INSTRUCTIONS FOR USE OF

PRIMARY STANDARD

VOLTAGE DIVIDER

VDR-106/7 and VDR-307

This instruction manual applies to the other Julie Kelvin-Varley Dividers except for impedance level, specific ratios or other special modifications (such as VDR-307 H, VDR-327 J, VDR-327 P).

For these special dividers, the individual specification sheet will be an addendum to this instruction manual.

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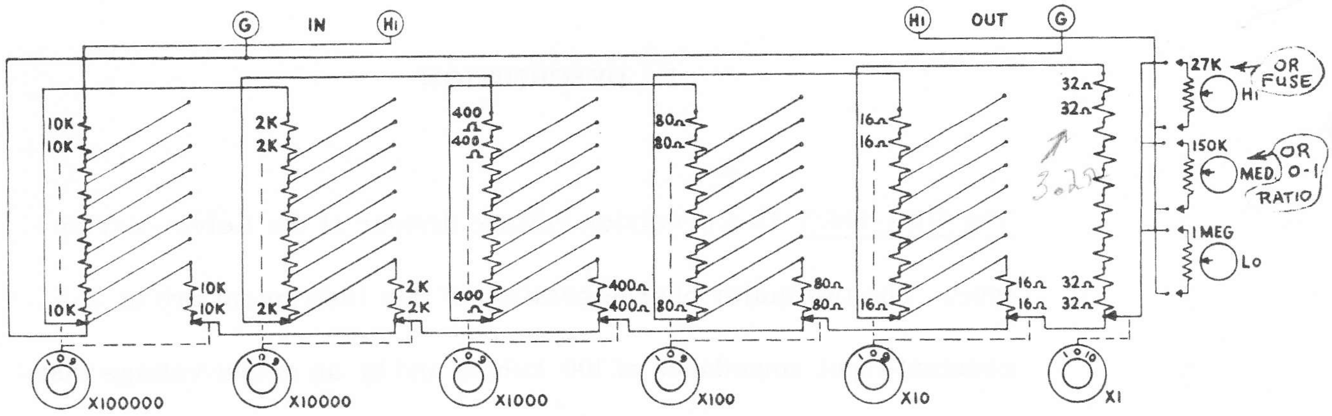
I. DESCRIPTION

The VDR-106/7 is a precision voltage divider of the Kelvin-Varley type. The two major characteristics of this instrument are a) a constant input impedance of 100 kohms and b) an output voltage that is a decimal part of the input voltage as indicated by the settings of the seven decade dials of the divider. A ratio of output to input voltage of unity is indicated by dial settings of 9-9-9-9-9-9-10.

The output indication has maximum accuracy under circuit conditions which allow no current to pass through the output terminal of the circuit. Leakage is held to such a small value that it does not appreciably affect the accuracy of the device.

Two buttons are provided for the protection of the divider and the equipment under test (such as standard cells). The "lo sensitivity" key inserts a 1 meg resistor in the output circuit and the "high sensitivity" key inserts a 1/100th amp instrument fuse in the output circuit (its resistance being about 100 ohms which has negligible effect on the circuit).

A RATIO switch, when set in "DIAL" position connects the output terminal to the switching circuit of the divider. When set to "1", the output terminal is connected to the input high terminal. When set to "O", the output terminal is connected to the input low terminal. The use of the "O" and "1" positions in standardization procedures will be discussed subsequently.



The VDR-106 is an older version of this divider with six decade dials and no Ratio switch. In place of the Ratio switch is a "medium sensitivity" key which inserts a 150 kohm resistor in the output circuit. Some of these dividers have a 27K resistor in place of the 1/100th amp instrument fuse. All older models can be modified to conform to the specs for the VDR-106/7.

The VDR-307 is not supplied with the Ratio Switch and has the "High", "Medium", and "Low" Sensitivity keys as described.

The fact that the circuit employed in this instrument contains neither potentiometers not verniers, that all decades are switched over the entire ten million to one range, and the fact that the precision matched, accuracy assuring decade resistors of the divider are oil-immersed and hermetically sealed essentially ensures the permenance of accuracy of this instrument.

