Pacific Standard Time. When Daylight Savings Time is in effect, remember to make appropriate time corrections.

LINE CALIBRATION ANCILLARY DATA SHEET
SUBMIT ONE PAGE EACH TWO HOURS
OR WHEN TRANSDUCER DEPTHS ARE CHANGED

DATE: _____

TIME BOOM RIGGED: _____
(OR DEPTH CHANGED)

SOUND VELOCIMETER DROP:
TIME: _____ HRS

17 ft _____ ft/sec
22 ft _____ ft/sec
27 ft _____ ft/sec

PARK VELOCIMETER AT 22 ft

FROM PREDICTED TIDE CHART, READ AND RECORD:

TIDE LEVEL AT BEGINNING _____ ft

PREVIOUS EXTREME _____ ft at _____ hrs

NEXT EXTREME _____ ft at _____ hrs

LINE SECTION TO BE CALIBRATED AND FREQUENCIES:

CALIBRATE L SECTION AT _____ kHz
M SECTION AT _____ kHz
S SECTION AT _____ kHz

IS SHIP PRESENT IN ARRAY: yes no (circle one)

WEATHER:

GENERAL: _____
(clear, sun, rain, overcast, etc.)

AIR TEMP: _____ °F

WIND FROM _____ AT _____ MPH

CONSOLE OPERATOR FOR EACH SECTION AND FREQUENCY

SECTION/FREQUENCY OPERATOR

Figure C1. Ancillary data sheet.

LINE CALIBRATION ANCILLARY DATA SHEET
SUBMIT ONE PAGE EACH TWO HOURS
OR WHEN TRANSDUCER DEPTHS ARE CHANGED

DATE: 27 Oct 78

TIME BOOM RIGGED: 0745
(OR DEPTH CHANGED)

SOUND VELOCIMETER DROP:
TIME: 0755 HRS

17 ft	<u>4935.8</u>	ft/sec
22 ft	<u>4932.0</u>	ft/sec
27 ft	<u>4930.2</u>	ft/sec

PARK VELOCIMETER AT 22 ft

FROM PREDICTED TIDE CHART, READ AND RECORD:

TIDE LEVEL AT BEGINNING 104.7 ft ~~104~~ 745

PREVIOUS EXTREME 105 ft at 0630 hrs

NEXT EXTREME 101.5 ft at 1245 hrs

LINE SECTION TO BE CALIBRATED AND FREQUENCIES:

CALIBRATE L SECTION AT	<u>3.212, 3.556, 3.910</u>	kHz
M SECTION AT	_____	kHz
S SECTION AT	_____	kHz

IS SHIP PRESENT IN ARRAY: yes (circle one)

WEATHER:

GENERAL: clear
(clear, sun, rain, overcast, etc.)

AIR TEMP: 65 °F

WIND FROM SSW AT 10 MPH

CONSOLE OPERATOR FOR EACH SECTION AND FREQUENCY

<u>SECTION/FREQUENCY</u>	<u>OPERATOR</u>
<u>L/3.212/3.556</u>	<u>Al C.</u>
<u>L/3.910</u>	<u>Bob S.</u>

Figure C-2. Example of completed ancillary data sheet.

APPENDIX D
OUTLINE FOR PROCEDURES SECTION AND EXAMPLE OUTPUT

OUTLINE FOR PROCEDURES SECTION AND EXAMPLE OUTPUT

Paragraphs A through I in Section IV, Procedures, contain instructions for the initial dialog with the computer. During this dialog the computer learns the operator's intent in the calibration, such as, frequencies, pulse lengths, etc.

Paragraph J starts the data acquisition phase. Figures D-1, D-2, and D-3 depict the operations performed in paragraphs A through R.

Figure D-4(a) is an example Status output obtained in paragraphs K, L, N, O, Q, and R. The operation code is shown at the top. Column 2 is a list of the SDVM output at each ping. Column 1 lists the SDVM output in volts squared. Column 3 contains a running sum of volts squared. Columns 4 and 5 count the pings and repeat the frequency. The variance value is computed on the list of dB values in Column 2. It is a measure of the scatter in the values, and shall be less than 0.1 (a standard deviation of 0.3 dB). The average value is presented in dB also, but it is an RMS average of linear volts.

Figure D-4(b) illustrates the output obtained in Section IV, Procedures, paragraph U.1. This collects the paired average values (which should be equal to within 0.5 dB) for inspection.

