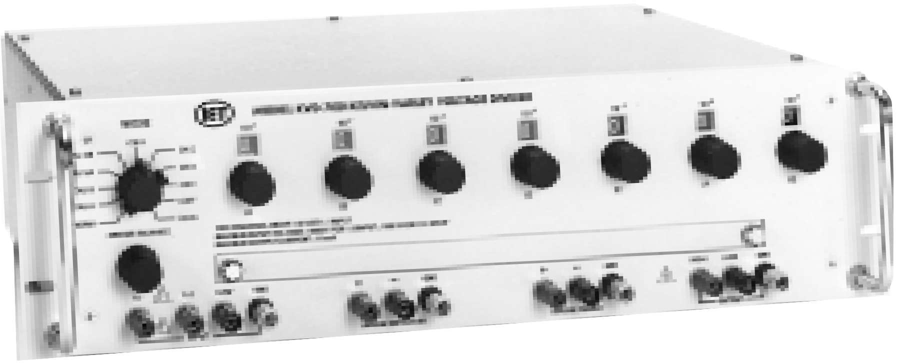
◆ PRECISION INSTRUMENTS FOR TEST AND MEASUREMENT ◆

KVD-700 SERIES

KELVIN-VARLEY
VOLTAGE DIVIDER

Operation Manual



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Contents

Figures

Chapter 1

INTRODUCTION

1.1 General Description

The KVD-700 (Figure 1.1) is a calibration grade voltage divider employing the Kelvin-Varley circuit. It is a highly accurate, stable, and linear primary ratio standard suitable for use in many applications requiring known voltage or current ratios. In particular, the KVD-700 is especially appropriate for use in bridge circuits, providing two legs of a bridge with a very well known ratio.

The KVD-700 has a resolution of 0.1 ppm and an absolute linearity of 0.1 ppm. It has a **1.0** input and a **1.1** input to allow over-ranging. Temperature coefficient of linearity is 0.1 ppm/°C, and power coefficient of linearity is 0.2 ppm/W.

The KVD-700 incorporates a number of advanced features making for convenience and high performance. These include self-calibration capability, very low tempco resistors, Kel-F mounted tellurium copper binding posts, sealed internal calibration potentiometers, and a convenient operating guide attached to the unit.

The KVD-700 features a built-in Wheatstone bridge self-calibration circuit so that the unit may be calibrated with a minimum of external instruments and without requiring another voltage divider.

The KVD-700 employs precision resistors which have been aged, temperature and power cycled to maximize long term stability, and matched to minimize temperature and power coefficients effects. The most significant decade is sealed in an oil bath to minimize temperature coefficient effects.

The switches used have gold plated solid silver alloy contacts for long life, minimum contact resistance, and no tarnishing. Gold also allows the use with low level signals. The switches have multiple wiper contacts to provide stable low contact resistance.

High quality gold plated tellurium copper binding posts serve to minimize the thermal emf effects which would artificially reflect a change in dc resistance measurements. They are mounted to the case on special Kel-F washers to insure low leakage. All other conductors within the instrument, as well as the solder employed, contain no metals or junctions that could contribute to thermal emf problems.

The front panel is clearly labelled showing step size for each decade. Maximum voltage and current limitations are indicated as well. The unit may be mounted in a standard 19 inch rack.

Applications include linearity determination, the measurement of voltage and resistance, the calibration of other dividers, potentiometers or similar devices involving both voltage and current.

Figure 1.1. Model KVD-700 Kelvin-Varley Voltage Divider

1.2 Circuit Description

1.2.1 Model

A Kelvin-Varley voltage divider may be thought of as being equivalent to a digital potentiometer, except that it has an additional, but variable resistance in series with the wiper arm. Such a circuit model of the KVD-700 may be seen in Figure 1.2. In the case of the KVD-700, the resistance between the input terminals 1 and 2 is 100 kΩ.

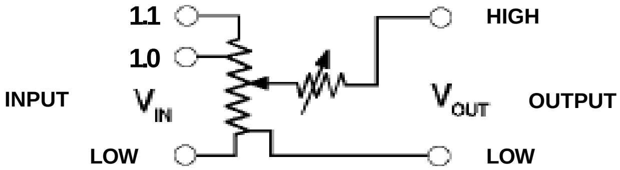


Figure 1.2. Digital Potentiometer Model for a Kelvin-Varley Voltage Divider

An actual digital potentiometer uses decades of resistor steps each decreasing by factor of ten. The problem with such a digital potentiometer, however, is that its resolution becomes limited by the value of ever smaller resistors. They become difficult to implement as the contact resistance of switches and connections become significant. A Kelvin-Varley circuit however overcomes this problem with its special design, described later.

Another way to model the KVD-700 is with the Thevenin equivalent circuit shown in Figure 1.3, where S is the dial setting. Note that if the output is being fed into a very high impedance, then the output impedance R_O, may be ignored. In general however the effect of load impedance, R_L must be taken into consideration, as will be discussed below. The approximate value of R_O is shown in Figure 1.4. It may be seen the output impedance is maximum at about the dial setting of 0.5 and drops to zero at both ends, 1.0 and 0. It is the value of R_O which will influence the effect of loading.

Note however that in general bridge applications, nominally zero current flows out of the divider as the bridge comes into balance, and therefore the divider effectively "sees" an infinite impedance, and the effect due to R_O may be safely ignored.

1.2.2 Theory of Operation

The actual circuit diagram of the KVD-700 is shown in Figure 1.5. This circuit is capable of dividing the input into 10^7 parts, i.e. 0.1 ppm. It consists of seven decades each of which divides its input voltage into 10 equal parts.

The implementation of this division may be seen as follows. The input voltage across each decade is divided by 10 equal resistances. Placing the resistance of the succeeding decade in parallel with a portion of the upstream decade reduces the effective resistance of that portion. In particular, examine the figure and note that first decade has 11 not 10 resistors (ignoring the 1.1 input resistor). The divider wipers from the second decade encompass two resistors totaling 20 kΩ. This 20 kΩ is shunted by 20 kΩ, the effective total resistance of the second decade with all the shunting in parallel with it, resulting in a total effective resistance of 10 kΩ for that step.

The 11 steps become equivalent to 10 steps of 10 kΩ each, and in this way all the steps are kept equal.

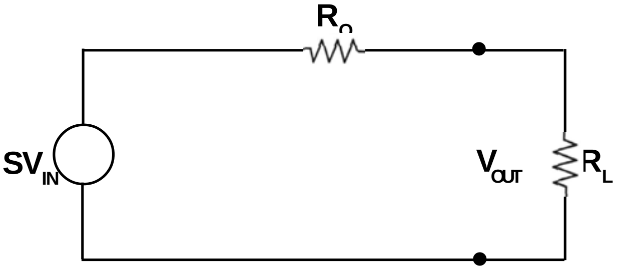
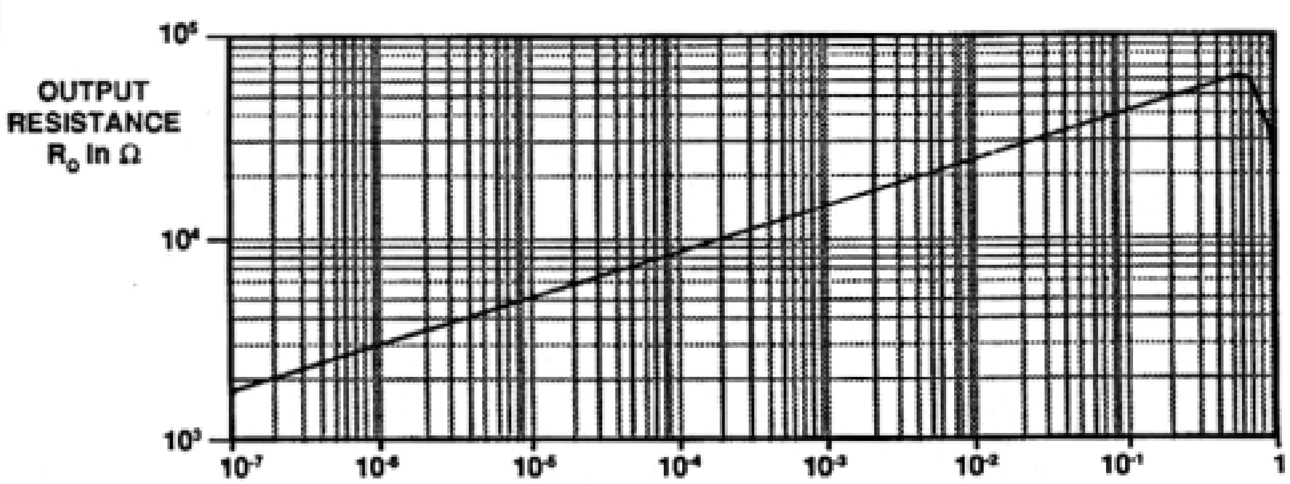


Figure 1.3. Thevenin Equivalent Circuit of a Kelvin-Varley Voltage Divider



RATIO DIAL SETTINGS (S)

Note: The value of the output resistance is a "smoothed" approximation.
The actual resistance "oscillates" around this value as lower decades are varied.

Figure 1.4. Approximate Value of Output Resistance as a Function of Dlal Setting (S)

Each step of the second decade is also 10 kΩ. The 20 kΩ of that decade, spanned by the switch contacts, are shunted by the 20 kΩ effective resistance of the third decade. Similarly 8 kΩ of the third decade are shunted by the 8 kΩ total resistance of the fourth decade.

Note that this pattern reduces the resistor value until an optimal value of 1 kΩ is reached and repeated. This allows the use of a resistance high enough to avoid contact resistance problems.

Note that the last decade uses only one switch wiper and can therefore span positions 0-10. With all significant decades set to 9, and the last one set to 10, the output is 1.0 or equal to the input.