Both styles divider are supplied for standard 19 inch rack mount. The VDR-106/7 requires 14" of rack height and is 6" deep, the VDR-307 requires 3 1/2" of rack height and is 6" deep.

II. SPECIFICATIONS

Range:	Every integral ratio from 0.0000000 to 1.0000000
Resolution:	Seven decades or ten million equal, discrete steps of 0.0000001 each yield a 1/10th part per million resolution.
Accuracy:	Ratio indicated is accurate to 0.0001% of full scale (1 PPM) absolute at 25°C with negligible power.
Stability:	0.0001% per year.
Maximum Excitation:	VDR-106/7 - 1,100 volts VDR-307 - 700 volts
Overall Resistance:	100,000 ohms $\pm$ 0.01%
Temperature Range:	For rated accuracy 20°C to 30°C on VDR-106/7: T. C. 0.00005% °C on VDR-307

III. CONNECTIONS

These dividers are provided with heavy copper terminals that are either silver or gold plated. If measurements are affected by thermal EMF's generated at these connection terminals, they will be minimized by using similar connecting leads. The "Input Low" and "Output Low" terminals are internally connected permanently.

Heavy connecting leads should be used whenever lead resistance may become a factor in a measurement, if lead compensation is required, the JULIE LEC-307 lead compensator is available. Care should be exercised to assure proper insulation of all connecting leads so that unanticipated leakage and inaccuracy is eliminated. The null detector used in precision measurement circuits must be adequately insulated to withstand such voltages as may be introduced between the circuit and the case and keep leakages below such values as would introduce errors to the measurements. Under some conditions it is adviseable to use a battery operated null detector that is effectively isolated from ground by mounting it on a styrofoam pad. The use of guarding circuits on the null detector is also of help in some instances.

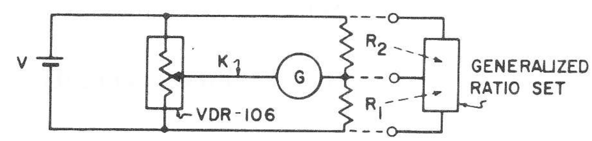
IV. APPLICATIONS

A) RESISTANCE MEASUREMENT

1. Ratio or Relative Resistance

Refer to figure 1. V is a suitably stable voltage source and G is a galvanometer of adequate sensitivity. R_1 and R_2 are the equivalent elements of a ratio set such as a potentiometer, a voltage-divider or any other conductive voltage-dividing network. For relative resistance measurements, R_1 is the unknown and R_2 is the resistor relative to which its value is to be determined. K is the dial setting.

Fig. 1



The ratio $\rho \left(= \frac{R_1}{R_1 + R_2} \right)$ is given, at null, by the expression

$$\rho = K \pm .000001$$

The relative resistance of R_1 with respect to R_2 is given by

$$R_1 = R_2 \left(\frac{K \pm 0.000001}{1\text{-}K \mp 0.000001} \right)$$

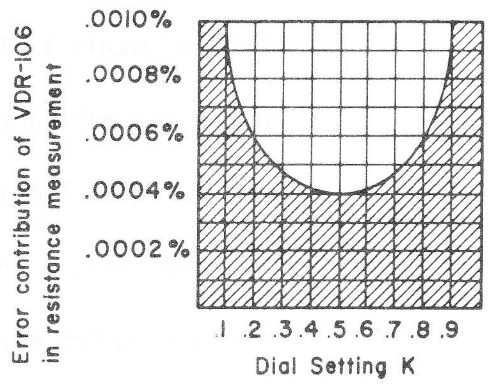
2. Absolute Resistance may be measured by replacing R_2 by a resistance standard of known absolute value. The percentage error in the measured value of R_1 at null is:

$$\pm \frac{0.0001}{K\,(1-K)} \%$$

This expression has a minimum value at K = 0.5, hence, for highest accuracy it is desireable that R_2 be of the same order or magnitude as R_1, so that K may be some value near 0.5 at null.