Figure D-4(c) results from the operation called for in Section IV, Procedures, paragraph U.5. This output lists the receive and transmit responses for all three transducers. The RRC column pertains to the carriage line transducer.

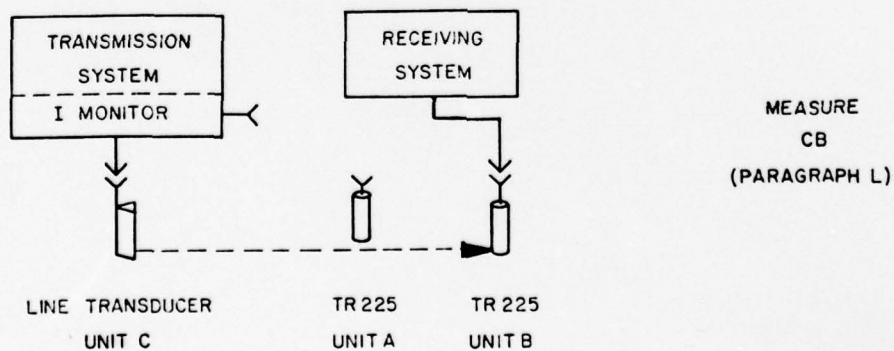
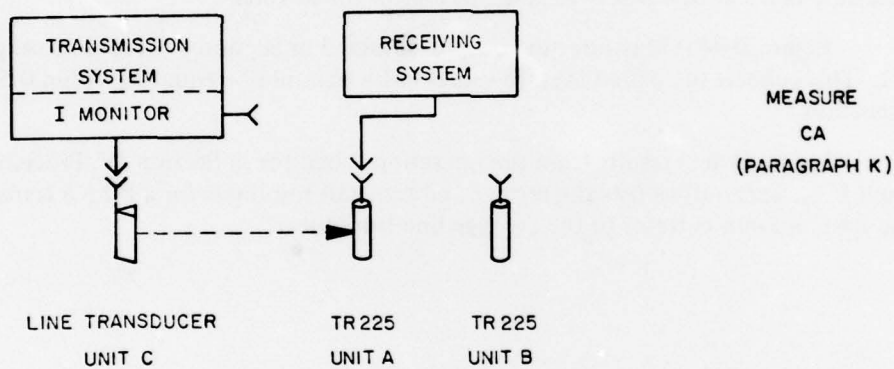
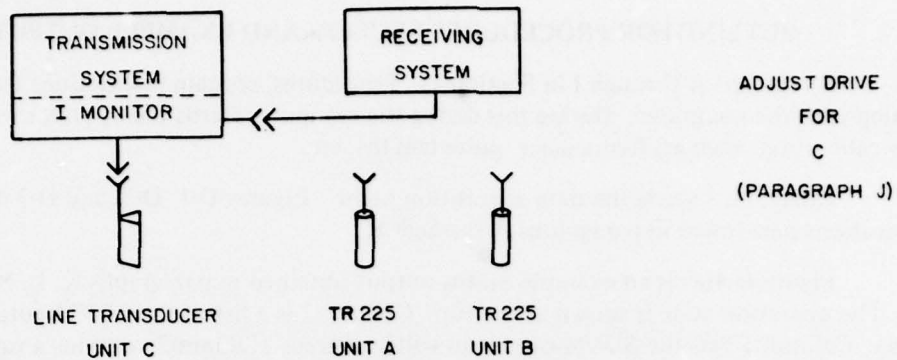


Figure D-1. Block diagram of procedures in Section IV.