At the low or zero end, a small series resistance is added between the **OUTPUT LOW** terminal, the lower end of the divider string, and the INPUT LOW terminal to compensate for contact and wiring resistance, thus bringing the voltage at the **OUTPUT LOW** terminal equal to the voltage at the **OUTPUT HIGH** terminal for all switches set to 0. This provides improved performance for low voltage outputs.

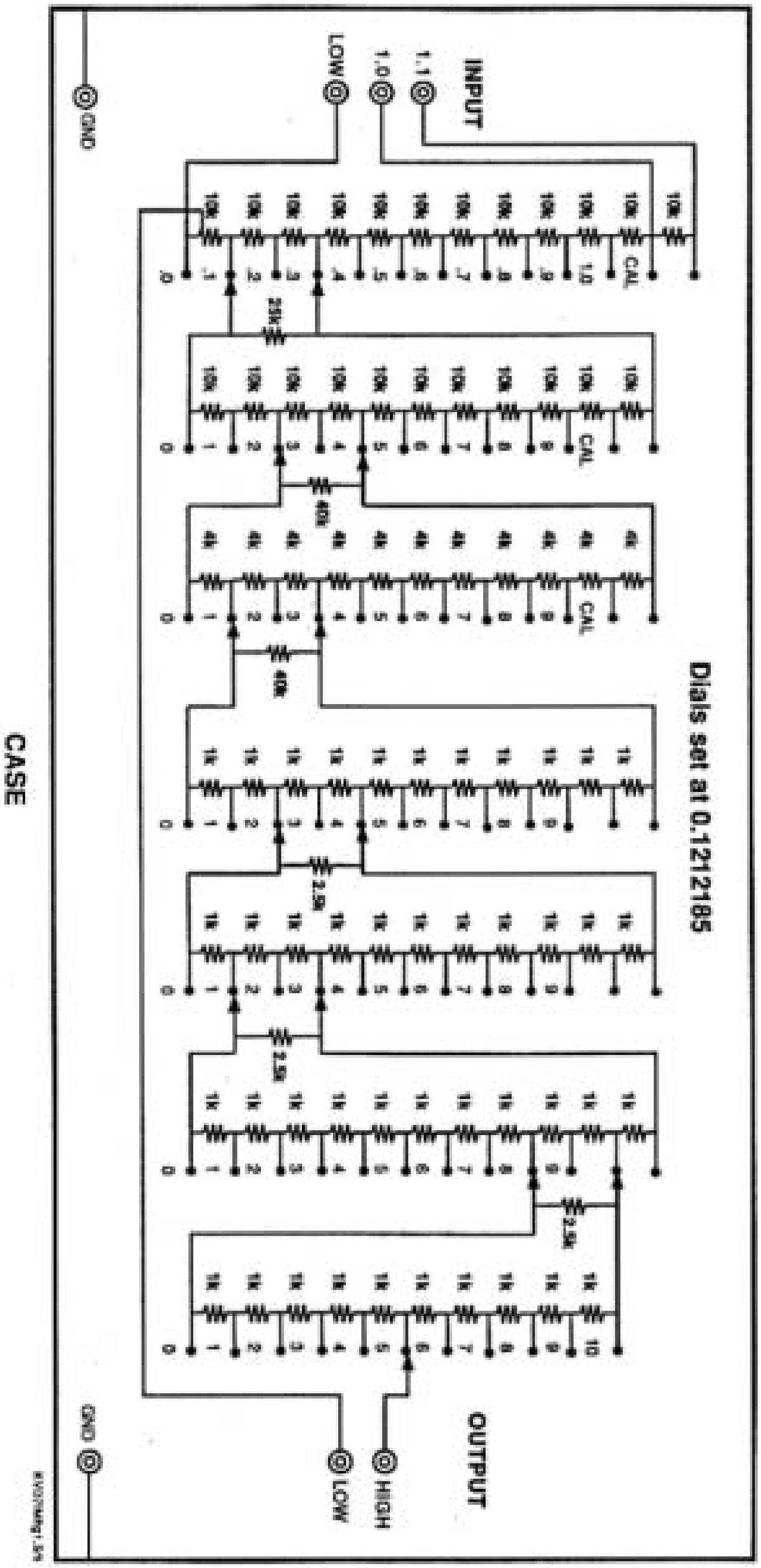


Figure 1.5. Schematic Diagram of KVD-700 Kelvin-Varley Voltage Divider Circuit

Chapter 2

SPECIFICATIONS

For convenience to the user, the pertinent specifications are given in an **OPERATING GUIDE**, typically shown in Figure 2.1, affixed to the case of the instrument.

Ratio Range:

0 to 1.0 of input at **1.0 INPUT**; 0 to 1.1 at **1.1 INPUT**.

Resolution:

0.1 ppm with 7 decades.

Absolute Linearity:

At 23°C, at low power; defined relative to zero and full scale outputs, at the output terminals. Quantitatively it is $[V_{out}/V_{in}] - S$, where **S** is the dial setting.

±0.1 ppm for S = 0.1 to 1.1.

±0.1 $(10S)^{1/3}$ ppm for S = 0 to 0. 1.

Short Term Linearity Stability:

When maintained under standard laboratory conditions of ±l°C and applied voltage of <100 V, linearity shall have a stability of ±0.01 ppm per day, and ±0.1 ppm per month.

Long Term Linearity Stability:

± 1.0 ppm/year for S = 0.1 to 1. 1.

± 1.0$(10S)^{2/3}$ ppm/year for S = 0 to 0.1.

Self-calibration restores linearity to 0.1 ppm.

Maximum Carryover Error:

±0.04 ppm.

Temperature Coefficient of Linearity:

±0.1 ppm/°C for S = 0.1 to 1.1.

±0.1$(10S)^{2/3}$ ppm/°C for S = 0 to 0.1.

Power Coefficient of Linearity:

±0.2 ppm/W for S = 0.1 to 1.1.

±0.2$(10S)^2$ ppm/Ω for S = 0 to 0.1.

Maximum Input Voltage:

1000 V at **1.0 INPUT**; 1100 V at **1.1 INPUT**.

Maximum Output Current:

11 mA.

Breakdown Voltage:

2500 V to case at sea level; 2000 V to case at 10,000 feet above sea level.

Input Resistance:

100 kΩ ±50 ppm at **1.0 INPUT; 110** kΩ ±50 ppm at **1.1 INPUT.**

Temperature Coefficient of Input Resistance:

±1.0 ppm/°C.

Maximum Input Power:

10 W at **1.0 INPUT; 11** W at **1.1 INPUT**.

Maximum Output Resistance:

66 kΩ, determined by shorting across the input and measuring the resistance across the output terminals. See Figure 1.4.

Thermal Voltages:

<0.5 µV at the output terminals.

End Errors:

Zero error at **OUTPUT LOW** terminal <±0.004 ppm of input;

Zero error at **INPUT LOW** terminal <±0.05 ppm of input;

Full scale error at **OUTPUT HIGH** terminal <±0.05 ppm of input.

Terminals:

High quality low thermal emf gold plated tellurium copper binding posts; standard 0.75" spacing; additional binding posts are connected to the case for shielding. Terminals are insulated from the case by non moisture absorbing Kel-F spacers.

Operating Conditions:

0°C to 50°C; 35% RH to 55% RH; for operating conditions below 15°C and above 35°C, linearity must be derated 0.1 ppm/°C from the temperature of calibration.

Storage Temperature:

-34°C to 70°C.

Dimensions:

5.25" high rack panel; Panel: 48.3cm W x 13.2 cm H (19.0" x 5.20" behind panel: 42.7 cm W x 12.4 cm H x 31.5 cm D (16.8" x 5.2" x 12.4"); in front of panel 3.8 cm (1.5").

Weight:

8 kg (18 lb)

Figure 2.1. Typical OPERATING GUIDE Affixed to Unit

Chapter 3

INSTALLATION

3.1 Initial Inspection

IET instruments receive a careful mechanical and electrical inspection before shipment. Upon receipt, verify that the contents are intact and as ordered. The instrument should then be given a visual and operational inspection.

If any shipping damage is found, contact the carrier and IET Labs. If any operational problems are encountered, contact IET Labs and refer to the warranty at the beginning of this manual.

Save all original packing material for convenience in case shipping of the instrument should become necessary.

3.2 Installation

For a rack mounted model, installation on a 19 inch rack may be made using the slots in the rack mounting ears. A mounting location that does not expose the unit to excessive heat or temperature variations is recommended.

For bench models, no installation as such is required, because this instrument series is not powered. Since it is a high accuracy instrument, it is recommended that a bench space be provided that would not expose it to abuse and keep it protected from temperature extremes and contaminants.

3.3 Repackaging for Shipment

If the instrument is to be returned to IET Labs, contact the Service Department at the number or address, shown on the front cover of this manual, to obtain a “Returned Material Authorization” (RMA) number and any special shipping instructions or assistance. Proceed as follows:

1. Attach a tag to the instrument identifying the owner and indicate the service or repair to be accomplished. Include the model number, the full serial number of the instrument, the RMA number, and shipping address.
2. Wrap the instrument in heavy paper or plastic.
3. Protect the front panel and any other protrusions with cardboard or foam padding.
4. Place instrument in original container or equally substantial heavy carton.
5. Use packing material around all sides of instrument.
6. Seal box with strong tape or strapping.
7. Mark shipping container “DELICATE INSTRUMENT,” “FRAGILE,” etc.

3.4 Storage

If this instrument is to be stored for any lengthy period of time, it should be sealed in plastic and stored in a dry location. It should not be subjected to temperature extremes. Extended exposure to such temperatures can result in an irreversible change in resistance, and require recalibration.

Chapter 4

OPERATION

4.1 Initial Inspection and Setup

This instrument was carefully inspected before shipment. It should be in proper electrical and mechanical order upon receipt.

An **OPERATING GUIDE**, like the typical one shown in Figure 2.1, is attached to the case of the instrument to provide ready reference to specifications.

4.2 Power Considerations

It is possible to damage the KVD-700 by applying too great a voltage to the input terminals or drawing more than 11 mA from the output terminals.

