ENDEVCO
AN AMPHENOL COMPANY

Calibrators for Acceptance and Qualification Testing of Vibration Measuring Instruments

Technical Paper 223

By R. R. Bouche and L. C. Ensor

CALIBRATORS FOR ACCEPTANCE AND QUALIFICATION TESTING OF VIBRATION MEASURING INSTRUMENTS

By R. R. Bouche and L. C. Ensor

Presented at 33rd Shock, Vibration and Associated Environments Symposium
Washington, D. C. Dec. 1963

INTRODUCTION

Purchasers of vibration measuring instruments frequently require acceptance and qualification tests to be performed by the instrument manufacturer. These tests specify calibrations to be performed on accelerometers and/or associated instruments to ensure satisfactory performance. In addition, many users of vibration instruments perform their own acceptance tests or periodic recalibrations. This paper describes the design details of calibrators suitable for these measurements which are in regular use by one manufacturer. An error analysis indicates the accuracy obtained when using these calibrators. The descriptions in this paper are intended to aid in the design and use of similar calibrators in other laboratories. This will result in more uniformity in calibration procedures throughout the industry and will provide better understanding of the significance of the calibration data obtained.

The calibrators described in this paper are used for calibrating accelerometers in the range from 5 cps to 10,000 cps, 0 to 100 g, and from -350° F to +750° F. Although used primarily for piezoelectric accelerometers, they can also be employed to calibrate other vibration transducers weighing up to 2 oz. The amplitude linearity and temperature response calibrators are designed differently than the sensitivity and frequency response measuring systems; sensitivity and frequency response calibrations are performed at a single acceleration level at various frequencies, while amplitude linearity and temperature response calibrations are usually performed at a single frequency. Although combined temperature and frequency response calibrations are possible over limited ranges, it is usually preferable to perform the calibrations separately and combine the results analytically.

Detailed error analyses for sensitivity and frequency response calibrations are included which indicate that at low frequencies the errors in calibration are comparable to those attained at the National Bureau of Standards. This occurs because the standards used are calibrated by the absolute reciprocity method at 50 cps. At higher frequencies the errors are slightly greater than the NBS errors since at these higher frequencies the standards are calibrated by the comparison method (using reference standards previously calibrated at NBS).

ENDEVCO CORPORATION · 801 SO. ARROYO PARKWAY · PASADENA, CALIF. 91109 · TELEPHONE 213 795-0271
Akron, Ohio • Albuquerque, New Mexico • Boston, Massachusetts • Chicago, Illinois • Houston, Texas • Huntsville, Alabama • Mountain View, California
Palo Alto, California • Philadelphia, Pennsylvania • Washington, D.C. • West Palm Beach, Florida
Representatives: Australia • Belgium • Canada • Denmark • England • France • Germany • Holland • Italy • India • Israel • Japan • Norway • S.Africa • Sweden • Switzerland
TWX: 910 588-3272 Cable: Endevco

SENSITIVITY AND FREQUENCY RESPONSE

Three calibrators used for sensitivity and frequency response calibrations are illustrated in Figures 1, 2, and 3. The shaker in Figure 1 is equipped with both an electrodynamic velocity coil standard and a piezoelectric standard. The second calibrator (Figure 2) is equipped with a piezoelectric standard using voltage amplifiers and the third (Figure 3) uses a piezoelectric standard with charge amplifiers. All standards are calibrated by the reciprocity method at 50 cps. In addition, the piezoelectric standards are calibrated by comparison to accelerometers previously calibrated at NBS.

The shakers are mounted on seismic blocks having resonance frequencies of 4 cps or less. The seismic block eliminates transmission of building vibration to the shaker and prevents shaker induced vibration from being transmitted to the electronic components in the calibrator.

Velocity Coil-Accelerometer Calibrator

The block diagram for the first calibrator, equipped with both velocity coil and accelerometer standards is shown in Figure 1b. The oscilloscope is used to monitor the wave form and assure that no significant distortion is present. Locating the velocity coil in the shaker itself provides a calibration capability which is identical to that available at NBS. The accelerometer standard, also calibrated by the reciprocity method, has the advantage that it can be used over a wide frequency range. The errors of the accelerometer standards are nearly the same as that of the velocity coil standard, as will be shown. The accelerometer standard and a test accelerometer are attached back-to-back in a fixture designed to be used at frequencies up to at least 4000 cps. The shaker is suitable for routine calibrations from 20 cps to 4000 cps. The velocity coil standard is used only at 50 cps, the frequency at which its reciprocity calibration is performed.

The audio oscillator is set at the desired operating frequency and the acceleration adjusted to approximately 5 g which is well within the operating range of the shaker. Switch No. 1 is set to select either the accelerometer or velocity coil standard. The decade capacity is set at the value for which it is desired to measure the voltage sensitivity of the test accelerometer being calibrated. Use of a gain attenuator and two amplifiers permits the calibration of test accelerometers having voltage sensitivities between 0.5 mv/g and 14 volts/g. The amplifiers and the gain attenuator are set so that the output for the test accelerometer at Switch No. 2 is somewhat less than the sensitivity of the coil and accelerometer standard. Both the accelerometer standard in combination with the third amplifier and the coil standard provide a calibrated sensitivity of exactly 100 mv (rms)/g (pk). (Note: frequency standard is unnecessary and is omitted when using the accelerometer standard. The voltage divider is then adjusted until the readings on the VTVM are identical with Switch No. 2 in either position.

To obtain the test accelerometer sensitivity in mv (rms)/g (pk), multiply the voltage divider reading by 100 times the first amplifier gain, times the second amplifier gain, and the gain attenuation. This procedure is repeated at each frequency at which a calibration is desired. The calibration obtained is the combined voltage sensitivity and frequency response of the test accelerometer.

Accelerometer-Voltage Amplifier Calibrator

The accelerometer-voltage amplifier calibrator is illustrated by the block diagram in Figure 2b. A reciprocity calibrated piezoelectric accelerometer is the only standard used. This calibrator is equipped with two vibration exciters in order to cover the entire frequency range from 5 cps to 10,000 cps. One shaker is used from 5 cps to 4000 cps and is rated at 50 pounds force. The other, used from 4000 cps to 10,000 cps, is rated at 0.5 pound force. The large shaker is operated at accelerations up to 10 g except where limited by a double displacement amplitude of 0.25 inch. The small shaker although capable of operating at accelerations up to 1 g, is usually used at 0.5 g to avoid overheating the driving coil at frequencies near 10,000 cps.