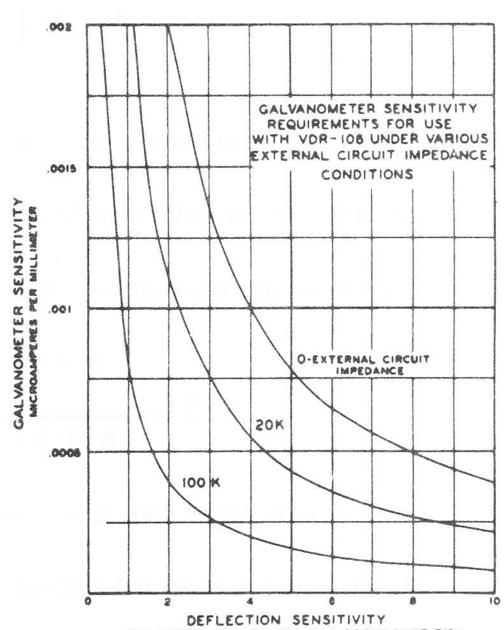
The following plot (Fig. 2) of percentage error in R_1 as a function of the value of K at which null is achieved will be useful.

Fig. 2



3. Sensitivity:

Galvanometer sensitivity requirements are dictated by the accuracy and the impedance levels involved:



The curve of Fig. 3 indicates the required galvanometer current sensitivity for desired scale sensitivity per 100 volts of bridge excitation, for a range of external circuit impedance of the device under test. This is the maximum impedance presented by the device under test in series with the galvanometer and voltage source, not including the impedance of the VDR-106. The curve is plotted for the 50% ratio-setting of the VDR-106 at which point it exhibits maximum internal impedance. The voltage source is assumed to have negligible impedance, and the "high" sensitivity button on the VDR-106 is assumed to be depressed.

4. Leakage:

Measurements to lppm accuracy require extreme care to prevent leakage errors. Leads should be short and teflon-insulated or air-supported. The battery or other voltage source should be isolated from the galvanometer through a minimum leakage resistance of 100,000 megohms. The bridge circuit is normally grounded at one of the galvanometer leads.

B) VOLTAGE MEASUREMENT

1. Absolute DC Voltage Measurements - Method I (for voltages, higher than that of a standard cell):

Refer to Fig. 4. V is the unknown voltage (for example, the potential drop across a zener diode), E is the known EMF of a standard cell or other reference voltage, and G is a galvanometer of adequate sensitivity (see discussion above).

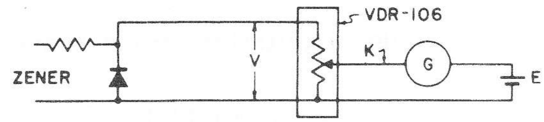


Fig. 4

At null:

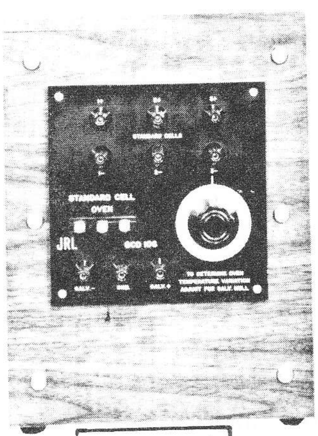
$$V = \left(\frac{E}{K \pm .000001} \right)$$

Where K is the dial setting. The uncertainty to which E is known must be allowed for, also. It is interesting to note that, with a primary standard cell set, such as the SCO-106 illustrated below, and a value of V near 6 volts, the absolute accuracy of measurement is about 0.0003%.

2. Absolute DC Voltage Measurement - Method II (for voltages lower than that of a standard cell):

Refer to Fig. 5. V is the unknown (small) voltage. E is the EMF of the standard cell. G is a galvanometer of adequate sensitivity (see discussion above) B is a suitably stable external power supply, R is a suitable rheostat, and S is a SPDT switch.