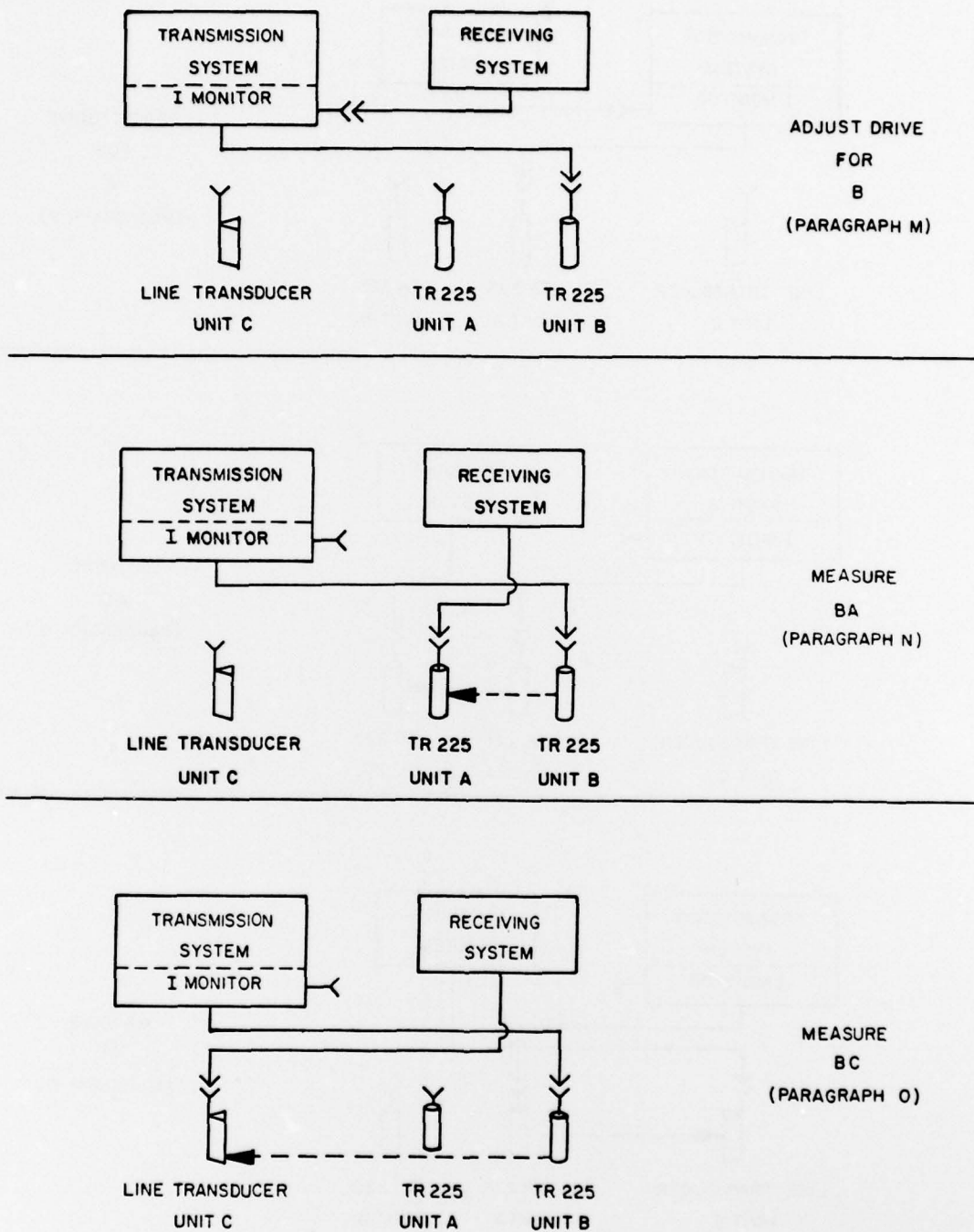


Figure D-2. Block diagram of procedures in Section IV.