Effective eddy currents may be induced in accelerometer cable by a combination of stray magnetic field and low accelerations. This effect can result in ground loop problems which can be eliminated by battery operating one of the voltage amplifiers when using the small shaker.

The standard accelerometer-voltage amplifier combination has been previously adjusted to a calibrated sensitivity of exactly 100 mv/g. When using the large shaker, the test and standard accelerometers are attached to a back-to-back fixture. Switch No. 1 positions the voltage divider in the circuit with the accelerometer having the highest sensitivity. Switch No. 2 is then alternated between the test and standard accelerometers while adjusting the voltage divider until both outputs are identical. The sensitivity of the test accelerometer is 100 times the test accelerometer output divided by the standard accelerometer output. This sensitivity calibration is repeated at each desired frequency in the range from 5 cps to 4000 cps.

Since the small shaker has a piezoelectric standard accelerometer built in, it is not necessary to use the back-to-back fixture. The test accelerometer is attached directly to the shaker and the ratio of the test to the built-in accelerometer output is measured using the same method employed with the large shaker. To verify that the sensitivity of the built-in accelerometer remains unchanged, the reciprocity calibrated accelerometer standard is attached to the small shaker and recalibrated at each frequency at which the test accelerometer is calibrated.

Although the procedure of changing a test accelerometer from shaker to shaker might appear quite cumbersome, it is possible to obtain calibration data throughout the range from 5 cps to 10,000 cps on a single accelerometer in approximately one hour.

Accelerometer-Charge Amplifier Calibrator

The block diagram of the calibrator using charge amplifiers is illustrated in Figure 3b. This calibrator is noteworthy for its simplicity of design. The gain adjust required to calibrate all piezoelectric accelerometers presently available is included in the charge amplifier. The reciprocity calibrated standard is adjusted so that its sensitivity is exactly 10 pcmb/g. This adjustment is made inserting the proper value of series capacitor between the accelerometer and its associated charge amplifier. The sensitivity calibration is performed by vibrating the shaker at the desired frequency at approximately 5 g. The gain ranges on the two charge amplifiers are adjusted until the output of the test accelerometer is somewhat smaller than that of the standard accelerometer. The switch is alternated between its two positions and the voltage divider adjusted until the outputs from the test and standard accelerometers are identical. The sensitivity of the test accelerometer is equal to ten times the voltage divider setting times the ratio of the gains used in the two charge amplifiers. This procedure is repeated at each frequency at which a calibration is desired.

The simplicity of this calibrator is achieved primarily through the wide gain ranges provided in the charge amplifier. This feature permits calibration of any piezoelectric accelerometer having charge sensitivity from 0.5 pcmb/g to 3000 pcmb/g. These amplifiers provide a much higher output signal than available in the two calibrators previously described. In addition, the complicated switching and attenuation circuits are eliminated. The accelerometer-charge amplifier calibrator is designed for use with piezoelectric accelerometers. It does not have the flexibility of the other two calibrators which can be used readily with other types of vibration pickups; e.g., electrodynamic velocity pickups, variable reluctance and differential transformer accelerometers. The shaker used in this calibrator is most useful in the frequency range from 20 cps to 4000 cps.

Shaker Characteristics

The shaker which is used in all three calibrators is suitable for any single axis vibration pickup weighing up to 2 oz. It may be used to calibrate heavier vibration pickups only over limited frequency ranges, since as the weight of the vibration pickup increases the maximum operating frequency decreases. This is not usually a problem because most of the heavier vibration pickups are designed to be used in lower frequency ranges. The one exception to this is the calibration of triaxial accelerometers in all three axes. Although the shaker used in these calibrators is suitable for the Z direction (directly perpendicular to the base of the accelerometer), it is not suitable for calibrating X and Y directions. This measurement of X and Y axes sensitivity requires a shaker whose moving element is specifically designed for mounting triaxial accelerometers in all three directions. It is expected, however, that the improved calibration shakers which have recently become available will be suitable for calibrating triaxial accelerometers.

The small shaker used for calibration to 10,000 cps may also be used for resonance frequency measurement (1, 2). This shaker has the advantage that the lowest elastic body resonance of the moving element is at 55,000 cps. As a result, it is suitable for performing calibrations at frequencies to at least 10,000 cps. At frequencies near 10,000 cps the use of fixtures between the shaker and the test accelerometer should be avoided. This requires that the shaker moving element be provided with several mounting holes in order to accommodate the variety of mounting studs used with accelerometers.

For calibration purposes, it is good practice to use a shaker only at frequencies above its rigid body resonance and below its elastic body resonance. Rigid body resonance is the resonance frequency determined by the stiffness of its flexure system and the weight of the moving element. The elastic body resonance is the resonance frequency determined by the distributed spring-mass characteristic of the moving element alone.

Excessive distortion may be present below the rigid body resonance. Under certain circumstances this distortion produces calibration errors which are not easily explained. To avoid these errors shakers selected for calibration purposes should have their rigid body resonance below the operating frequency range.

A shaker may be used near or above its elastic body resonance if care is taken to assure that there is no relative motion between the test and standard accelerometers and that the apparent weight as seen by each accelerometer is sufficiently large. Considerable experience is required in using a particular shaker near the elastic body resonance to assure that these two requirements are met. True resonance frequency of an accelerometer is obtained only when the structure apparent weight is not sufficiently large; the resonance frequency of the accelerometer will increase with a corresponding improvement in frequency response. This effect should not be confused with the effect of the accelerometer apparent weight on the structure motion as discussed by Schloss (3). The apparent weight of any mounting fixture must also be large enough to ensure that lowest accelerometer resonance frequency is determined. Consequently, the deviations from flat frequency response will always be equal to or less than the deviations measured during calibration.

It is also important when using shakers for calibration purposes, to avoid frequencies where excessive transverse motion is present. The shaker employed in two of the calibrators exhibits transverse motion peaks near 900 cps, 2400 cps, and 3200 cps, similar to those shown in reference (4). It can, however, be used as long as these few frequencies are avoided. Shakers which show considerably improved transverse motion characteristics have recently become available. However, there is still need for a reasonably priced small calibration shaker with both good transverse motion characteristics and high frequency capability which is suitable for calibrating all accelerometers.

Error Analyses

Table 1 lists the various errors which occur in reciprocity calibration of a standard at 50 cps. They are comparable to the errors experienced at NBS when calibrating standards (5). Errors are minimized because a shaker is selected in which the phase shift is exactly 0° or 90° between the driver coil and velocity coil or piezoelectric accelerometer output. The estimated error for these calibrations is determined from the square root of the sum of the squares of the individual measurement errors. Experience indicates that the repeatibility of the reciprocity calibration is comparable to this estimated error.

