NBS

Technical Note No. 220

SOME MODIFICATIONS IN METHODS OF CALIBRATION OF UNIVERSAL RATIO SETS

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Issued August 30, 1964

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David Ramaley

Universal Ratio Sets can be calibrated by a number of different methods. The well established methods are very briefly outlined and emphasis is placed on some more recent developments. The choice of methods will depend upon available laboratory equipment and other considerations.

1. Introduction

Universal Ratio Sets [1, 2, 3] [1], commonly abbreviated URS, are now usually constructed as six dial instruments. Seven dial instruments probably will be available commercially in the future. Five dial varieties will not be considered in this paper.

Because the ratio set is a ratio device, it need not be calibrated in terms of any particular unit of resistance. A convenient unit for calibration is one two-thousandth of the total resistance of the twenty-step dial. If this unit is used, the settings 0 and 20 on the high dial will have no corrections. Usually the corrections at other settings of a URS are small (a few milliohms).

Conventional methods of calibration are mentioned first, followed by a description of several modified methods. Some of these modified calibration methods are applicable to resistive voltage dividers and other ratio devices.

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[1] Figures in brackets indicate the literature references at the end of this paper.

2. Conventional Method for the Calibration by Means of Standard Resistors and Direct Reading Ratio Sets

A conventional method of calibration is described in a Department of the Navy Instrument Calibration Technique [4] and also by at least one manufacturer's instruction manual.

The person performing the calibration should be acquainted thoroughly with decade calibration methods [2, 3] . Peacock [5] gives additional information on resistance decade calibration.

The step decades of ten ohms-per-step and lower are calibrated by conventional step substitution methods. The resistors of the twenty step dial can be measured by the double substitution method of comparing four-terminal resistors with two-terminal standards [2, 3] . It will be necessary to solder in leads to the appropriate points on the resistance coils to make the connections needed for most commercial ratio sets now on the market. Total resistance of the twenty-step dial circuit can be obtained by comparison with two one-thousand ohm resistors in series. This measurement furnishes the conversion factor for changing the measured resistances in ohms of all decades to resistances in terms of the arbitrarily chosen unit.

Another procedure for calibration of the twenty-step dial involves taking difference readings on the URS across a precision standard resistor. This is described in the calibration instruction procedures for the URS first mentioned.

Compensation of the ten ohm-per-step and lower decades needs to be tested in a suitable bridge circuit to insure adequate stability of overall URS resistance regardless of dial settings.

3. A Modification of the Calibration of the One Hundred Ohm-Per-Step Dial by Means of Trimmed Resistors

If one has available either ten or twenty one-hundred ohm, closely adjusted resistors (± 0.002 percent) of precision quality, with low temperature coefficients, this method is convenient.

3.1. Trimmer Adjustments

Good quality, small adjustable resistors, commonly referred to as "trim pots" in the radio industry, are connected across the individual one-hundred ohm resistors. A good trimmer resistor of one megohm magnitude and low temperature coefficient connected across the potential terminals of a precision standard resistor constitutes a trimmable standard with good stability for short periods of time. Combinations of trim resistors of other magnitudes can be utilized for this purpose also, provided the selection offers an appropriate magnitude and does not reduce the overall resistance of the unit excessively.

A good test to evaluate the suitability of a group of trimmed resistors is to adjust all the resistors to equality within about a part per million and then recheck this equality several times over a period of about two or three hours. After this period of several hours, the maximum spread in individual resistance should not exceed about four parts per million.

Adjusting and comparing resistors to about one part per million can be accomplished by using any appropriate bridge circuit with adequate stability and resolution. Universal or Direct Reading Ratio sets may be used for this purpose. In making the comparison of the precision trimmed resistors the contact variations should be less than 100 microhms, and consequently the resistors should be mounted on mercury-surfaced stands.

If the trimmed resistor group fails to demonstrate adequate stability over a two hour period one may resort to better quality trimmer components, closer temperature control or possibly a series of resistors with lower temperature coefficients.

3.2. Calibration Arrangement

Figure 1 shows an arrangement for calibration of a URS using twenty trimmed resistors. The resistors are mounted on mercury contact stands and connected to two resistance boxes and to the URS as shown. These resistance boxes should be of the best quality. The boxes are connected in parallel so that they may be adjusted in fine increments. Usually these boxes will be adjusted so that the URS reading difference corresponding to power application at points 0 and 20 will be exactly 2000.0000 (interpolating between steps on the 0.001 ohm-per-step dial on the URS). This arrangement is thus direct reading in terms of the arbitrarily chosen resistance unit, and the corrections to step 0 and step 20 will be 0.0000.