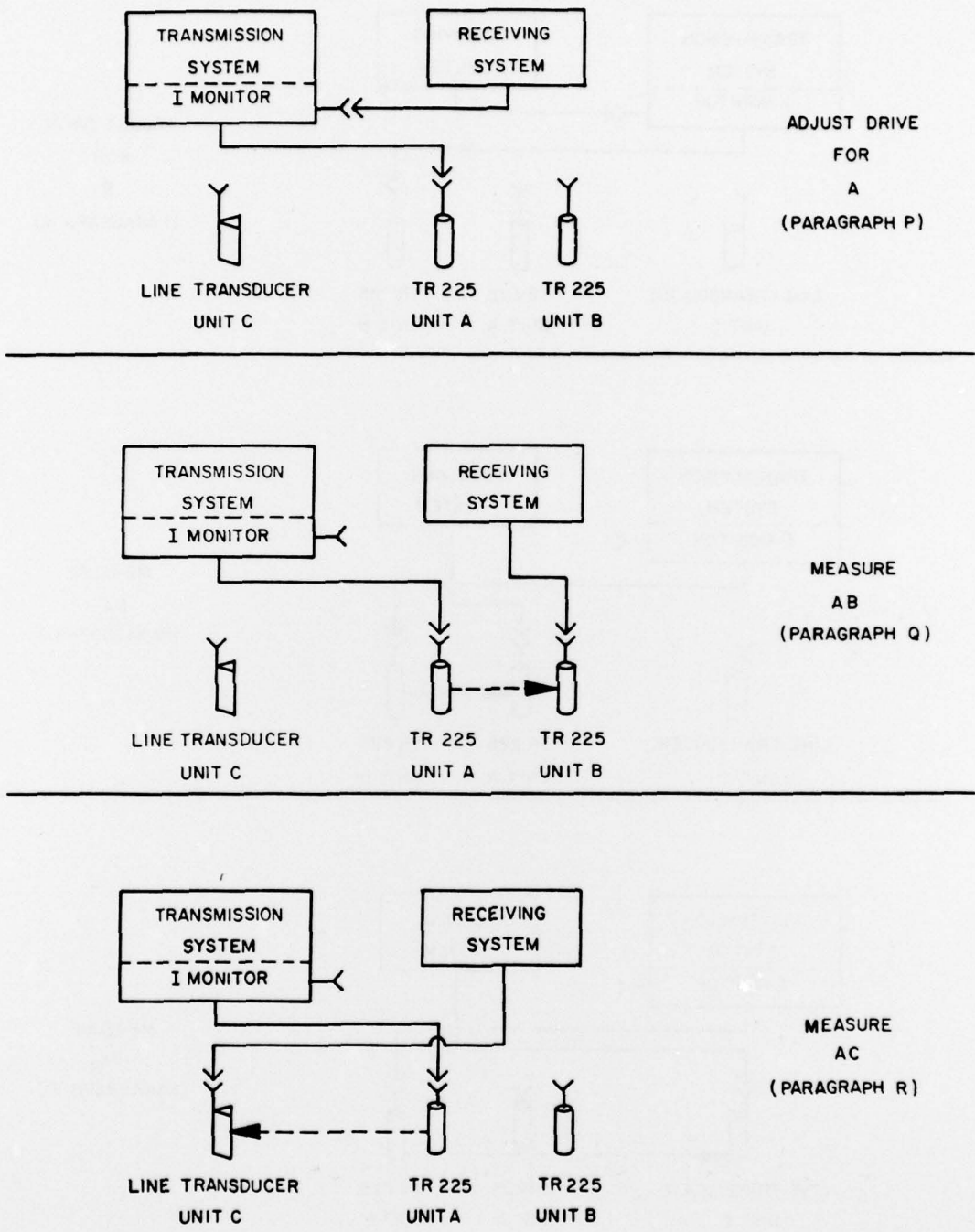


Figure D-3. Block diagram of procedures in Section IV.

OPERATION CODE (PARA 0)		FREQUENCY	
BC	5.000 KHZ		
VOLTS=	.0041686874	DB=	-23.8000030518
VOLTS=	.0040738005	SUM=	.0041686874
VOLTS=	.0042657871	SUM=	.0082424879
VOLTS=	.0043651573	SUM=	.0125082768
VOLTS=	.0039810706	SUM=	.0168734342
VOLTS=	.0041686874	SUM=	.0208545029
VOLTS=	.0042657871	SUM=	.0250231922
VOLTS=	.0042657871	SUM=	.0292889774
VOLTS=	.0041686874	SUM=	.0335547626
VOLTS=	.0040738005	SUM=	.0377234519
VOLTS=	.0041686874	SUM=	.0417972505
VOLTS=	.0040738005	SUM=	.0459659398
VOLTS=	.0042657871	SUM=	.0500397384
VOLTS=	.0041686874	SUM=	.0543055236
VOLTS=	.0042657871	SUM=	.0584742129
VOLTS=	.0040738005	SUM=	.0627399981
VOLTS=	.0041686874	SUM=	.0668137968
VOLTS=	.0043651573	SUM=	.0709824860
VOLTS=	.0040738005	SUM=	.0753476322
VOLTS=	.0042657871	SUM=	.0794214308
VOLTS=	.0042657871	SUM=	.0836872160

COL 1	COL 2	COL 3	COL 4	COL 5
FREQUENCY 1	5.000 KHZ			
VARIANCE	.012199326			
NUMB OF	OUT OF			
SAMPLES	RANGE	AVERAGE	OFFSET	D4(a)
20	0	-23.78	0.0	
SOUND VELOCITY=	4932.000	TIME=	808	
FREQUENCY 1	5.000 KHZ			
A TO B = -21.20	A TO C = -20.83	B TO C = -23.78		
B TO C = -21.25	C TO A = -20.64	C TO B = -23.69		

FREQUENCY	5.000 KHZ	TIME:	809	CARRIAGE ELEMENT	L
RECEIVE RESPONSES	RRR	RRB	RRC		
TRANSMIT RESPONSES	-204.05	-204.46	-194.96		
	164.93	164.52	174.12		

Figure D-4. Status output example.