After the piezoelectric accelerometer is reciprocity calibrated at 50 cps, it is calibrated from 10 cps to 10,000 cps by direct comparison to an accelerometer that has been previously calibrated at NBS. The velocity coil is also calibrated with reference to the NBS calibrated standard, but only at 50 cps, the frequency at which it is used. The error analysis in Table 2 includes the errors of 1% and 2% achieved by NBS. The voltage ratio error is larger above 4000 cps because on the small shaker the test and standard accelerometers must be mounted consecutively. Below 4000 cps a larger shaker is used which permits use of the back-to-back fixture and simultaneous readings of two standard accelerometers.

Table 3 is the error analysis of test accelerometer sensitivity obtained when using the standards described above. In addition to reciprocity and comparison calibrations of the standard, the piezoelectric accelerometer standards are calibrated by the optical method at 5 cps. The error for this calibration is 0.9% as listed in Table 3. The estimated errors applicable to the test accelerometer sensitivity at various frequencies are listed in the last five lines of the table. These errors are determined by taking the root mean square of the individual errors listed in Table 3 which correspond to applicable frequencies. The estimated error in the sensitivity at 50 cps does not exceed 1%, which is comparable to the error estimated on calibrations performed at NBS. The error at the other frequencies are up to 0.7% larger than the error at NBS.

Instead of referring to the detailed errors in the tables, the following simplified statement of errors is used. The estimated error of the test accelerometer sensitivity does not exceed 1.5% at frequencies up to 900 cps, 2.5% up to 4000 cps, and 3% up to 10,000 cps. These errors are obtained by grouping the root mean square values in Tables 2 and 3 and rounding off to the next higher 0.5%.

AMPLITUDE LINEARITY CALIBRATOR

The amplitude linearity calibrator is pictured in Figure 4a. High accelerations are achieved with a resonance beam attached to a ten pound force rated shaker. The moving element of the shaker is sufficiently small so that the beam resonates at its fundamental free-free mode. The beam is specially designed with a clamping fixture to minimize stress concentrations on the beam and avoid excessive fatigue failure. The design of the beam with this particular shaker results in a resonance frequency of approximately 220 cps. With this beam many hours of operation at 100 g can be obtained before fatigue failure of the beam occurs. Operation at up to 200 g can also be performed with somewhat lesser beam life. This design is particularly advantageous in that there is no relative motion between the test and standard accelerometers. The standard accelerometer is mounted at the opposite end of the shaker moving element from the beam. If desired, a back-to-back fixture may be used. Both the test and standard accelerometers are then mounted on the fixture and the fixture may be attached either on the beam or on the opposite end of the moving element.

Figure 4b shows a block diagram of the 100 g calibrator. The decade capacities and the voltage divider are adjusted until the outputs from the test and standard accelerometers are equal at 10 g as indicated by the VTVM. The applied acceleration is then increased to the desired level while the frequency is adjusted to the beam resonance. Amplitude linearity deviation is determined from the change in voltage reading obtained by switching the voltmeter from the standard accelerometer output to the test accelerometer output.

The estimated error in measuring amplitude linearity deviation on this calibrator does not exceed 1%. The standard accelerometer is previously calibrated by one of the absolute calibration methods. The optical method may be used as accelerations near 100 g. In addition, the amplitude linearity of the standard accelerometer may be verified by calibrating at higher accelerations on a shock calibrator. One such device, described in reference (6), is suitable for calibration up to 10,000 g.

TEMPERATURE RESPONSE CALIBRATOR

The temperature response calibrator shown in Figure 5a is used for calibrations from -300° F to +750° F. These calibrations are usually performed at a single frequency. A comparison method is used in which the standard accelerometer is kept at room temperature outside the temperature chamber. The operation of the calibrator is similar to that of the amplitude linearity calibrator. The standard accelerometer is mounted to the shaker moving element at the end opposite from the test accelerometer. The shaker is operated in the vertical direction. A ceramic rod is attached to the top of the moving element and passes through the wall of the chamber. A steel fixture with thermocouple inserted is attached to the top of the ceramic rod and the test accelerometer is mounted on the fixture. Chamber temperature is automatically controlled by the output of the thermocouple.

The block diagram of the calibrator is shown in Figure 5b. The shaker is vibrated at approximately 3 g. In practice, up to four accelerometers may be calibrated simultaneously by using a larger mounting fixture and additional amplifier-voltmeters for each accelerometer. The standard accelerometer is monitored to ensure that the acceleration level remains unchanged during the calibration procedure. Since the standard accelerometer is at the bottom of the shaker, it remains at room temperature. The sensitivity deviation at each temperature is indicated by the changes in voltmeter readings for each test accelerometer.

Three sources of error are present in performing this calibration. First, the error in maintaining constant acceleration which throughout the calibration is approximately 0.5%. Second, the scale reading of the voltmeter for the test accelerometer may be in error up to ± 2% if readings at all temperatures are made on the same range. The third source of error is the combined effect of the temperature response of the particular accelerometer being calibrated and the accuracy of the temperature measurement. More specifically, it is determined by the rate of change of the test accelerometer output with respect to temperature. The temperature is measured by the thermocouple output on a potentiometer to within the accuracy of the thermocouple. For most accelerometers, the estimated total calibration error is less than 5%.

This calibrator is designed primarily for use in the frequency range from 50 cps to 200 cps. The frequency range is extended down to 5 cps by inserting a DC bias voltage (7) on the driving coil of the shaker to support the weight of the moving element and accelerometer and by removing the stiff flexure plates normally used on the shaker. The frequency range may be extended to 4000 cps by using a back-to-back calibration fixture inside the chamber. Extreme care must be used here. The standard accelerometer must have small output deviations over the temperature range of intended calibration. In addition, frequencies where transverse motion is present must be avoided.

COMBINED ENVIRONMENTAL CALIBRATIONS

The state of the calibration art is not yet sufficiently developed to permit combined calibrations of temperature response and amplitude linearity over the entire frequency range of operation of all vibration pickups. Fortunately, accurate calibrations can be achieved by performing the amplitude linearity and temperature response calibrations at a single frequency as described above and then combining the results analytically with sensitivity and frequency response calibration data. This procedure is recommended for vibration pickups with small internal damping which are not used near their resonance frequency. It is particularly suitable for piezoelectric accelerometers which have almost zero damping and are normally used at frequencies below 1/5 of their resonance frequency. Although very small changes in internal damping and resonance frequency probably occur at temperature extremes, these changes have no effect on response below 1/5 the accelerometer resonance frequency.