Bridge balance readings are taken next on the URS corresponding to power supply connections to all points, 0 to 20 inclusive. Because all twenty of the trimmed resistors are considered equal in resistance, the corrections to all twenty steps on the URS can be written down by inspection of the twenty-one URS readings simply by comparison with the 0 or 20 step reading. The correction to the ten steps on the 10 ohm-per-step dial should be obtained at this time, also, by taking an additional reading with power applied at point 1 (fig. 1) and with the 10 ohm-per-step dial set at X. This correction to the 10 ohm-per-step dial in terms of the unit for the 100 ohm-per-step dial is discussed under topic 6, pages 7 and 8. An example of calibration data for the 100 ohm-per-step dial and X step on the 10 ohm-per-step dial is given in table 1.

It is of interest to mention that this same procedure of using a sequence of trimmed resistors can be utilized for calibration of resistive voltage dividers and some types of potentiometers.

4. Calibration of the One-Hundred Ohm-Per-Step Decade with Twenty Untrimmed Resistors

The same calibration can be performed with untrimmed resistors provided the correction for each resistor is known with respect to the mean of the group of twenty. The calibration technique is the same as with the trimmed resistors, but the computation of corrections is somewhat more complicated. Table 2 gives an example of data for such a calibration for a group of untrimmed resistors. The zero reading on the URS should be large enough to accommodate changes encountered because of differences in corrections to individual resistors of the group. A zero reading of 0.0300 will probably be adequate for use with most groups of one-hundred ohm standard resistors. If standards are closely adjusted, the zero reading can be much less. To increase the zero reading, the lead resistance from the zero point on the resistor stand to the URS is increased. The arrangement should be made direct reading by adjusting the resistance boxes (fig. 1) until the URS reading difference between balances taken with power applied to the 0 and 20 points is exactly 2000.0000. The last place is obtained by interpolation. If the arrangement is not made direct reading, computations are somewhat more complicated.

Computed readings of column 5 of table 2 are obtained by adding the summation of corrections to the resistors to the zero reading of the URS plus the step change readings that would have occurred for perfect 100 ohm resistors. Corrections given in the last column are obtained by comparing columns 5 and 6. These corrections are identical to those in table 1 for the same URS when calibrated with trimmed resistors.

5. Calibration with Ten One-Hundred Ohm Resistors

Ten one-hundred ohm resistors, either trimmed or untrimmed, plus a thousand ohm resistor can be used to calibrate the one hundred ohm-per-step URS dial*. The thousand ohm resistor can be trimmed to equal the resistance of the ten one-hundred ohm resistors, or it can be left untrimmed. All eleven resistors are placed in a series arrangement as in figure 1. This modification requires only eleven resistor positions and is represented in the diagram by means of the dashed line jumper which bypasses and removes from the circuit the unnecessary resistor holders. The one thousand ohm resistor is situated in location 10-11, and the hundred ohm resistors in locations 1-10.

With power applied to point 0, a URS reading is taken and then another URS reading taken at point 11. The resistance boxes are adjusted so that the reading difference between these two balances is exactly 2000.0000. The correction to the setting 10, or midpoint, is obtained by taking a reading with power applied at point 10, then exchanging resistor 1 with resistor 11 and taking another reading with power applied at point 1 (fig. 1). The average of these two readings will be that reading which would have been obtained for a midpoint reading of two perfectly matched 1000 ohm resistors. In fact, if the thousand ohm resistor has been perfectly trimmed, we should observe

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* The ten ohm-per-step decade and setting 10 on the one ohm-per-step decade can be calibrated with ten trimmed or untrimmed resistors in a manner similar to that described in sections 3 and 4. The one hundred ohm-per-step dial is shorted out by a jumper to eliminate the unnecessary resistance in the circuit. Likewise the resistance in the string of ten resistors can be reduced by shunting with a standard resistor of appropriate magnitude. This same method can be continued for the calibration of the 1 ohm-per-step and even lower decades.

identical readings before and after the resistor exchange. As an example let us suppose that with the ten one-hundred ohm resistors to the left of the power connection the URS reading is 1000.0128 and that with the one-thousand ohm resistor to the left, the URS reading is 1000.0086. This case would represent an untrimmed thousand ohm situation. For a trimmed thousand ohm resistor, both readings should be 1000.0107 or the average of readings obtained with untrimmed resistors. Furthermore, let us suppose that we have readings for connections at position 0 and position 11 which are 0.0113 and 2000.0113, respectively. The resulting correction to the 10 step is + 0.0006.