The input or output must therefore be limited in some fashion. A power supply with current limiting may be used, or current limiting in the form of a resistor or an 11 mA fuse may be inserted in series with the input and/or output.

Whenever significant power is applied to the KVD-700, it should be allowed to stabilize for a few minutes as settings are changed. As may be seen from figure 1.5, if 10 W were applied across the most significant decade resistor string, 1 W would be dissipated across each 10 kW resistor, but only 0.25 W would be dissipated across the two resistors shunted between the wiper arms. This causes differential heating, and the drift must be allowed to stabilize. The oil bath in which the most significant decade is contained serves to more evenly distribute the temperature variation. After the application of high power, the unit should be allowed to cool for a few hours before the application of low power.

4.3 Loading Errors

As may be seen from Figure 1.3, the output voltage of an unloaded Kelvin-Varley divider is given by:

$$\mathbf{V_{OUT} = SV_{IN} + DEV}$$

where DEV is the fractional linearity deviation. When a load is applied, the output becomes:

$$\mathbf{V_{OUT} = SV_{IN} + DEV - R_O/R_L}$$

where R_O is the output resistance which may be determined by shorting the input leads and measuring across the output leads, or can be approximated by using Figure 1.4. $\mathbf{R_O}$ ranges from zero to about 66 kΩ. $\mathbf{R_L}$ is the load resistance applied at the output.

It may be seen that it is the relative size of the term $\mathbf{R_O/R_L}$ to the linearity deviation that determines the Importance of the loading error. In particular, for the KVD-700, $\mathbf{R_L}$ must be greater than 1 TΩ, i.e. 10^{12}, for the loading effect to be <.03 ppm for the maximum $\mathbf{R_O}$. It will be smaller for lower output resistances at other settings.

Note that even meters having virtually "open circuit" input impedance, e.g. 10 GΩ will still have an effect on linearity of up to many ppm's, depending on setting S.

A bridge circuit under balanced conditions will effectively draw no current from the KVD-700 and approach a true open circuit.

4.4 Switch Conditioning

The switch wipers employed in this unit are self cleaning constructed of solid silver alloy with solid silver alloy contacts. Whenever left idle, the wipers and contacts must be conditioned or “rebroken in” to remove the film of silver oxide that develops over time. This is standard metrology practice when high accuracy is required. This effect is of the order of less than 1 mΩ, so it may be ignored whenever measurements of that magnitude are not important.

To perform this “breaking in”, simply rotate each switch seven to ten times in each direction.

4.5 Operation and Controls

Figure 4.1 shows the front panel and the various controls and connection terminals of the KVD-700 divider.

In normal operation, place the **MODE** switch in the **NORM** position. The other positions are for the various calibration steps described later.

The input voltage is usually connected to the **1.0 INPUT** or if required to the **1.1 INPUT**. The latter is used whenever an “overrange” output greater than 100% of a nominal value is required. Secure connections should be made to the terminals using spade lugs, banana jacks, or bare wire. Caution should be exercised since most often such connectors are usually made of brass which can add thermal emf. Copper or copper alloy connections should be used, or bare wire which is tinned copper may be employed. Similar connections are made to the **OUTPUT** terminals.

Implement any current limiting protection as described in the power considerations discussion of section 4.2. Observe all safety precautions if high voltages are used.

The dials may be set and read directly on the front panel. Some decades have a CAL and blank positions to be used only in the calibration mode. The least significant decade has a **10** setting which can be use to provide an output of 1.0, i.e. 100% of the input.

If the KVD-700 is to be used at a temperature considerably different from its latest calibration temperature or if an extended period of time has passed since its latest calibration, a self calibration should be performed as described in the Chapter 5.

End errors should be considered in any application. Either the specified values should be used or the end errors may measured as described in the Maintenance section below.

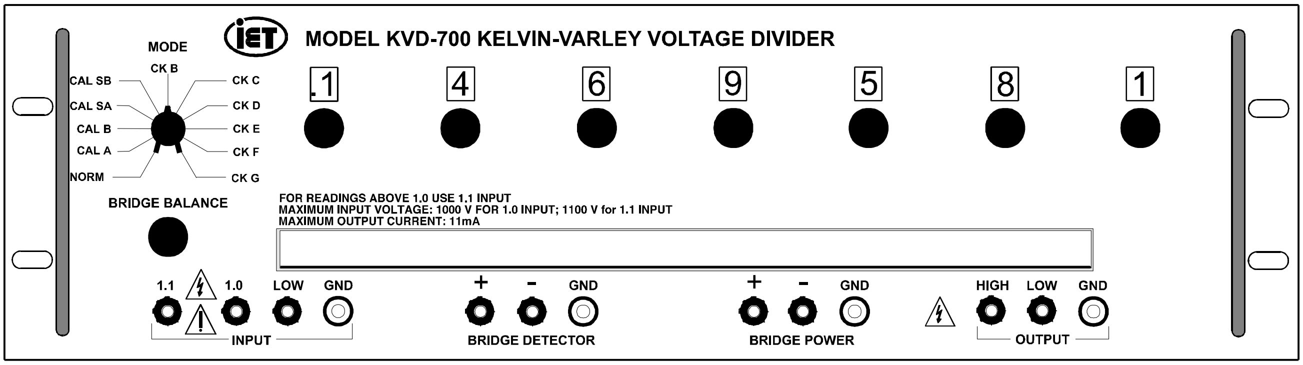


Figure 4.1. Front Panel of KVD-700

4.6 Representative Bridge Applications of the KVD-700

There is a broad spectrum of applications for a Kelvin-Varley divider, such as calibrating other voltage dividers, measuring unknown voltages, and measuring unknown resistances. There are a number of sources for detailed information on these -common and many other applications. Some are given in Appendix A. One application, the calibration of a voltage divider is essentially described in the following chapter on calibrating the KVD-700.

Consult IET Labs for additional references and information.

Chapter 5

SELF-CALIBRATION

5.1 Introduction

As may be seen from the schematic of a Kelvin Varley voltage divider shown in Figure 1.5, the linearity depends primarily on the equivalence of the resistance steps.

The self-calibration feature takes advantage of this fact by incorporating a Wheatstone bridge to make all the resistance steps equal to one step used as a reference. Adjustable trimmers in the first three decades allow setting the various resistors and shunts with respect to the initial reference resistance. This can compensate for the effects of aging and temperature and results in maintenance of the absolute linearity to ±0.1 ppm of input.

5.2 Self-Calibration Setup

Refer to Figure 5.1 to set up the KVD-700 for self calibration. Use low thermal emf connections as described in Section 4.4.

Prepare a stable dc voltage source or batteries capable of supplying 10 to 20 V.

Connect a null detector to **BRIDGE DETECTOR** terminals. An analog or digital voltmeter with input impedance > 10 MΩ may be used if it provides a stable resolution of 0.1 µV or better.

5.3 Self-Calibration Procedure

5.3.1 First Decade

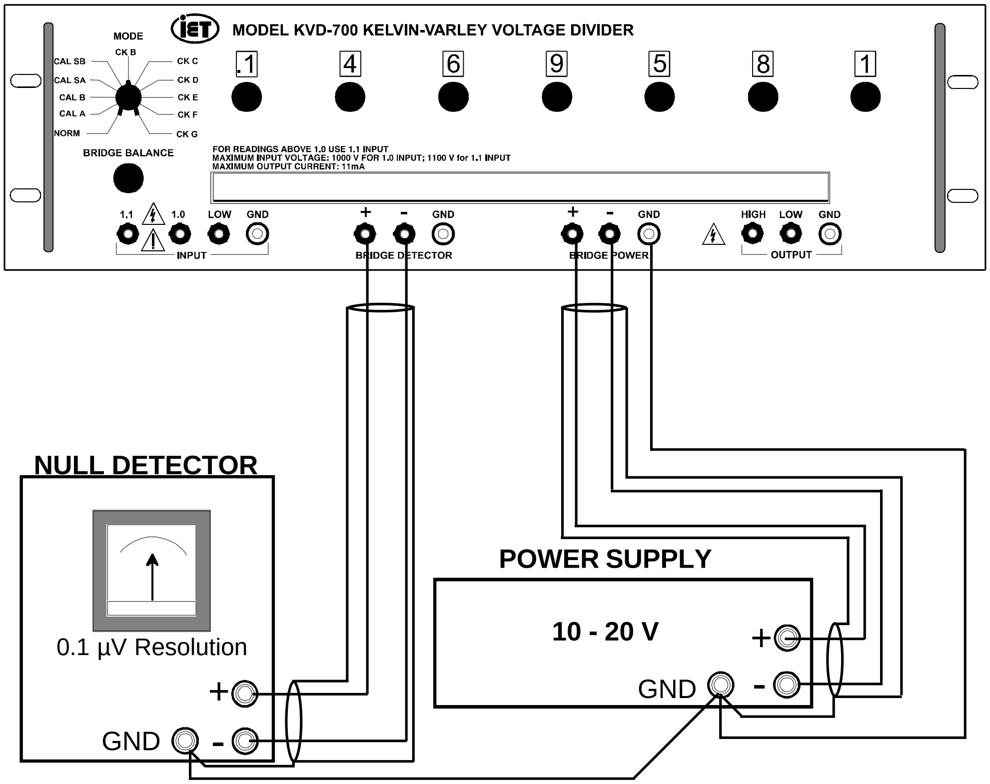
1. Set the KVD-700 switches to .0000000
2. Set the **MODE** switch on the KVD-700 to **CAL A.**
3. Set the null detector to zero with any offset or zero control.
4. Set the dc voltage supply to 20 V. ,
5. Connect the dc voltage supply as shown to the **BRIDGE POWER** terminals. Batteries may be used.
6. Adjust the **BRIDGE BALANCE** control on the KVD-700 for a zero reading on the null detector. Note that this control is a combination of two concentric potentiometers with fine and coarse ranges.
7. Remove the dust cover below the divider knobs by removing the two thumbscrews. This exposes the trimmers for the first two decades.
8. Advance the most significant divider decade **A** to 0.1
9. Set the leftmost **A DECADE .1** trimmer which may be reached through an access hole to obtain a null reading within ±0.5 µV.
10. Repeat the above two steps for **A** decade settings **0.2** through **CAL** and obtain a null with the associated trimmer. Reconfirm periodically the original **BRIDGE BALANCE** null at the **.0** setting of the first decade.