Other vibration pickups which are normally used near their resonance frequency require combined amplitude linearity and temperature response calibrations. (See Figure 15.23 in reference 8.) Fortunately, the transducer types which require combined environmental calibration are normally used only at frequencies up to a few hundred cps, and the special back-to-back fixture need not be employed. If combined temperature and frequency response calibration is attempted at frequencies above several hundred cps, the calibration results are frequently a measure of calibration error and not of accelerometer performance.

Since the internal resistance of piezoelectric accelerometers decreases at elevated temperatures, this may affect response of the associated amplifier at frequencies below 50 cps. For this reason, it is sometimes desirable to verify the response at temperature of the accelerometer-amplifier system at frequencies as low as 5 cps. The combined temperature-low frequency calibration may be omitted if the resistance of the accelerometer is measured at the maximum operating temperature and the low frequency characteristics of the amplifier are known.

CONCLUSIONS

The calibrators described in this paper are suitable for verifying the characteristics of vibration pickups for use in most vibration measuring applications. The three calibrators described for sensitivity and frequency response measurements are representative of the progress made in these calibrations over the past several years. The calibrator equipped with the velocity coil and reciprocity calibrated accelerometer is capable of performing calibrations comparable to those available at the National Bureau of Standards. The calibrator equipped with piezoelectric accelerometer and charge amplifiers is the simplest to operate, yet maintains accuracies similar to the other sensitivity calibrators described.

The amplitude linearity and temperature response calibrators are used at frequencies up to several hundred cps. The amplitude linearity, temperature response, sensitivity, and frequency response calibration results can be combined analytically without sacrificing over-all accuracy. It is not normally necessary to perform these calibrations simultaneously.

REFERENCES

1. Bouche, R. R., "Characteristics of Piezoelectric Accelerometers", Test Engineering, October, 1962, Pages 16-18, 22,24, and 38.

2. Bouche, R. R., "Instruments for Shock and Vibration Measurements", Experimental Techniques in Shock and Vibration, ASME, 1962, Pages 71-80.

3. Schloss, F., "Inherent Limitations of Accelerometers for High-Frequency Vibration Measurements", JASA, 33, 4, 1961, Page 539.

4. Bouche, R. R., "Improved Standard for the Calibration of Vibration Pickups", Experimental Mechanics, 1961, 1, 4, Pages 116-121.

5. Levy, S., Bouche, R. R., "Calibration of Vibration Pickups by the Reciprocity Method", Journal of Research, National Bureau of Standards, 57, 4, 1956, Pages 116-121.

6. Bouche, R. R., "The Absolute Calibration of Pickups on a Drop-Ball Shock Machine of the Ballistic Type", Proc. IES, 1961, Pages 115-121.

7. Reznek, Ben, "Elimination of Static Shaker Deflections by D.C. Armature Biasing", IES Proc., 1963, Pages 425-432.

8. Bouche, R. R., "Inductive-Type Pickups", Shock and Vibration Handbook, McGraw-Hill Book Company, Inc., New York, New York, 1961, Volume I, Chapter 15, Pages 15-16.

TABLE 1. Analysis of Sensitivity Errors for Reciprocity Primary Standards Calibrated at 50 cps

Measurement	Error	
	Electrodynamic Velocity Coil	Piezoelectric Accelerometer
	per cent	per cent
Mass	0.05	0.05
Transfer Admittance Intercept	0.2*	0.2**
Distortion	0.1	0.1
Voltage Ratio	0.2**	0.2*
Frequency	0.05	0.05
Amplitude Linearity	0.0	0.0
Environmental Effects (Temperature, Acoustic, etc.)	0.0	0.2
Estimated Error***	0.3	0.4

* Assumes 90 degree phase shift.

** Assumes zero-degree phase shift.

*** Determined from the root mean square of the individual errors listed in this table.

TABLE 2. Analysis of Frequency Response Errors for Primary Accelerometer Standards Calibrated from 10 cps to 10,000 cps.

Measurement	Error
	per cent
NBS Calibrated Standard (10 cps - 900 cps)	1.0
NBS Calibrated Standard (900 cps - 10,000 cps)	2.0
Relative Motion (900 cps - 4000 cps)	0.5
Relative Motion (4000 cps - 10,000 cps)	1.0
Voltage Ratio (10 cps - 4000 cps)	0.2
Voltage Ratio (4000 cps - 10,000 cps)	0.4
Estimated Error (10 cps - 900 cps)	1.0*
Estimated Error (900 cps - 4000 cps)	2.1*
Estimated Error (4000 cps - 10,000 cps)	2.3*

* Determined from the root mean square of the individual errors.

TABLE 3. Estimated Error of Sensitivity and Frequency Response Calibrators

Measurement	Error		
	Velocity Coil Standard+	Accelerometer-Voltage Amplifier Standard	Accelerometer Charge Amplifier Standard
	per cent	per cent	per cent
Standard Sensitivity (50 cps)	0.3	0.4	0.4
Standard Sensitivity (5 cps)	---	0.9	---
Standard Sensitivity (10-900 cps)	---	1.0	1.0
Standard Sensitivity (900-4000 cps)	---	2.1	2.1
Standard Sensitivity (4000-10,000 cps)	---	2.3	---
Voltage Ratio (5-4000 cps)	0.2	0.2	0.2
Voltage Ratio (4000-10,000 cps)	---	0.4	---
Relative Motion (900-4000 cps)	---	0.5	0.5
Relative Motion (4000-10,000 cps)	---	1.0	---
External Capacity	0.5	0.5	0.25
Amplifier Gain	0.2	0.2	0.7**
Amplifier Frequency Response	---	0.5	0.5
Frequency	0.1	---	---
Environmental Effects (Temperature, Acoustic, etc.)	0.5	0.5	0.5
Estimated Error (50 cps)	0.8*	0.9*	1.0*
Estimated Error (5 cps)	---	1.3*	---
Estimated Error (10-900 cps)	---	1.5*	1.5#*
Estimated Error (900-4000 cps)	---	2.3*	2.4#*
Estimated Error (4000-10,000 cps)	---	2.7*	---

\+ Used at 50 cps only.

* Determined from the root mean square of the applicable individual errors.