Figure D-5 shows example output from the TTY which occurs at Section IV, Procedures, paragraph U.7. The sample number is the calibration start time and TIME: _____ is the time the computation was completed. The transmit and receive responses for these transducers are given at the bottom. The line transducer, regardless of which section is being calibrated, is listed under column C.

TRANSDUCER CALIBRATION
25 APR 78 TIME: 809

SAMPLE NUMBER 746

FREQUENCY 5.000KHZ

CARRIAGE ELEMENT L

CURRENT 30.00

	A TO B	A TO C	B TO C
SPREADING LOSSES	-11.7	-20.8	-23.4

AVERAGED RECEIVE LEVELS:

A TO B	-21.20	A TO C	-20.83	B TO C	-23.78
B TO A	-21.25	C TO A	-20.64	C TO B	-23.69

	A	B	C
RECEIVE RESPONSES	-204.05	-204.46	-194.86

TRANSMIT RESPONSES	164.93	164.52	174.12
--------------------	--------	--------	--------

LP00 - NOT READY

Figure D-5. Example of TTY output.

APPENDIX E
HISTORICAL RECORD SHEETS

HISTORICAL RECORD SHEETS

The historical record sheets are used to compute a historical running average value for the calibration constants for the three transducers, and to collect on one page all calibrations of the line transducer relating to a particular section and frequency.

The entries on the data sheets include coefficients for use in a recursive filter. This filter performs the running average function, and tends to reduce the scatter of the calibration values to be used. The filter is a low pass recursive with a 90-day time constant. The values of β and α to be used in the filter equation depend upon the number of days since the last calibration, and are listed in Table E-1.

The filter can be entered with a single new calibration, or if several repeated calibrations are performed on the same day or during the same week, the average of those separate values can be recorded on the data sheet as the value to be filtered. Also, during start up, or if more than 145 days have elapsed since the last calibration, at least three calibrations should be performed within a week, and that average value entered in the data sheet.

The two types of data sheets are shown in Figures E-1 and E-2. These are to be copied for use in the calibration log book. The type shown in Figure E-1 is to be used for the two auxiliary transducers, unit A and unit B. The type shown in Figure E-2 is used for the line transducer, unit C. One separate sheet is needed for each combination of line section (L, M, or S) and for each separate frequency.

Figure E-3 is a partially filled in example data sheet of the Figure E-1 type, to help describe the purpose and use of the form.

Assume that on 10 February 1979, a set of calibrations were accomplished for section L at 4.5, 5, and 5.5 kHz. The last calibration accomplished was 3 January 1979, for section M at 8 kHz. The previous \bar{R}_S for unit A was -204.13. This data is on line one of Figure E-3.

Now on 10 February 1979, the L section calibration at 4.5 kHz results in a R_S for unit A of -203.47. This is within the bounds shown in the last two columns of line 1, so the unit A R_S is accepted. The unit B R_S would be accepted or rejected from data on the unit B page. Now, the L section is calibrated at 5.0 kHz, resulting in R_S of A of -204.50, also within bounds from line 1. Finally, the L section is calibrated at 5.5 kHz, resulting in an R_S for A of -203.85, also in bounds. If all data are otherwise qualified, then the unit A data sheet for 10 February 1979 can be filled in as follows:

- (1) Enter the date and day of year.
- (2) Subtract last day from present day to obtain days since last calibration.
- (3) Under Frequency, enter the three frequencies used in the days calibration.
- (4) Average the three R_S values

$(-203.47 - 204.50 - 203.85)/3 = -203.94$ and enter the average under the R_S column.

Table E-1. Filter coefficient selection.

DAYS SINCE LAST CALIBRATION	COEFFICIENTS	
	β	α
0-5	.05	.95
6-10	.10	.90
11-15	.15	.85
16-20	.20	.80
21-26	.25	.75
27-32	.30	.70
33-39	.35	.65
40-46	.40	.60
42-54	.45	.55
55-62	.50	.50
63-72	.55	.45
73-82	.60	.40
83-94	.65	.35
95-108	.70	.30
109-125	.75	.25
126-145	.80	.20
146-171	.85	.15
172-207	.90	.10
208-270	.95	.05
270-UP	1.00	0.00

Coefficients to be used in the filter equation.

$$\bar{R}_{s(\text{new})} = [R_{s(\text{new})}] * [\beta] + [\alpha] * [\bar{R}_{s(\text{old})}]$$

(5) The "Days since last calibration" is 38 days. Consulting Table E-1, read $\beta = .35$ and $\alpha = .65$. Enter these values in the form.