5.3.2 Second Decade

1. Set the KVD-700 switches to .0000000
2. Set the null detector to zero with any offset or zero control.
3. Set the dc voltage supply to 10 V.
4. Adjust the **BRIDGE BALANCE** control on the KVD-700 for a null reading on the null detector.
5. Set the **MODE** switch on the KVD-700 to **CAL B**
6. Set the **B DECADE 0** trimmer to obtain a null reading within ±1 µV.
7. Advance the **B** decade one step to 1.
8. Set the **B DECADE 1** trimmer to obtain a null reading within ±1 µV.
9. Repeat the above two steps for **B** decade settings **2** through **CAL** and obtain a null with the associated trirmmer. Reconfirm periodically the original null at the .0 setting of the first decade, at **MODE SWITCH** setting **CAL A**.

5.3.3 Shunt Resistors

1. Set the KVD-700 switches to .0000000
2. Set the **MODE** switch on the KVD-700 to **CAL A**.
3. Adjust the null detector to zero with **BRIDGE BALANCE** control on the front panel.
4. Set the **MODE** switch on the KVD-700 to **CAL SB**
5. Set the **SHUNTS SB** trimmer to obtain a null reading within ±1 µV.
6. Set the dc voltage supply to 20 V.
7. Set the **MODE** switch on the KVD-700 to **CAL A.**
8. Adjust the **BRIDGE BALANCE** control on the KVD-700 for a null reading on the null detector.
9. Set the **MODE** switch on the KVD-700 to **CAL SA**
10. Set the SHUNTS SA trimmer to obtain a null reading within ±0.5 µV.
11. Disconnect the null detector and the power supply.
12. Return the **MODE** switch on the KVD-700 to **NORM**.



Connect only one end of shields to gnd.
Use bare wire or low thermal emf leads.

KVDFIG5.1PM

Figure 5.1. Setup for Self-Calibration

Chapter 6

MAINTENANCE

6.1 Preventive Maintenance

The KVD-700 is enclosed in a dust-tight housing which will limit the entry of contaminants to the inside of the instrument. If it is maintained in a generally clean or air conditioned environment, cleaning will be seldom required. Switches should be conditioned periodically as described in Section 4.4.

6.2 Verification of Performance

The calibration of the KVD-700 consists primarily of the measurement or verification of the leakage resistance, the linearity of the output, and the end errors.

The results of these verifications determine if calibration or service is required.

6.2.1 Required Test Equipment

Figure 6.1 lists the equipment required for the various tests to follow with typical specifications and possible sources.

6.3 Verification of Leakage Resistance

Refer to Figure 6.2 for the setup for this test.

1. Observe all safety precautions with the use of high voltages.
2. Use teflon insulated wire for the various connections.
3. Connect the equipment as shown in Figure 6.2, using items 2 and 4 from the list of Figure 6.1 along with a 1.1 MW shunt resistor across the meter. The 1.1 MW shunt assumes that the meter has an input resistance of 10 MW which results in an effective resistance of 1 MW. If the meter being used has a different impedance, use an appropriate shunt to provide a net resistance of 1 MW.
4. If the voltmeter, item 4 of Figure 5.1, has a case ground, connect it to the case of the power supply.

	DESIRED SPECIFICATIONS	TYPICAL EQUIPMENT
1.	Isolated dc voltage source with high stabilty,(<50 ppm/hour), low ripple, capable supplying up to 300 V into 100kΩ.	IET Labs, Inc Model VI-700HV
2.	Isolated dc voltage source 0-1100 V	Various
3.	100 kΩ voltage divider or resistive divider with ratio accuracy of 0.1 ppm of input	IET Labs, Inc Model KVD-700
4.	High impedance (>10 MΩ) voltmeter with a 100 μV full scale, capable of resolving 0.1 μV, with good isolation to serve as null detector.	Various
5.	Lead compensator with a resolution of 0.1 mΩ, and a ratio capability of 110:1.	John Fluke Co. Model 721A

Figure 6.1 Required Equipment for Verification

5. Apply 1000 V across the test unit and read the voltage across the meter. 1 mV represents a leakage of 1 TW, i.e. 10^{12} W. If the leakage is greater than indicated by 1 mV, ascertain that the humidity is within operating conditions. If a problem persists, cleaning or service must be undertaken.

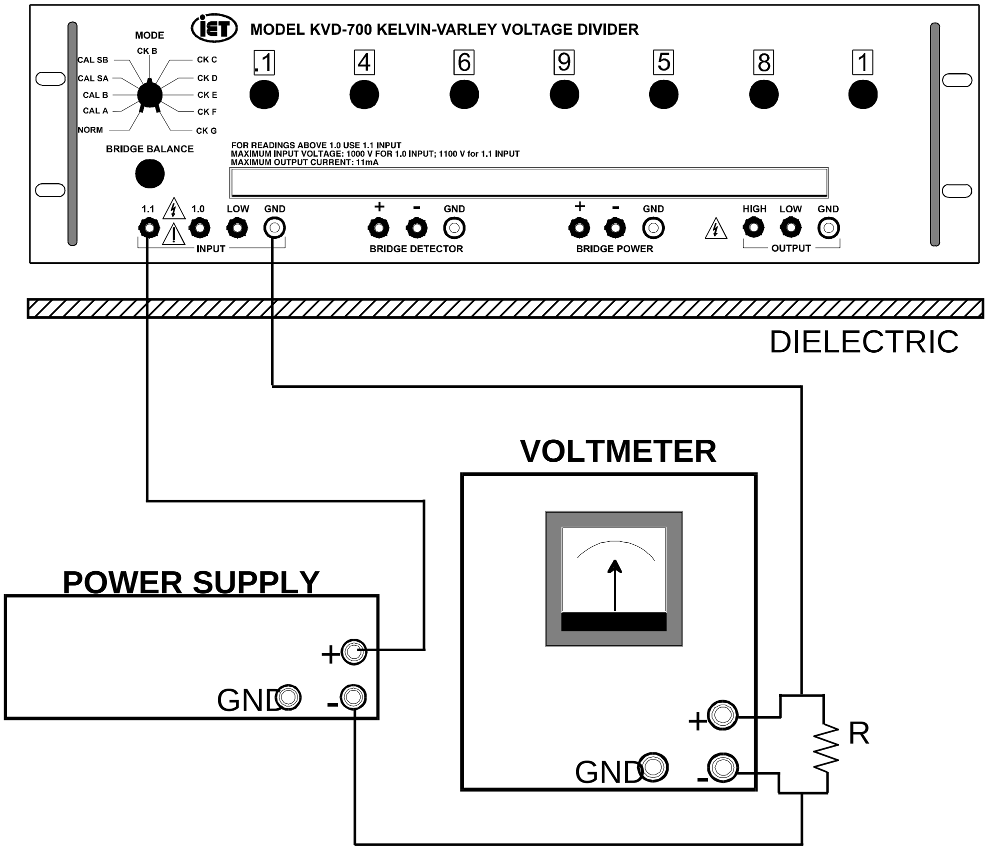
6.4 Verification of Absolute Linearity of First Decade

The verification of the linearity of the KVD-700 may be beyond the capabilities of many laboratories requiring specialized equipment and a controlled environment.

In order to perform such calibration steps, however, a dc source, a null detector, a calibrated resistive divider, and a lead compensator are employed. Figure 6.1 lists these items with their required performance specifications. **Self-calibrate the KVD-700 as described in Chapter 5 before proceeding.**

Absolute linearity is defined as the accuracy, expressed in ppm, relative to the output at the end scale settings of 0 and 1. The divider is defined as correct at these settings. Linearity deviation is the fractional error from ideal perfect linearity.

The test described below is carried out after performing an internal calibration which in itself adjusts the linearity to 0.1 ppm. It is implemented by comparing the divider under test to a standard divider, item 3 of Figure 6.1, as conceptually shown in the bridge balancing scheme of Figure 6.3. The actual physical connections are shown in Figure 6.4.



KVDFIG6.2PM

Figure 6.2. Setup for Leakage Resistance Test

To perform the linearity verification proceed as follows:

1. Perform a self-calibration as described in Chapter 5.
2. Connect the equipment as shown in Figure 6.4
3. Connections should be made as shown with shielded cables. The shields should be grounded at only one end to avoid ground loops. Radial grounding should be used terminating at a single point, such as the voltage source ground.
4. Set The front panel **MODE** switch to **NORM**.
5. Set both the KVD-700 and the calibrated divider to zero.
6. Set the voltage source to 100 V.
7. Turn on all equipment and allow it to warm up until it stabilizes at laboratory temperature.
8. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
9. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
10. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
11. Set both dividers to full scale and adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.