\# Calibrator normally used from 20-4000 cps.

** Amplifier specially calibrated and adjusted.

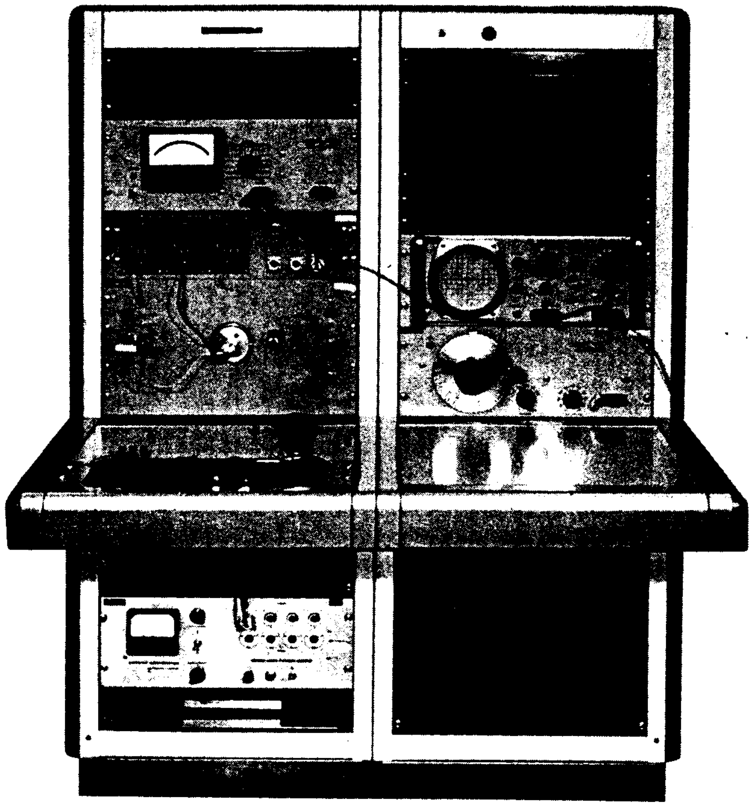

FIGURE 1a. Sensitivity and Frequency Response Calibrator Equipped with Velocity-Coil and Piezoelectric Accelerometer-Voltage Amplifier Standards.

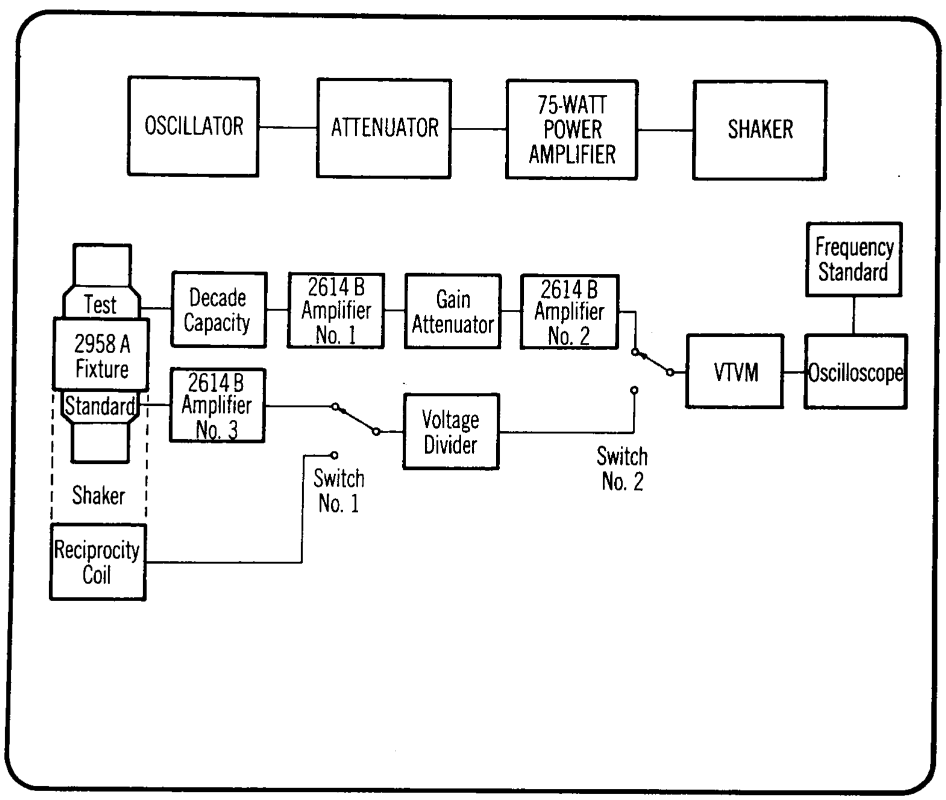

FIGURE 1b. Sensitivity and Frequency Response Calibrator Equipped with Velocity-Coil and Piezoelectric Accelerometer-Voltage Amplifier Standards - Block Diagram.