SCO-106



0.0001%

PRIMARY-STANDARD ABSOLUTE VOLTAGE REFERENCE
Three primary cells in a ±0.01°C oven. Bureau of Standards Certified to 1ppm.

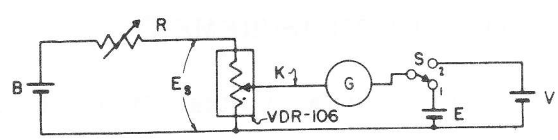


Fig. 5

The measurement process requires two steps:

1. With S in position 1, K is set to the ratio between the standard cell EMF and some convenient voltage value, E_s such as 10 volts (B must be greater than 10 volts) and "R" is adjusted so as to null G. Note: By selecting values of E_s such as 10 volts, 100 volts, etc. K will be direct-reading in the cell EMF, except for the decimal point.

2. With S in position 2, K is readjusted to null G. Assuming negligible drift in E_s during the readjustment of K, the value of V is given by:

$$V = E \frac{K_2}{K_1} \pm 0.000002 \, (E_s).$$

where K_1 is the ratio setting employed in step 1, and K_2 is the ratio setting arrived at in step 2. The uncertainty to which E is known must be allowed for, also. If the SCO-106 is used for E (see below) and E_s is set to 10 volts, the total uncertainty in the determination of a one volt "V" is 21 microvolts.

C) CURRENT MEASUREMENT

Current measurement are made by using a known resistance (shunt) in series with the current circuit being measured and reading the voltage drop developed. The current determined is calculated by Ohm's Law and the accuracy of the calculation is determined by the arithmetic sum of the error contributions of each component in the circuit.

D) OPERATION AS A VOLTAGE DIVIDER ONLY

In the Kelvin-Varley circuit there are a number of shunt paths. As a result, the unit may be used as a potential divider only. The resistance between the "Output High" terminal and either end of the divider is not a linear function of the divider setting and the unit must not be used as a rheostat or variable resistance device.

E) MEASUREMENTS AT ZERO ARM CURRENT

The divider calibration is done under zero arm current conditions only. A current in the output circuit of 2×10^{-6} x divider current will, at worst condition, introduce approximately 1 ppm error.

V. CALIBRATION

The JULIE DIVIDER carries a 5 year warrantee on its linearity. It will remain within 1 PPM of absolute linearity without correction. The stability and accuracy of this device is such that ratio calibration can be meaningfully checked and correction factors be developed to use it for .1 PPM measurements. Procedure for this calibration is detailed in the JRL "Precision" Journal Vol IV. No. 1 which is included in this manual. Enclosed also, is a letter from NBS in which they state their approval of this method.

VI. MAINTENANCE

The only field maintenance required on the voltage divider is replacement of the instrument fuse in the high sensitivity key. If the divider operates on low or medium sensitivity but not on high, a blown fuse is indicated. This replacement must be a 1/100th amp LITTLEFUSE type: MICRO 1/100A P/T 278.010. In replacing the fuse in the divider, extreme care must be used to prevent short circuits from occurring due to bending of air insulated busbars or resistor leads. If ratio of the divider is far off from its proper value, a visual inspection of these leads may reveal such short circuits. Gentle bending of the busbar to eliminate this type of problem is permissable. MORE EXTENSIVE REPAIRS MUST BE MADE AT THE FACTORY.

J·R·L PRECISION

. . . an aperiodic journal devoted to the difficult art of one part per million

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VOLUME IV NO. 1 JUNE 1961

ESTABLISHING RATIOS TO ONE PART IN TEN MILLION

HISTORY OF ULTRA-PRECISE RATIO MEASUREMENTS: 1956 to 1961

Julie Research Laboratories has been using the uniquely precise and stable NB-1* resistor design in DMR Primary Standard Resistance Sets since 1955 and in VDR Primary Standard Dividers since 1956.

This company has followed a policy of conservative rating of these standards and instruments and has gone so far as to develop new techniques for verification of the unusually high accuracies specified for its equipment.