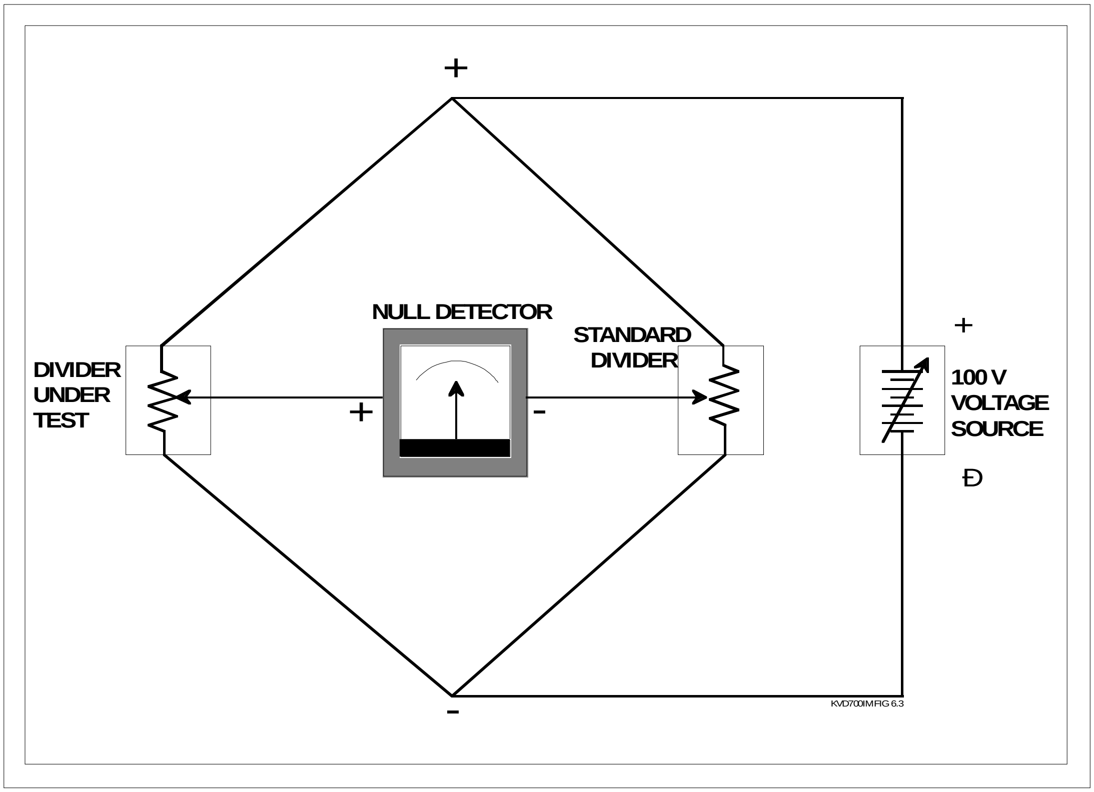


Figure 6.3. Conceptual Representation of Linearity Verification Test

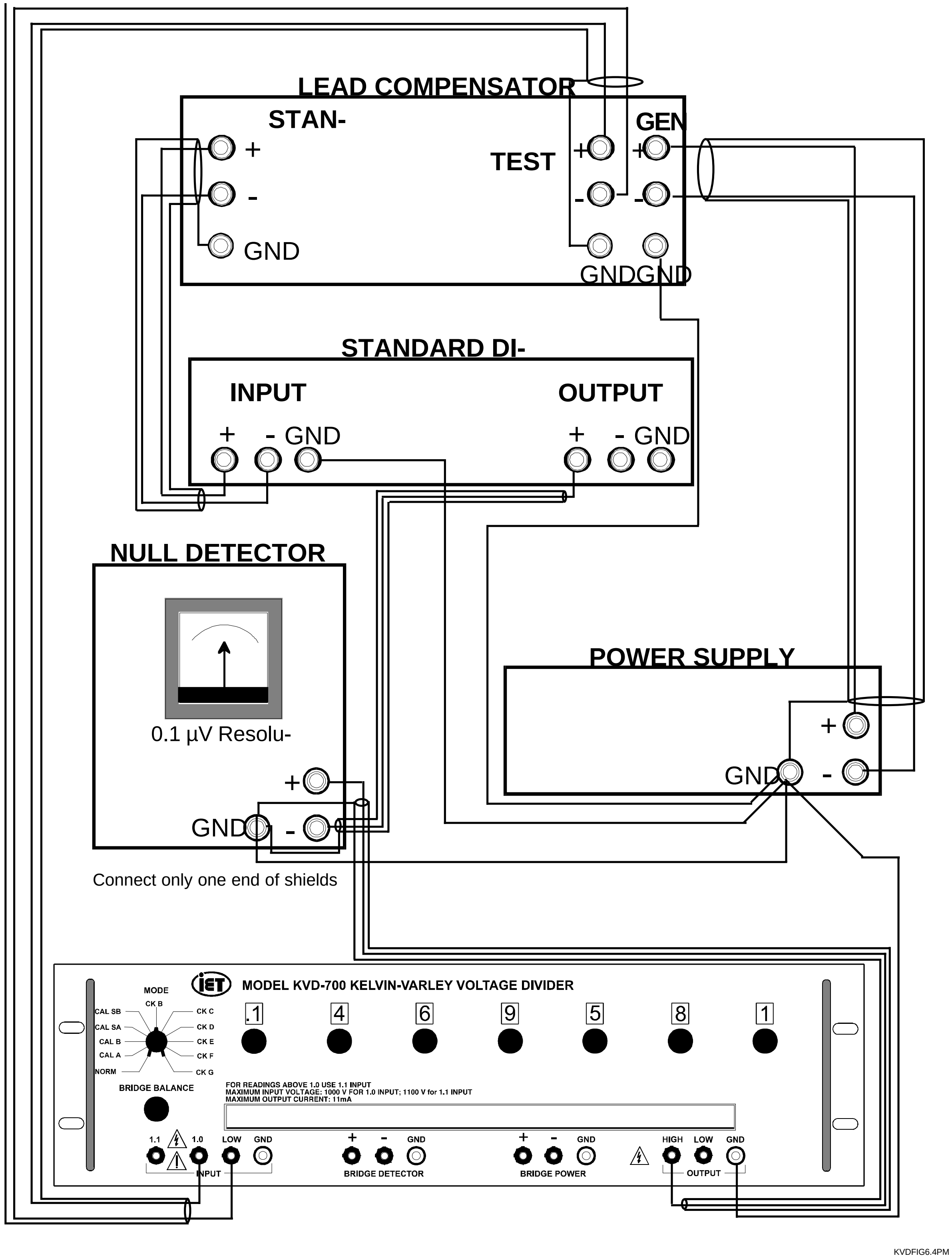


Figure 6.4. Setup for Linearity Verification Test for First Decade

12. Return both dividers to zero and readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set both dividers to the first calibration point, e.g. 0.1 and adjust the standard divider for a near zero indication on the null detector.
15. Confirm or determine the relationship between the null detector reading and a fixed deviation of say 1 ppm or 0.1 ppm by changing the standard divider by such increments and corresponding these changes with the null detector readings. This should produce 100 µV for 1 ppm for the first decade. Some standard dividers may not allow such a test. If actual quantitative results for the deviations are being recorded, ascertain that the null detector reads a positive difference when the KVD-700 ratio is greater than the ratio of the standard divider. In this way, the polarity of the deviation errors will be in the correct sense.
16. The difference between the standard divider and the divider under test (KVD-700), expressed in ppm, plus the reading of the null detector, expressed in ppm, should agree within 0.2 ppm. If desired, record these deviations in a correction table or on correction graphs, although this is not particularly necessary for this very highly linear instrument. Each setting on each dial should be compared in this fashion.
17. In addition all settings of the form n-9-9-9-9-9-10, where n is the setting of the most significant digit and goes from 0 to 1.0.
18. The setting of all zeros must be confirmed.

6.5 Verification of Decade Linearity

In order to proceed to the second and lower decades, connect the equipment as shown in Figure 6.5, where the front panel **MODE** switch allows direct access to the individual decades and places each of them, in turn, as the most significant decade in a bridge circuit as shown in Figure 6.3.

6.5.1 Decade B

1. Set the **MODE** switch to **CK B** for Decade B the second most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-0-0-0-0-0-0.
4. Set the voltage source to 100 V.
5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.
11. Set the KVD-700 back to 1.0-0-0-0-0-0-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-n-0-0-0-0-0 where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.
17. Set the KVD-700 to 1.0-(n-l)-9-9-9-9-10 where n is the same as above.
18. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.5.2 Decade C

1. Set the **MODE** switch to **CK C** for Decade C the third most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-9-0-0-0-0-0.
4. Set the voltage source to 100 V.