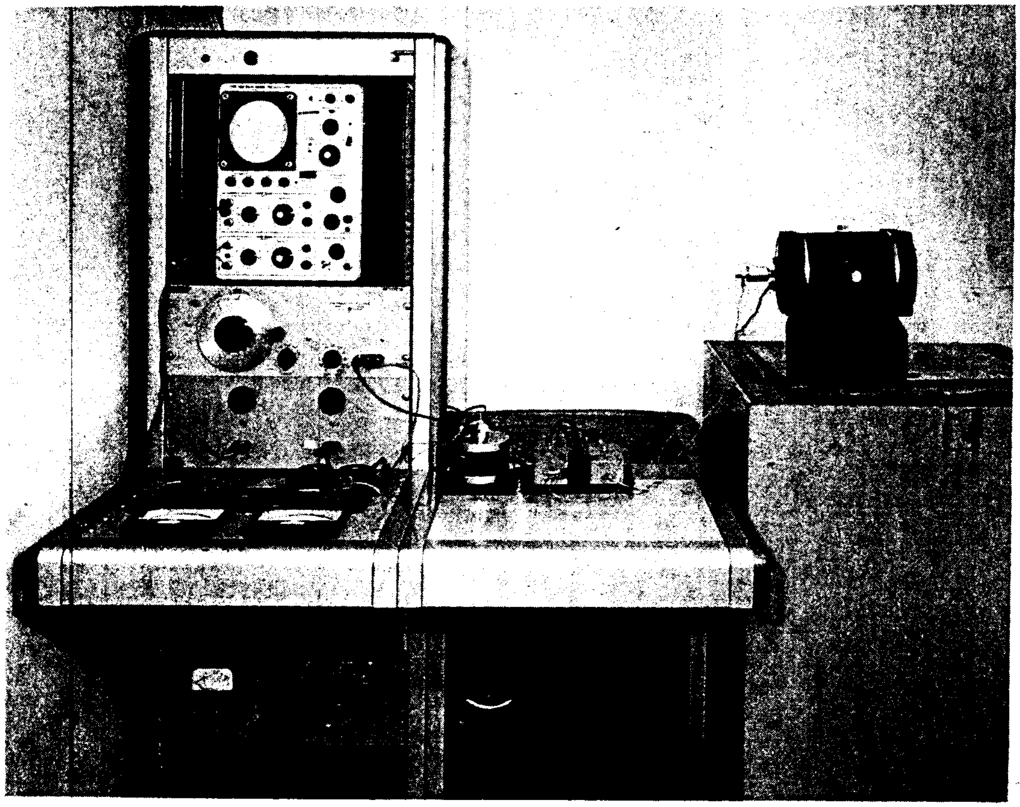

FIGURE 2a. Wide Frequency Range Sensitivity Calibrator Equipped with Piezoelectric Accelerometer-Voltage Amplifier Standard.

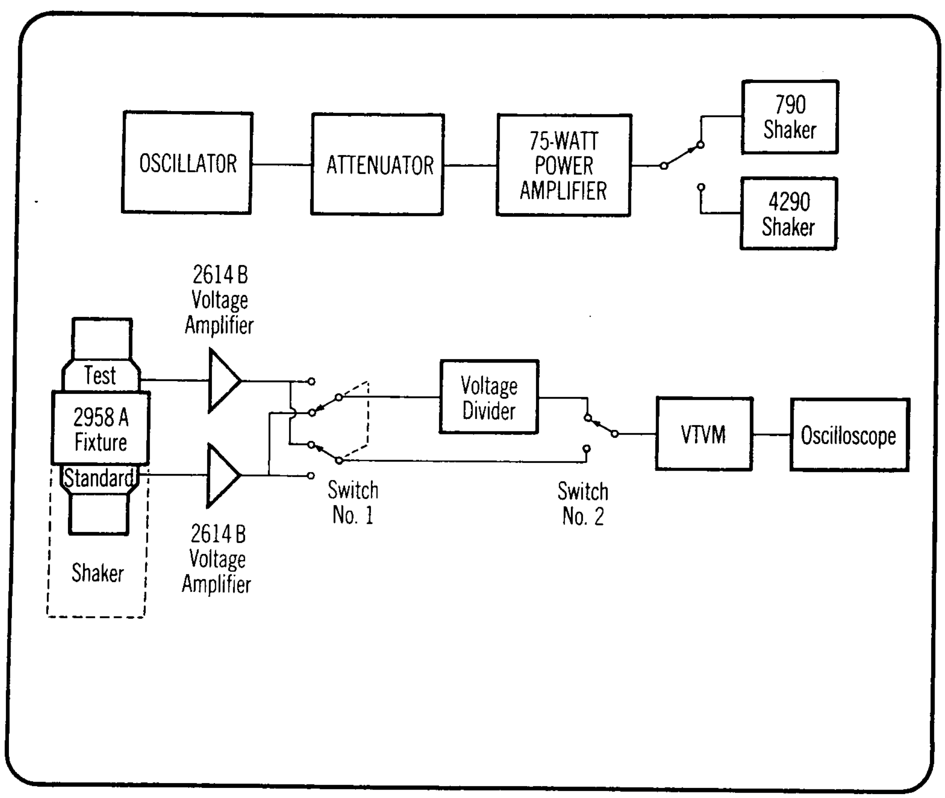

FIGURE 2b. Wide Frequency Range Sensitivity Calibrator Equipped with Piezoelectric Accelerometer-Voltage Amplifier Standard - Block Diagram.

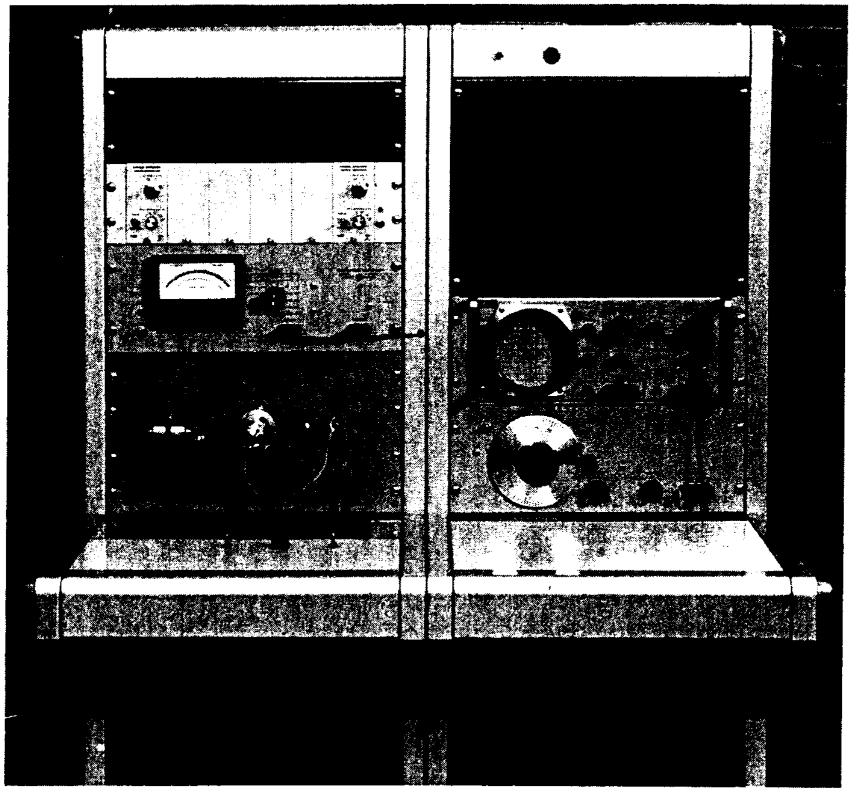

FIGURE 3a. Sensitivity and Frequency Response Calibrator Equipped with Piezoelectric Accelerometer-Charge Amplifier Standard.