The information in this edition of *Precision* is presented in the hope that it will facilitate the measurement and verification of ratios by standards laboratories.

*Patent applied for

INTRODUCTION

In previous issues we have discussed the 0.0001% VDR-106 Primary Standard Voltage Divider and the DMR Series of Decade Resistance Sets independently. In this issue we will expand the previous discussions by explaining how the DMR Series Resistance Sets can be used to check ratio accuracies with uncertainties of one part in ten million (0.00001%), and, concurrently, how the DMR Series may be used to verify the 0.0001% accuracy of the VDR-106.

RESISTOR ERROR

In Volume II, No. 2 of *Precision*, we explained the self-checking feature of the DMR Series which allows determinations of relative accuracies of individual resistors to within

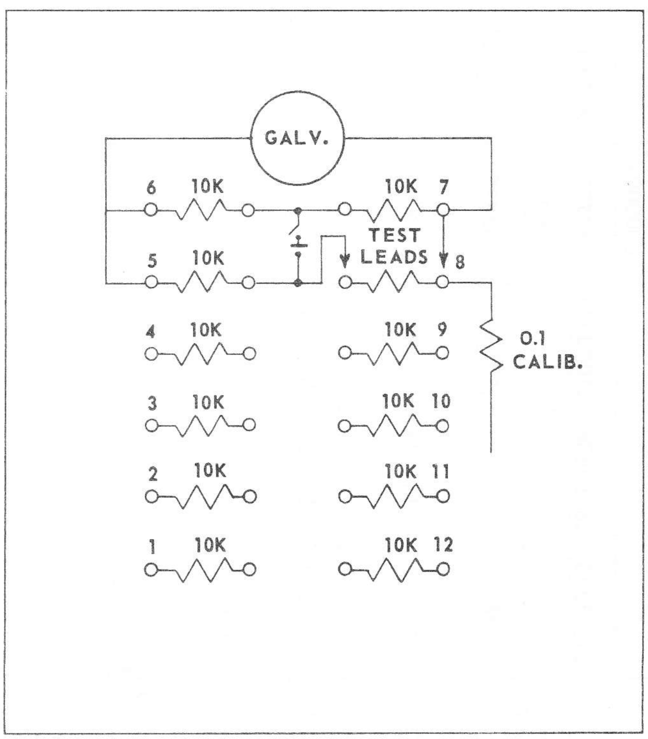

FIGURE 1

RESISTOR NUMBER	COLUMN A RESISTANCE DEVIATION IN PPM	COLUMN B CUMULATIVE DEVIATION IN PPM	COLUMN C RATIO ERROR IN PPM
1	−1	−1	−0.1
2	−1	−2	−0.2
3	0	−2	−0.2
4	+1	−1	−0.2
5	0	−1	−0.2
6	+1	0	−0.1
7	−1	−1	−0.2
8	+2	+1	+0.0
9	0	+1	0
10	+1	+2	−
11	+2	+4	−
12	+1	+5	−

FIGURE 2

DMR CALIBRATION CHART

Theoretical Ratio to 1 part per 10,000,000

	N = 12	N = 11	N = 10	N = 9	N = 8	N = 7	N = 6	N = 5	N = 4	N = 3	N = 2	N = 1
K = 1				-.0000001								
	.0833333	.0909091	.1000000	.1111111	.1250000	.1428571	.1666667	.2000000	.2500000	.3333333	.5000000	1.0000000
K = 2				-.0000002								
	.1666667	.1818182	.2000000	.2222222	.2500000	.2857143	.3333333	.4000000	.5000000	.6666667	1.0000000	
K = 3				-.0000002								
	.2500000	.2727273	.3000000	.3333333	.3750000	.4285714	.5000000	.6000000	.7500000	1.0000000		
K = 4				-.0000002								
	.3333333	.3636364	.4000000	.4444444	.5000000	.5714286	.6666667	.8000000	1.0000000			
K = 5				-.0000002								
	.4166667	.4545455	.5000000	.5555555	.6250000	.7142857	.8333333	1.0000000				
K = 6				-.0000001								
	.5000000	.5454545	.6000000	.6666667	.7500000	.8571429	1.0000000					
K = 7				-.0000002								
	.5833333	.6363636	.7000000	.7777778	.8750000	1.0000000						
K = 8				+0								
	.6666667	.7272727	.8000000	.8888889	1.0000000							
K = 9				+0								
	.7500000	.8181818	.9000000	1.0000000								
K = 10	.8333333	.9090909	1.0000000									
K = 11	.9166667	1.0000000										
K = 12	1.0000000											