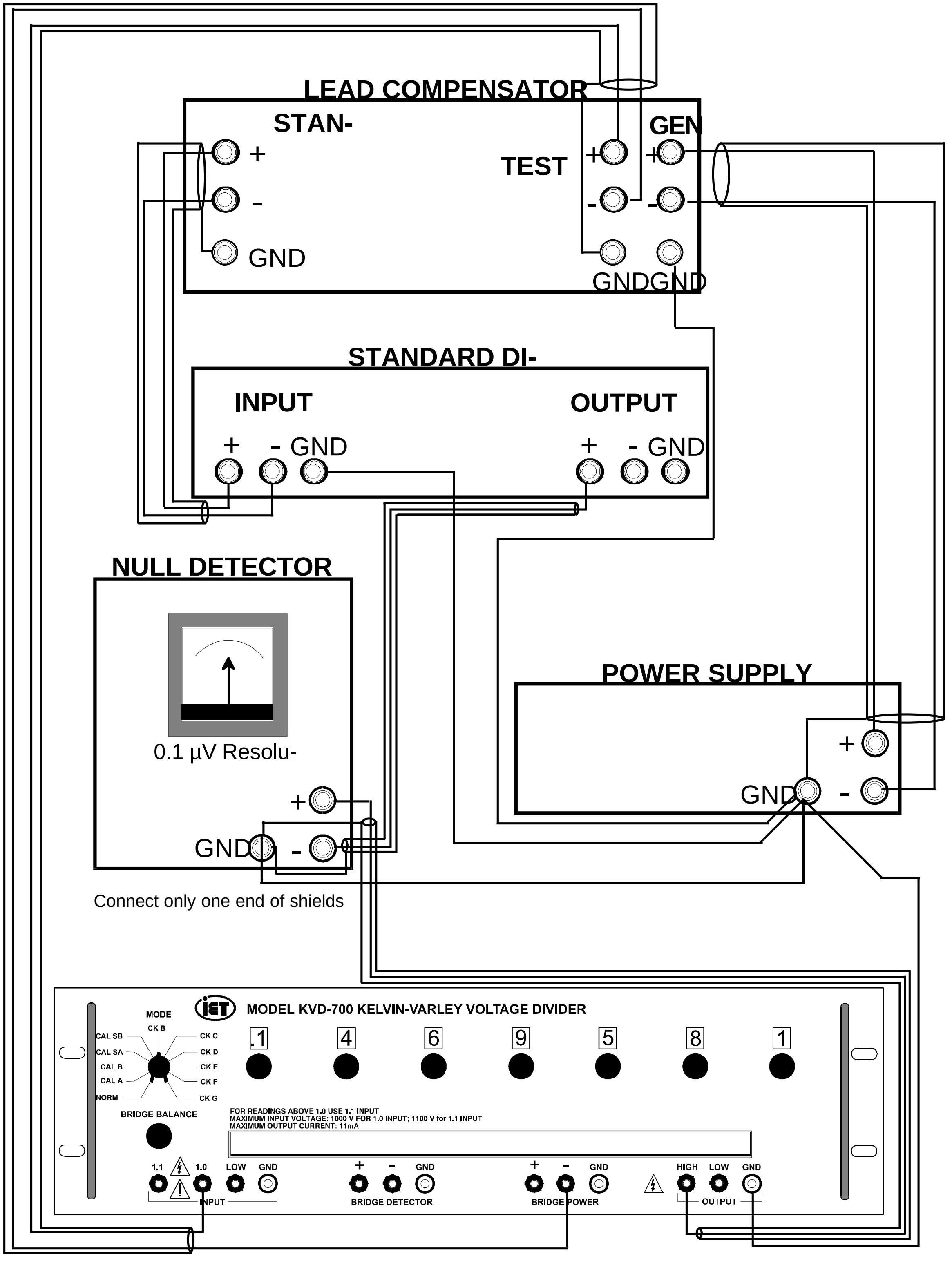


Figure 6.5. Setup for Linearity Verification Test for First Decade

5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.
11. Set the KVD-700 back to 1.0-9-0-0-0-0-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-9-n-0-0-0-0 where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.
17. Set the KVD-700 to 1.0-9-(n-1)-9-9-9-10 where n is the same as above.
18. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.5.3 Decade D

1. Set the MODE switch to **CK D** for Decade D the fourth most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-9-9-0-0-0-0.
4. Set the voltage source to 10 V.
5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.
11. Set the KVD-700 back to 1.0-9-9-0-0-0-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-9-9-n-0-0-0 where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.
17. Set the KVD-700 to 1.0-9-9-(n-l)-9-9-10 where n is the same as above.
18. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.5.4 Decade E

1. Set the **MODE** switch to **CK E** for Decade E the fifth most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-9-9-9-0-0-0.
4. Set the voltage source to 10 V.
5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.

11. Set the KVD-700 back to 1.0-9-9-9-0-0-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-9-9-9-n-0-0 where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.
17. Set the KVD-700 to 1.0-9-9-9-(n-l)-9-10 where n is the same as above.
18. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.5.5 Decade F

1. Set the **MODE** switch to **CK F** for Decade F the sixth most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-9-9-9-9-0-0.
4. Set the voltage source to 10 V.
5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.
11. Set the KVD-700 back to 1.0-9-9-9-9-0-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-9-9-9-9-n-0 where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.
17. Set the KVD-700 to 1.0-9-9-9-9-(n-l)-10 where n is the same as above.
18. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.5.6 Decade G

1. Set the **MODE** switch to CK G for Decade G the fifth most significant decade.
2. Set the standard divider to zero.
3. Set the KVD-700 to 1.0-9-9-9-9-9-0.
4. Set the voltage source to 10 V.
5. Place the null detector in the zero mode, adjust it for a zero deflection or a zero reading and return it to the operating mode.
6. Adjust the **LOW BALANCE** controls of the lead compensator to obtain a zero indication on the null detector.
7. Turn the **HIGH BALANCE COARSE** control to the same setting as the **LOW BALANCE COARSE** control.
8. Set the standard divider to full scale.
9. Set the KVD-700 to 1.0-9-9-9-9-9-10.
10. Adjust the **HIGH BALANCE FINE** control to obtain a zero indication on the null detector.
11. Set the KVD-700 back to 1.0-9-9-9-9-9-0 and set the standard divider to zero.
12. Readjust the **LOW BALANCE FINE** control if necessary to obtain a zero indication on the null detector.
13. If necessary, set the null detector to sufficient sensitivity.
14. Set standard divider to 0.n for n=0 to 9.
15. Set the KVD-700 to 1.0-9-9-9-9-9-n where n is the same as above.
16. Using the null detector determine that the deviation is within the limits of $(10S)^{1/3}$, where S is the setting.

6.6 Verification of End Errors

The absolute linearity deviations determined or verified in the above procedure are with respect to the output terminals, i.e. they assume that the settings of 0 and 1.0 are defined as correct. Linearity relative to the input, i.e. terminal linearity requires the following procedure. Two end corrections are obtained, one relative to the input common terminal and the second relative to the output common terminal. These corrections, as well as the full scale correction, account for the uncompensated portion of the contact and wiring resistances.

1. Connect the equipment as shown in Figure 6.6 and set the voltage source to 1000 V. In the tests to follow the voltages measured represent a relation of 10 µV to .01 ppm. Convert the voltages accordingly. Set the KVD-700 to zero and measure the voltage between the **OUTPUT HIGH** and the **INPUT LOW**. This is the zero or low end correction relative to input common. Confirm that it is <±0.05 ppm of input.
2. Change the setup to the configuration of Figure 6.7. Note the change in the polarity of the voltage source. With the KVD-700 still set to zero, now measure the voltage of the **OUTPUT HIGH** relative to **OUTPUT LOW**. This is the zero or low end correction relative to output common. Confirm that it is <±0.004 ppm of input.
3. Modify the setup as shown in Figure 6.8. Set all dials to full scale and measure the voltage between the **OUTPUT HIGH** and the **INPUT HIGH**. This is the fun scale correction. Confirm that it is <±0.05 ppm of input.
4. Repeat the above steps for the **1.1 INPUT**.

6.7 Calibration

If the above tests indicate any linearity not within allowable limits, then a calibration procedure must be undertaken. The KVD-700 has trimmers for the first three decades and shunts which allows for significant adjustment and should be sufficient to bring the unit within a linearity of ±0.1 ppm.

The calibration goes in the order of fine to coarse, beginning with the calibration of the third or C decade and proceeding to the most significant two decades A and B. The calibration of these two is the same as the self-calibration.

6.7.1 Calibration of C Decade

1. Remove the top and bottom covers of the KVD-700 and locate the **INTERNAL MODE** switch and the various trimmer potentiometers on the bottom side of the calibration board as shown in Figure 6.9.
2. Locate trimmers **TlC** through **T12C**. These are sealed potentiometers with good mechanical stability.
3. Set the second, third, and fourth decade switches to the blank position.
4. Set the first step to 4007.63 W.
5. Adjust **T12C** trimmer as needed.
6. Connect the system as shown in Figure 5.1, the setup for self-calibration. Do not apply any voltage.
7. Turn all decade switches at least twice around all positions to remove any possible buildup of contamination at the contacts.
8. Set the divider to .0000000.
9. Set the front panel **MODE** switch to **NORM**.
10. Set the internal **MODE** switch to **CAL C**
11. Turn the second decade B switch to the blank position.
12. Apply 10 V from the power supply to the **BRIDGE POWER** binding posts.
13. Adjust the front panel **BRIDGE BALANCE** control to obtain a null within ±10 µV.
14. Confirm that the **T2C** trimmer is not at an extreme position and has some adjustment range in both directions.
15. Readjust the front panel **BRIDGE BALANCE** control to obtain a null within ±10 µV.
16. Set the C decade switch to position 1.
17. Adjust the associated trimmer **T3C** to obtain a nun reading within ±10 µV.
18. Confirm the repeatability of the C decade switch contact resistance by rotating the switch and returning to the setting under test

and confirming that the null remains within ±10 µV. If it does not the switch must be rotated, cleaned, or replaced.

19. Repeat the above three steps with C decade switch position 2 through **CAL**, adjusting respectively trimmers **T4C** through **T12C**, as shown in Figure 6.9.
20. Return C decade switch to 0.
21. Set the **INTERNAL MODE** switch to the **CAL SC** position.
22. Adjust the associated trimmer **T1C** to obtain a null reading within ±10 µV.
23. Confirm the repeatability of the C decade switch contact resistance by rotating the switch and returning it to 0, confirming that the null remains within ±10 µV. If it does not the switch must be rotated, cleaned, or replaced.
24. Restore the **INTERNAL MODE SWITCH** to the **NORM** position.
25. Perform a self-calibration as described in Chapter 5.

6.8 Bridge Calibration

This Bridge Calibration procedure needs to be performed only if it is not possible to get a null reading with the **BRIDGE BALANCE** control while performing a calibration.

This procedure is therefore performed to allow the front panel **BRIDGE BALANCE** control to have sufficient range to implement the calibration of the first three decades, A, B, and C. If a balance zero cannot be obtained for C, perform the Bridge C Arm Calibration below. If a balance cannot be obtained for A or B, perform the Bridge A-B Arm Calibration below. If a problem is not encountered, this calibration is not required.

6.8.1 Bridge C Arm Calibration

1. Remove the top and bottom covers of the KVD-700 and locate the **INTERNAL MODE** switch and the various trimmer potentiometers on the bottom side of the Wheatstone bridge circuit board as shown in Figure 6.10.
2. Locate trimmers **R203** and **R205**. These are sealed potentiometers with good mechanical stability
3. Set the front panel **MODE** switch to **NORM**.
4. Set the **INTERNAL MODE** switch to **CAL C.**
5. Set the divider to .0000000.
6. Set the B, C, and D decade switches to the blank positions.
7. Set the resistance of the C decade to 4007.63 W by adjusting the **T12C** trimmer located on the calibration board shown in Figure 6.10.
8. Connect the system as shown in Figure 5.l.
9. Set the B decade switch to the blank position.
10. Apply 10 V from the power supply.
11. Observe the range of null as the **BRIDGE BALANCE** is varied from end to end, and set it to the midpoint of its electrical travel.
12. Set **R205** on the calibration board of Figure 6.9, to obtain a reading of 0 ±20 µV.
13. Set **T2** for a null reading of 0 ±50 µV.
14. Observe the range of null as the **BRIDGE BALANCE** is varied end to end; it should be approximately ±100 µV.
15. Set the voltage to 0 ±2 µV.