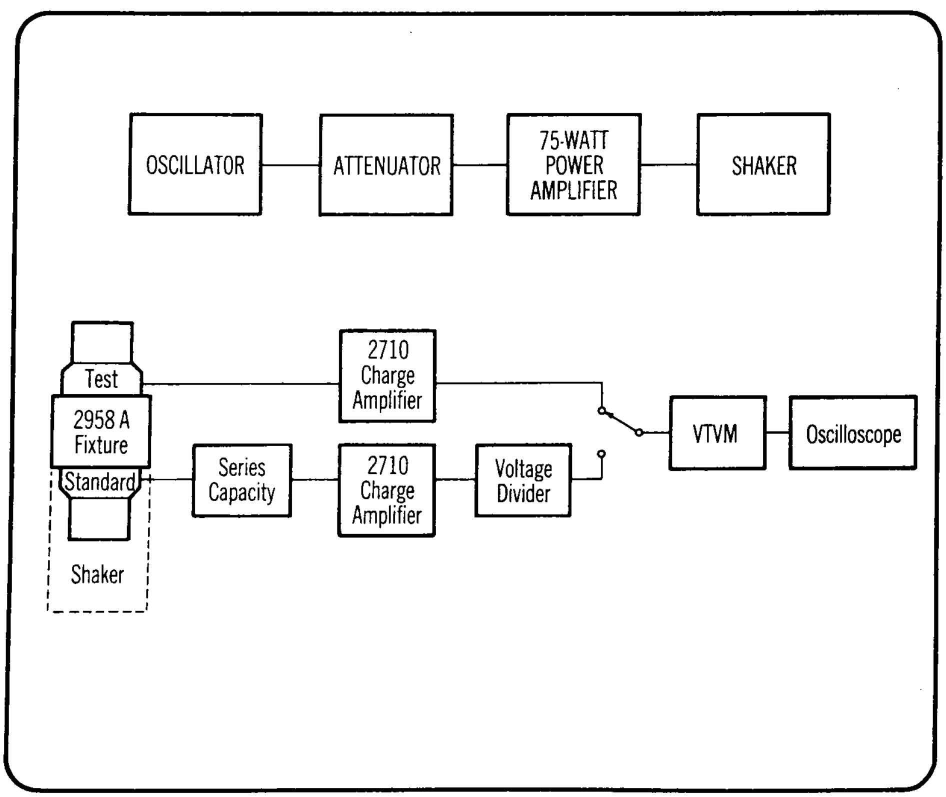

FIGURE 3b. Sensitivity and Frequency Response Calibrator Equipped with Piezoelectric Accelerometer-Charge Amplifier Standard - Block Diagram.

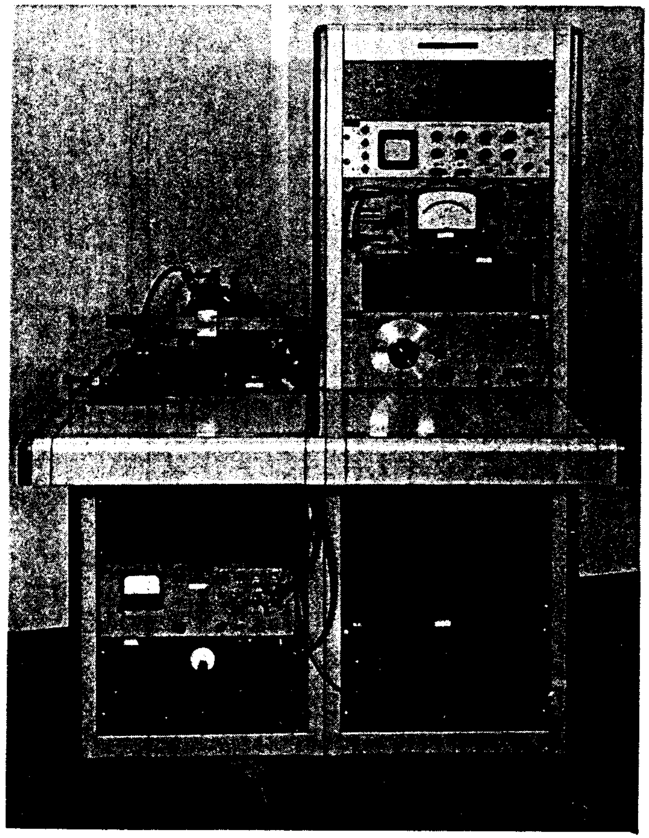

FIGURE 4a. Amplitude Linearity Calibrator.

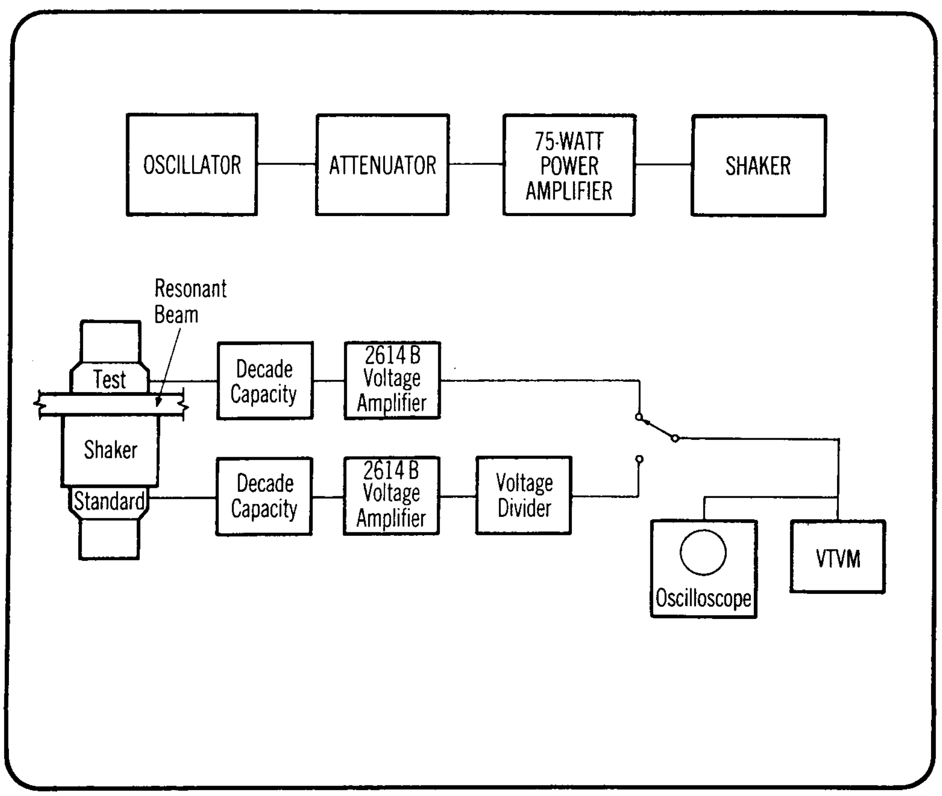

FIGURE 4b. Amplitude Linearity Calibrator - Block Diagram.