FIGURE 3

one part per million by using two of the twelve resistors in the DMR as ratio arms and one of the remaining ten as a comparison standard.† We will use such data to establish the ratio accuracy of a DMR-105 Resistance Set.

Similar resistance deviation data may be obtained with the use of any *stable* bridge with limited accuracy, but with *resolution* capable of measuring resistance deviation to within 0.0001%. In such a case the deviations of the individual resistors are obtained, starting from a suitable initial bridge balance. It is important that all bridge settings except for the last place decade must remain fixed when intercomparing individual resistors in order to insure that the deviations observed are significant. In addition all resistors should be measured twice in order to insure that the deviation readings are significant to within one part per million.

Typical results obtained by either of the above methods are shown in Column A of Figure 2. The deviations are in 0.01 ohm units (ppm) for each 10,000 ohm resistor of the DMR-105 Set.

†Note that in Figure 1, we are using a DMR-105 Set, comprising twelve 10,000 ohm primary standard resistors. In this resistance range the combined residual ratio error introduced by interconnection wiring and insulation leakage will be less than one part in 10,000,000 (for a series string of ten resistors) if resistance uncertainty is less than 0.01 ohms and leakage uncertainty is greater than 125,000 megohms. Copper links are available for all DMR Sets which permit series connections with uncertainties of less than 0.001 ohms. External wiring for all tests should have insulation of the quality used in Julie Research Laboratories Resistance Sets and Primary Standard Divider VDR-106; i.e., ceramic, Teflon®, polystyrene or glass.

THEORETICAL RATIO

The DMR-105 Set permits series interconnections of its twelve Primary Standard Resistors to obtain 66 ratios. These ratios are defined by the fraction $r = k/n$ where n is the total number of input resistors in the string and k is the number (less than n) across which the output voltage is developed. Additional ratios may be obtained by parallel as well as series connection of resistors, but for the purpose of this paper we will confine ourselves to the simple series connections. The 66 ratios are shown in Figure 3. It will be noted that approximately half of these ratios are distinct and give unusually good coverage of the ratio interval from 0.0833333 to 1.0000000. The remaining points are redundant and afford an opportunity for multiple checking of the same ratio point.

RATIO ERROR – DMR-105

The closely matched resistors of a DMR-105 Set usually permit establishment of the ratios of Figure 2 to accuracies of 0.0001 to 0.0002% *without* need for correction or calibration. However, we wish to show here how the resistance deviation data obtained in the earlier section may be used to obtain ratio corrections to an accuracy of the order of 0.00001% (one part in ten million).

By using the data of column A, Figure 2, ratio error in parts per million may now be calculated as follows:

Accumulated sum of Resistance Deviation,

$$\hat{b}_k = a_1 + a_2 + \ldots + a_k \quad \text{[Data shown as column B]}$$

$$= b_{k-1} + a_k \qquad (1)$$

$$\text{Ratio Error (ppm)} = \frac{1}{n}\left[b_k - \frac{k}{n}(b_n)\right] \qquad (2)$$

As an example, the ratio error of the first nine resistors in the typical DMR-105 shown in Figure 1 is calculated in Column C of Figure 2. The error calculation from equation (1) for a ratio of 5/9 is as follows:

$$\text{Ratio Error} = 1/9\left[-1 - 5/9(+1)\right] = -0.2 -$$

These corrections may be calculated and tabulated in the spaces left in the chart of theoretical ratios shown in Figure 3. Note that the errors obtained for this typical nine-resistor string are less than 0.2 ppm before correction. Completion of the above chart for all values of ratio desired establishes a Primary Ratio Reference DMR-105 with ratio certainty of the order of one part in 10,000,000.