6.8.2 Bridge A-B Arm Calibration

1. Set the front panel **MODE** switch to **CAL A**.
2. Set the **INTERNAL MODE** switch to **NORM**.
3. Set the divider to .0000000.
4. Connect the system as shown in Figure 5.l.
5. Apply 20 V from the power supply.
6. Adjust the **BRIDGE BALANCE** midway in its travel.
7. Set **R203** on the Calibration Board, as shown in Figure 6.10 to produce a reading of 0 ±20 µV.
8. Observe the range of null as the **BRIDGE BALANCE** is varied end to end, and observe the voltage change from approximately -150 µV to +150 µV.
9. Disconnect external equipment.
10. Return the **MODE SWITCH** to **NORM**.

6.9 Parts Diagrams

The location of the various parts and assemblies of the KVD-700 are shown Figures 6.11 through 6.15 with various views of the instrument and its subassemblies for ease of physical location.

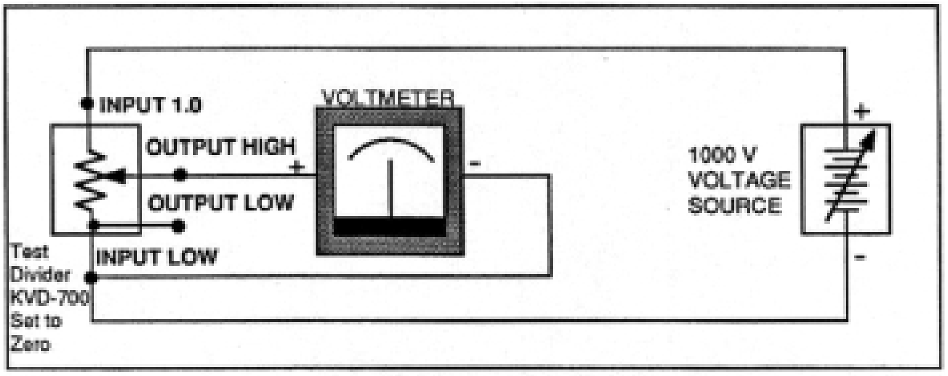


Figure 6.6. Setup Diagram for Measurement of Zero End Correction Relative to Input Common

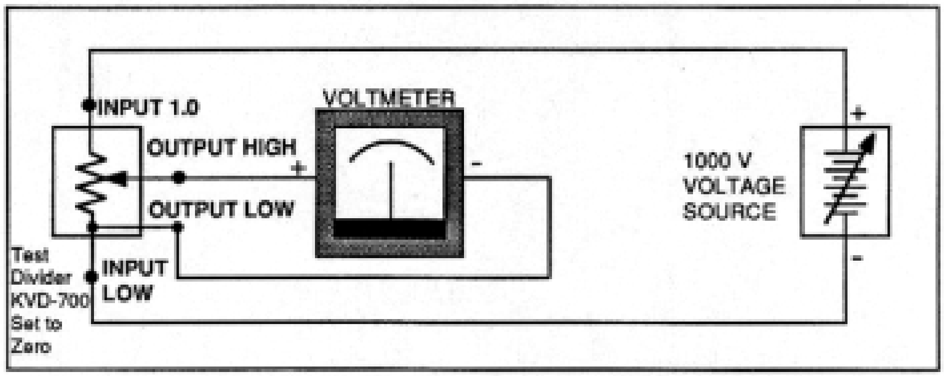


Figure 6.7. Setup Diagram for Measurement of Zero End Correction Relative to Output Common

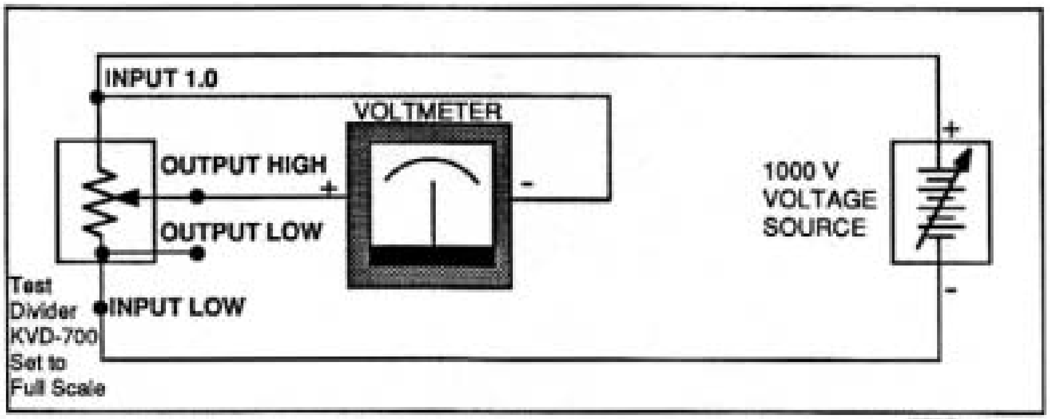


Figure 6.8. Setup Diagram for Measurement of Full Scale Correction

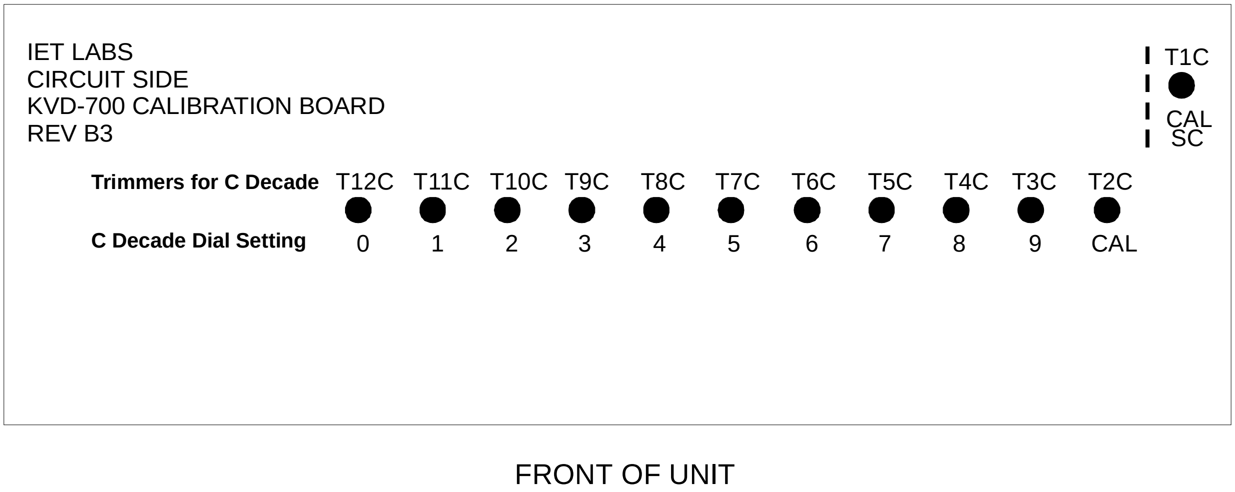


Figure 6.9. Bottom View of Calibration Board and Location of C Decade Trimmers

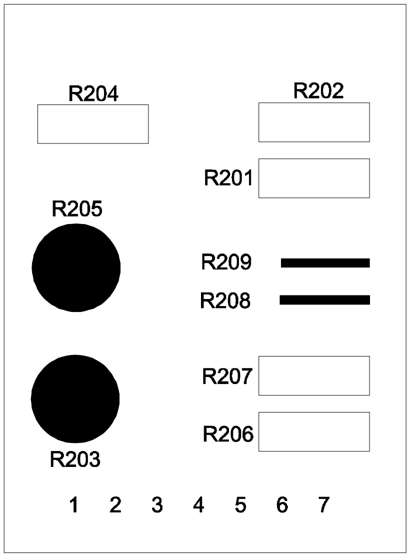


Figure 6.10. Layout of Internal Bridge Calibration Board and Location of Trimmers