(6) Now the filter computation can be accomplished. The equation is given at the bottom of Table E-1, and is repeated here as an example.

$$\begin{aligned}\bar{R}_S(\text{new}) &= R_{S(\text{new})} * \beta + \alpha * \bar{R}_S(\text{old}) \\ &= -203.94 * .35 + .65 * (-204.13) \\ &= -71.38 + (-132.68)\end{aligned}$$

$$\bar{R}_S(\text{new}) = -204.06$$

This value is to be entered in the \bar{R}_S column.

(7) The last two columns are filled with the $\bar{R}_S \pm 0.7$ dB to be used as future bounds.

To continue the example, on 16 February 1979, the M section was again calibrated at 8.0 and 8.5 kHz. The 8 kHz calibration resulted in R_S for Unit A of -204.56 (which is within bounds of the last two columns for the 10 February entry), and the 8.5 kHz calibration is -204.46 . The 6 day β and α values are read and entered, and the filter equation used to find a new \bar{R}_S , from which the ± 0.7 dB bounds can be computed and used during any following calibration.

The Figure E-3 shows the entries for unit A. A separate sheet of the Figure E-1 type will be kept for unit B.

Figure E-4 is an example entry on a data sheet of the type in Figure E-2. One sheet is required for each different line transducer section and each different frequency. Figure E-4 is for line section L, for the single frequency 50 kHz.

The value for J, the reciprocity constant for this frequency is entered at the top of the form for use at each entry. The value for J can be found in two ways. First, it can be computed from

$$J = -355.00 - 20 \log (f(\text{kHz})).$$

In the example,

$$\begin{aligned}J &= -355.00 - 20 \log (5.0) \\ &\quad - 20 (.6990) \\ &= -355.00 - 13.98\end{aligned}$$

$$J = -368.98.$$

Secondly, it can be calculated from TTY output sheet after a calibration at any frequency. Thus,

$$J = R_S - L_S.$$

Now, to the example. Eight December 1978 was the last time the L section had been calibrated at 5 kHz. At that time, it was also calibrated at 4.5 and 5.5 kHz, but these values are entered on other sheets. The top line of Figure E-4 shows the previous results. The measured \bar{R}_S is read from the TTY output and entered. The new \bar{R}_S is computed with equation and coefficient values found in Table E-1, as before.

Do not enter or use the Source Level data on the TTY output. The \bar{R}_S column is found from the filter. The \bar{L}_S column is found from the \bar{R}_S and J values from

$$\bar{L}_S = \bar{R}_S - J.$$

Note that \bar{R}_S is a negative number and that J is a large negative number, so that \bar{L}_S is a positive number.

Only $\bar{R}_S \pm 0.7$, (the last two columns) are used for future data qualifications.

Also, on 9-10 December, during the ship test, the calibration values for the L section at 5.0 kHz entered into the computer were read off the sheet between the double lines, namely

$$\bar{R}_S = -194.70 \text{ and}$$

$$\bar{L}_S = 174.28.$$

Now, on 10 February 1979, another calibration for the L section at 5.0 kHz was performed. The measured values for $\bar{R}_S = -195.26$. The following steps are used to fill out the line 2 on the example Figure E-4.

- (1) Enter the date, and note the day of the year.
- (2) Days since last calibration can be found by noting that 1978 contained 365 days and that 8 December came 23 days before the end of the year ($365 - 342 = 23$). Ten February is 41 days into the new year. So, days since last calibration is 64 ($41 + 23$).
- (3) Table E-1 is consulted for 64 days to find $\beta = .55$ and $\alpha = .45$.
- (4) The filter is used, and the new \bar{R}_S is calculated to be -195.01.
- (5) From $\bar{L}_S = \bar{R}_S - J$, we find that

$$\bar{L}_S = (-195.01) - (-368.98)$$

$$\bar{L}_S = -195.01 + 368.98 = 173.97.$$
- (6) The last two columns are filled with $\bar{R}_S \pm 0.7$, for use as future data qualifications.
- (7) The new values between the double lines (\bar{R}_S and \bar{L}_S) are entered into the computer for use during the ship test.

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