The temperature coefficient matching and stability of a DMR Set is such that in a typical laboratory environment, a single calibration will be usable for several months. When required, recalibration by the method given is relatively fast and simple.

APPLICATION OF THE PRIMARY RATIO REFERENCE

Maintenance of the 0.0001% (one part per million) rated accuracy of the Julie Research Laboratories Primary Standard Divider VDR-106 is based on complete production and measurement tests described in an earlier *Precision* Volume III, No. 4. A quick and independent check of this performance is possible using the DMR-105 Set as a Primary Ratio Reference. The test circuit is as shown in Figure 4.

To ensure that a combination of power supply leakage resistance and galvanometer leakage resistance does not introduce substantial errors in the ratio determination, one side of the galvanometer circuit is grounded as shown, and a battery and battery switch properly floating on polystyrene, glass or Teflon insulation are used as a source.* With this circuit set-up it is only necessary to select a ratio, adjust the dials of the VDR-106 for no deflection on the galvanometer when the battery switch is thrown and compare this figure to the ratio reference calibration chart of Figure 2. The VDR-106 data is taken to one part in ten million by recording the setting of the six dials and estimating the seventh place from the galvanometer deflection.

*A suitable test for leakage effects may be made with any high range megohmeter. Before the calibration test of a VDR-106, it is possible to make an operational check of the complete circuit by splitting the DMR-105 Set into two groups of six resistors each and intercomparing them in the circuit of Figure 4.

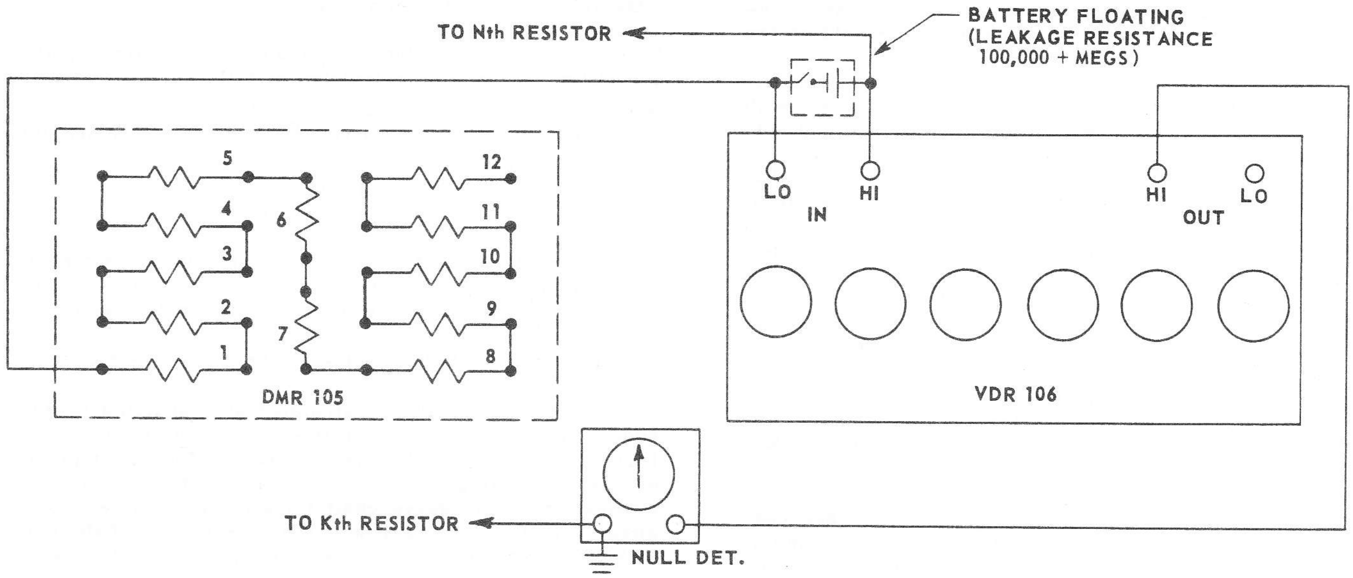

FIGURE 4
CONNECTION DIAGRAM – DMR-105 and VDR-106

(Note: All leads must be insulated 100,000 megohms or more above ground. Teflon insulation is suitable.)