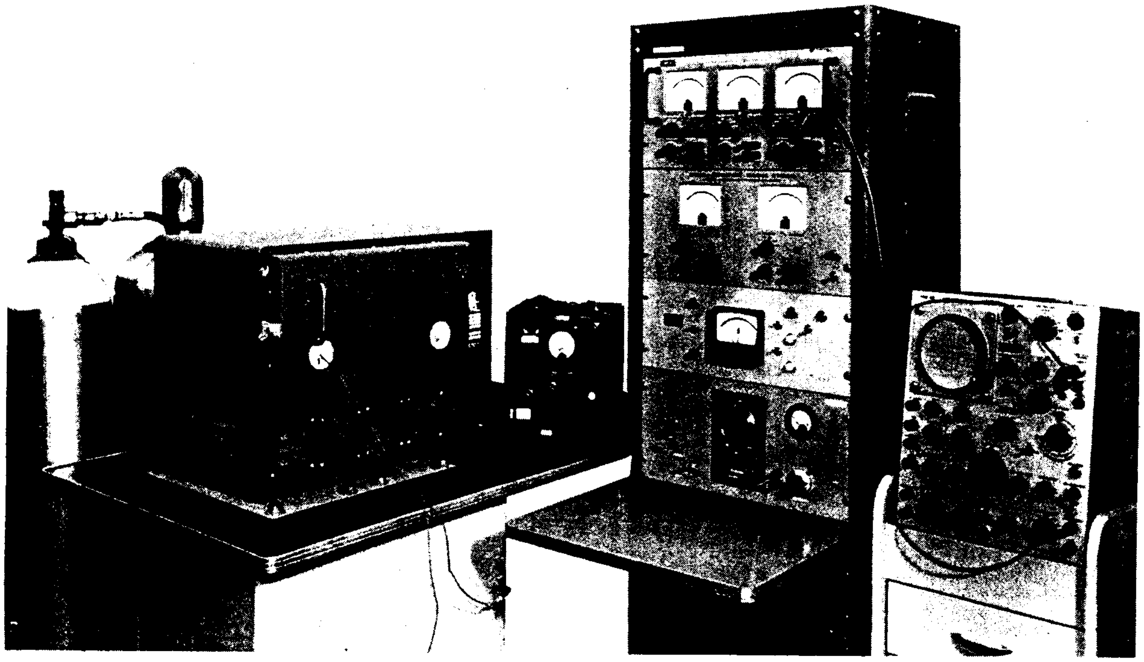

FIGURE 5a. Temperature Response Calibrator.

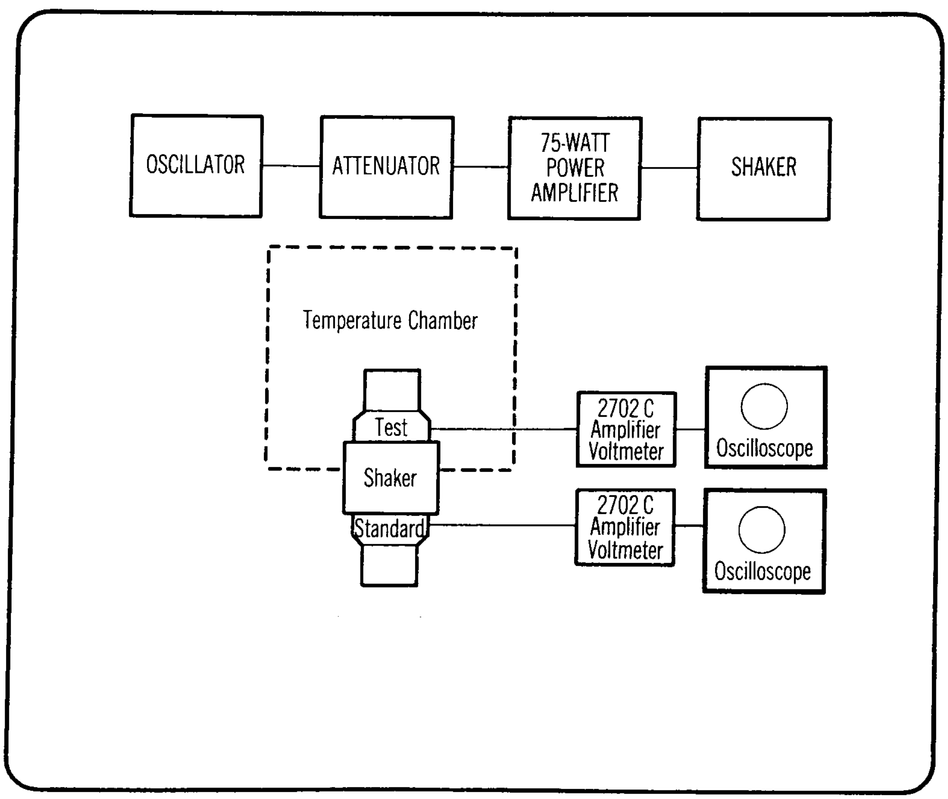

FIGURE 5b. Temperature Response Calibrator - Block Diagram.

ENDEVCO
AN AMPHENOL COMPANY

10869 NC Highway 903, Halifax, NC 27839 USA

endevco.com | sales@endevco.com | 866 363 3826

© 2022 PCB Piezotronics - all rights reserved. PCB Piezotronics is a wholly-owned subsidiary of Amphenol Corporation. Endevco is an assumed name of PCB Piezotronics of North Carolina, Inc., which is a wholly-owned subsidiary of PCB Piezotronics, Inc. Accumetrics, Inc. and The Modal Shop, Inc. are wholly-owned subsidiaries of PCB Piezotronics, Inc. IMI Sensors and Larson Davis are Divisions of PCB Piezotronics, Inc. Except for any third party marks for which attribution is provided herein, the company names and product names used in this document may be the registered trademarks or unregistered trademarks of PCB Piezotronics, Inc., PCB Piezotronics of North Carolina, Inc. (d/b/a Endevco), The Modal Shop, Inc. or Accumetrics, Inc. Detailed trademark ownership information is available at www.pcb.com/trademarkownership.

TP223-011922