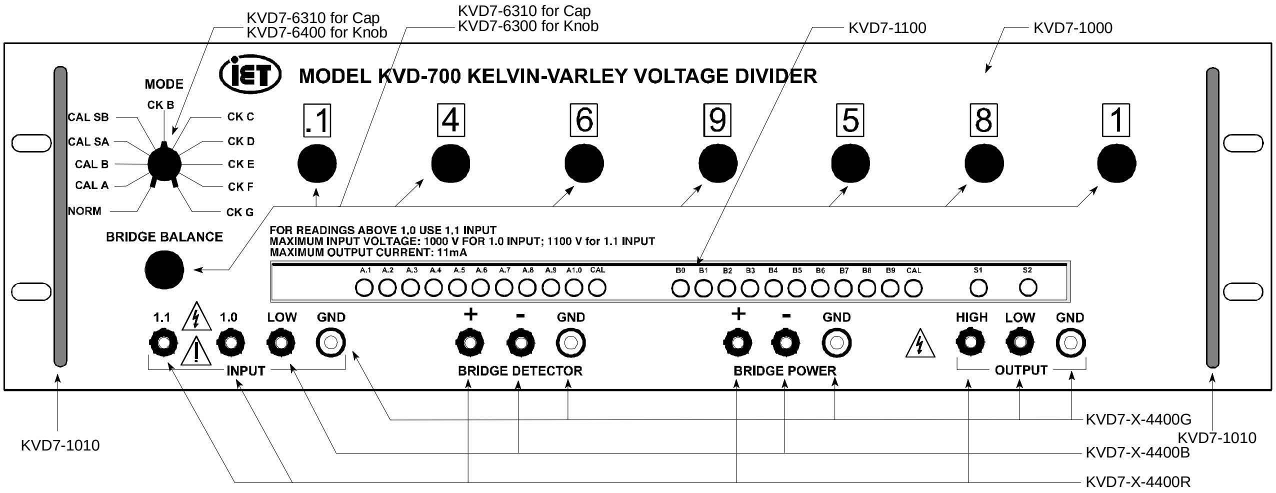


Figure 6.11. Replacement Parts Location: Front Panel

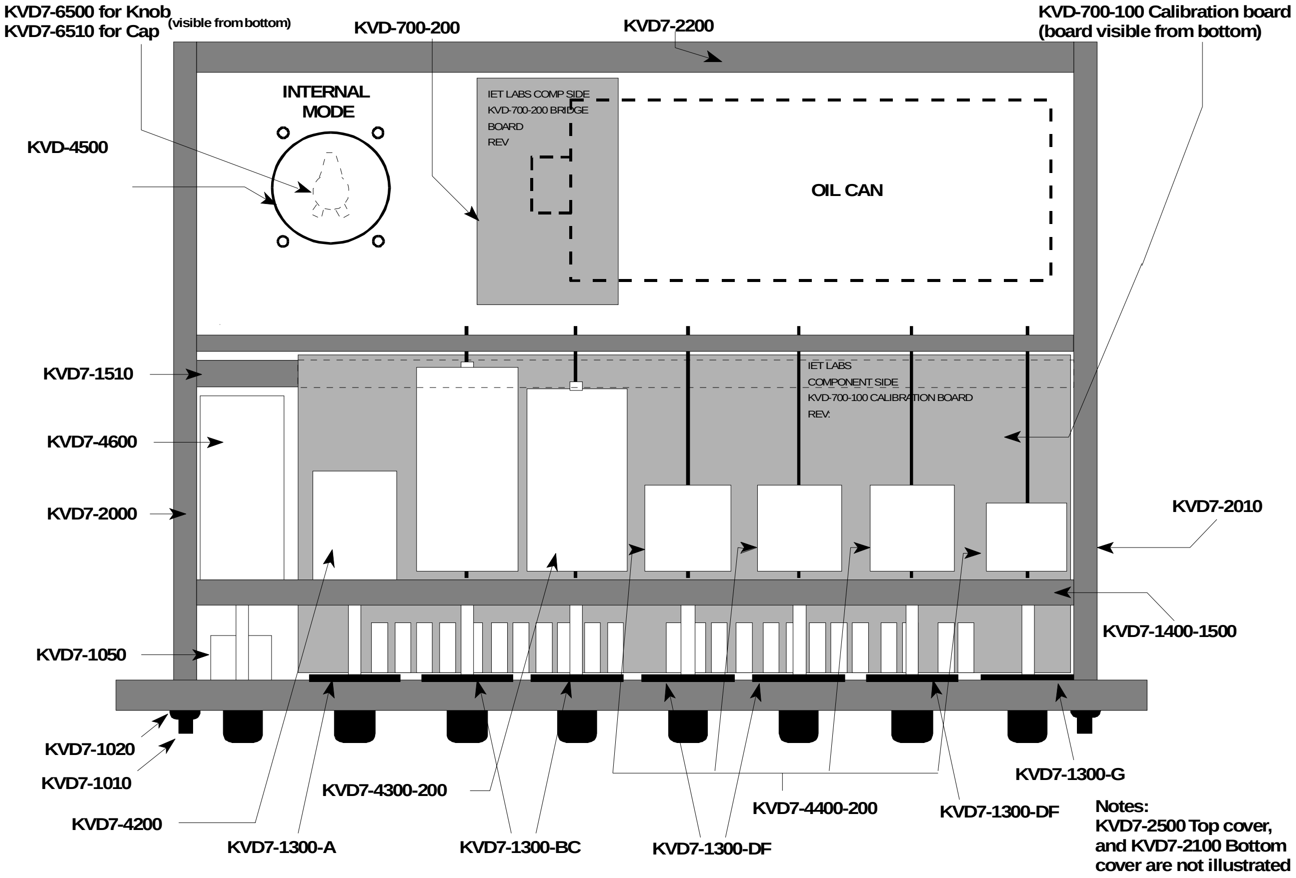


Figure 6.12. Replacement Parts Location: Top View of Unit

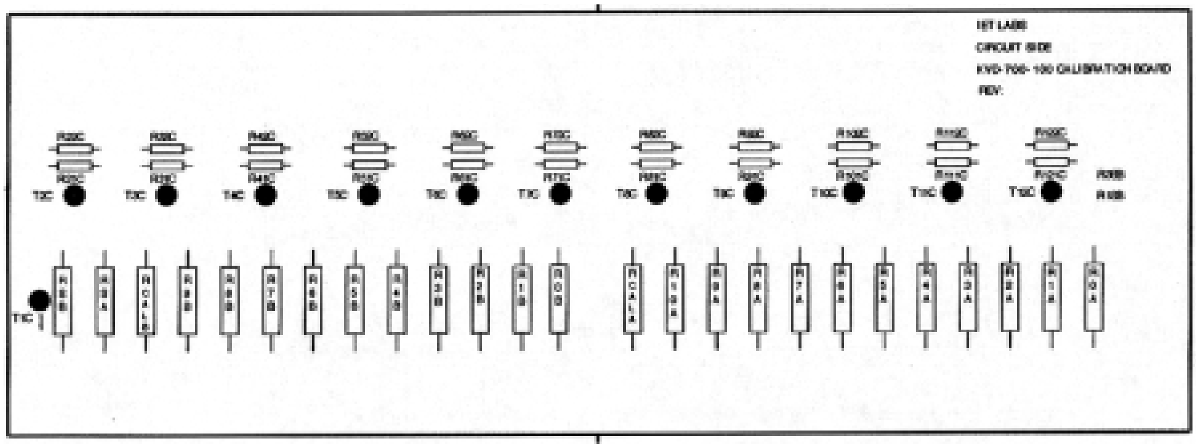


Figure 6.13. Replacement Parts List: Bottom View of Calibration PC Board

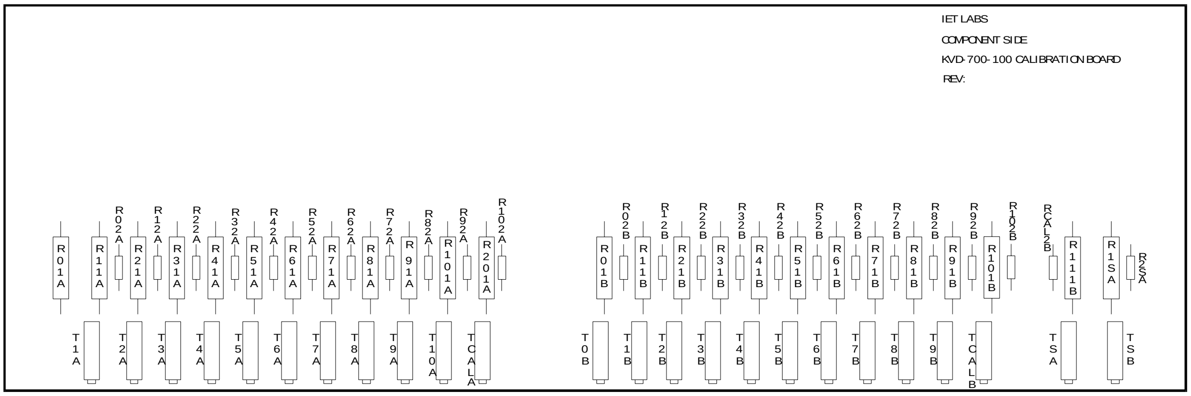


Figure 6.14. Replacement Parts List: Top View of Calibration PC Board

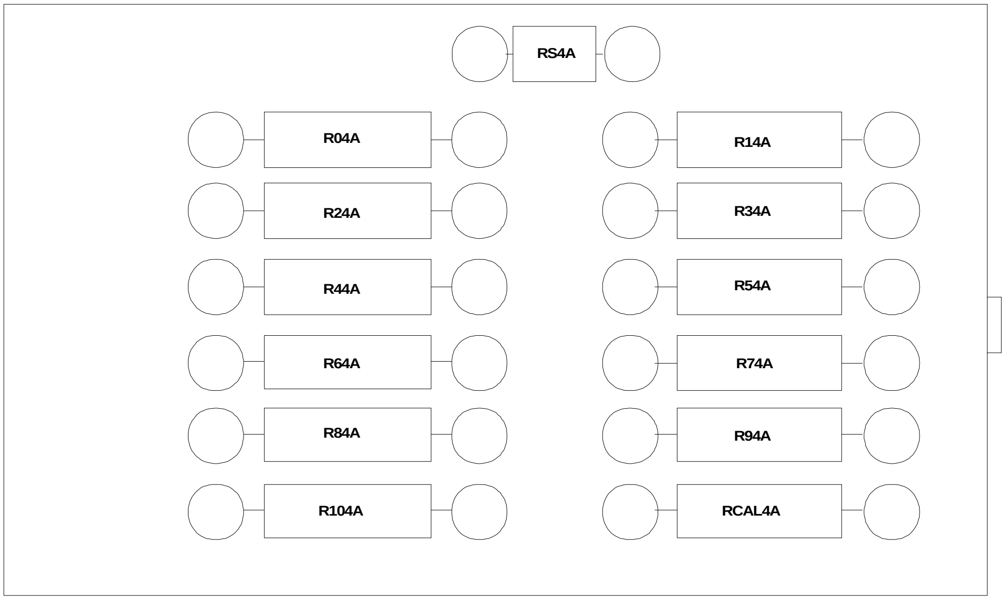


Figure 6.15 Replacement Parts Location: Top View of Oil Can

Appendix A

BIBLIOGRAPHY

The following articles may be useful in understanding the use and calibration of a Kelvin-Varley voltage divider.

1. Andrew F. Dunn, Calibration of a Kelvin-Varley Voltage Divider," National Research Council Report No. 7863.
2. M. L. Morgan and J. C. Riley, "Calibration of Kevin-Varley Voltage Divider," IRE Trans. on Instrumentation, vol 1-9, pp 237-243; Sept. 1960.