STABILITY OF ULTRA-PRECISE RATIOS

The stability of resistance ratios with temperature, voltage, humidity and time is largely a function of the stability of the basic resistors used and of the design of associated interconnections, insulation and switching components. Primary Standard Dividers manufactured by Julie Research Laboratories achieve unique accuracy and stability through the use of the type NB-1 resistor and consistently meticulous design of all associated components.

Of over 100 VDR Dividers in production and laboratory use since July 16, 1956, only one has been returned to the factory out of accuracy specification. Other units checked, including Serial Nos. 2 and 16 maintained here at Julie Research Laboratories, are still within one part per million as specified in our literature. This complete absence of drift prevailed despite instances of years of service under extreme environmental conditions in production testing. It should be noted that these units have no facilities for adjustments or recalibration. As with all JRL Dividers, no adjustments are required to maintain the stated accuracy.

This reliability history permits Julie Research Laboratories to offer a factual Written Performance Guarantee of 0.0001% ratio accuracy for a five year period for the Model VDR-106 Primary Standard Divider.

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

ADDRESS REPLY TO
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D. C.

IN YOUR REPLY
REFER TO FILE NO.
1.1

Gentlemen:

Ref: Voltage Divider
Our Test No.
Your Order No.

We have received your order and/or the Voltage Divider referred to above, which instrument is being submitted to us for calibration.

The calibration of ratio devices involves no reference to National Reference Standards of any kind, such as standard resistors. By intercomparing closely-matched resistors any user can himself establish accurately known resistance ratios on a scale in steps of $\frac{1}{N}$, where N is the number of resistors connected in series.

In the past our usual test on apparatus of this type has involved a time-consuming check of each position of each dial against our calibrated precision ratio device known as a "Universal Ratio Set". The fee for this test varies from $154 to $181, depending upon the number of dials involved. The purpose of this letter is to call your attention to the advantages of a simpler, faster, and less expensive test which, while not covering as many dial settings, gives reasonable assurance regarding the accuracy of adjustment of the divider. For this test a group of nine closely-matched resistors is employed to establish accurately known ratios on the scale of ninths, 1/9, 2/9, 3/9, etc.

The National Bureau of Standards will calibrate promptly resistance-type voltage dividers on the scale of ninths under Test Fee Schedule 201.102z for a fee of $45.* The scale of ninths is particularly valuable because each position of every dial is involved at some stage in the test. At these discrete settings .111111, .222222, etc. the accuracy of calibration is somewhat better than what can be realized with our calibrated universal ratio device. For well-adjusted dividers our test document will state the deviation observed at the time of test to the nearest digit in the sixth decimal place.

In your reply please state if you want the simple $45 test or the full test.

Sincerely yours,

Resistance and Reactance Section
Electricity Division

* $45.00

Circle 5-2727

JRL JULIE RESEARCH LABORATORIES, INC.
211 WEST 61st STREET, NEW YORK, N. Y. 10023

WARRANTY

JULIE RESEARCH LABORATORIES, INC. guarantees to the original purchaser that this instrument, Model VDR 106/7, shall be free from defects in material and workmanship and shall maintain its rated accur- :acy of 0.0001% for a period of five (5) years after date of initial shipment. Our liability is limited to repairing and replacing any defective part with the exception of vacuum tubes, panel lamps, fuses, choppers, and batteries. The warranty lapses, if upon our investigation, we judge that the instrument has been abused in any way.