Corrections to steps 1 thru 9 are obtained next by placing the one-hundred ohm resistors in the appropriate positions and taking the necessary step readings. Next, the hundred ohm resistor group is placed in position to obtain readings for correction computations for steps 11 thru 19. The corrections of the ends (0.0000) and midpoint (+ 0.0006) of the decade are used for setting up the conditions for determining corrections to the other steps.

This method can be further extended to use only five one-hundred ohm resistors if a five-hundred ohm or two one-thousand ohm resistors (in parallel) are available. In fact, there are a number of other calibration combinations which can be used. However, additional complication of computations make such calibrations more difficult.

6. Modified Method of Calibration of the Ten Ohm-Per-Step and Lower Decades by Means of a Universal Ratio Set or Resistive Voltage Divider

If the 100 ohm-per-step dial is shorted out by a jumper, the overall resistance of the URS becomes 111.110 ohms and the maximum number of possible step changes for a six dial ratio set is 111,110.

Thus, if we connect a shorted URS directly to an unshorted URS, we have about twenty times the number of available step changes on the unshorted ratio set as on the shorted set. This calibration then becomes similar to the typical calibration of common types of potentiometers by means of the URS. Readings can be taken on the unshorted or standard set corresponding to step changes for each step of all of the ten step decades of the shorted ratio set. This arrangement gives excellent resolution and provides a convenient method of calibration. Corrections to the several dials are obtained by multiplying the URS reading differences by a factor obtained from the known correction to setting X of the ten ohm-per-step dial. As an example let us assume that the actual correction to this dial is + 0.0014. Let us also suppose that the standard URS reading difference corresponding to setting 0 and setting X of the 10 ohm-per-step dial on the URS under calibration is 1890.007. Thus the multiplying constant desired would be 100.0014 divided by 1890.007 or 0.05291060. When all of the standard URS reading differences are multiplied by this constant, the actual dial steps for all of the ten step decades are obtained. The corrections then can be ascertained by simple inspection.

This method can be modified for even greater convenience if the standard URS is made direct reading by a factor of twenty according to the known correction to setting X on the 10 ohm-per-step dial. The circuit for this is shown in figure 2. The two resistance boxes are placed in parallel to permit adjustment of resistance in very fine increments. Let us assume for example that the correction to setting X of the 10 ohm-per-step decade is + 0.0014. The standard URS reading difference would then be made to equal 2000.028 by adjustment of the resistance boxes for a twenty times direct reading arrangement. All URS reading differences divided by 20 would thus give the desired information for readings taken on all steps of the ten step decades. Table 3 gives an example of calibration with this arrangement for the 10 ohm-per-step dial and two steps on the 1 ohm-per-step dial.

A resistive voltage divider with a resolution of a part per million can be used in this same manner to calibrate the ten step URS decades*. However, the high resistance of the divider and the low resistance of the shorted URS (111.11 ohms) may require an especially sensitive galvanometer or null detector in the precise balancing of the resultant bridge circuit.

7. Calibration of the One-Hundred Ohm-Per-Step Dial and Setting X on the Ten Ohm-Per-Step Dial by Means of Another URS

The two ratio sets are connected as shown in figure 3. Here G_1 and G_2 are adjustable clips or other convenient devices which permit connection at any point along the connectors between the two ratio sets. These adjustable connections enable one to secure the desired readings for the zero step settings of the ratio sets and also for the twenty step settings. These adjustments are made so that the balanced bridge reading differences are equal for both ratio sets when the 100 ohm-per-step dials are set respectively at zero and twenty. For example, if the standard URS reads 0.0080 when the URS being calibrated reads 0.0000, then the standard should read 2000.0080 when the other URS reads 2000.0000. It is well to allow about 0.008 ohms extra coverage on the standard URS if one plans to set the URS under calibration on the various steps and take the corresponding reading on the

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* Although not a part of the subject under consideration, it is interesting to note that the second and lower dials of a Kelvin-Varley type resistive voltage divider or potentiometer can be calibrated by this same method by shorting out the proper portion of the first dial circuit.

standard URS. One can do it in reverse manner by setting the standard URS and reading the URS to be calibrated. For this situation the extra coverage setting of about 0. 008 ohm should be in the URS being calibrated. Purpose of the extra coverage is to insure that the reading of the lowest dial will be large enough to accommodate corrections to any of the twenty steps involved in the calibration.

If the standard URS has been calibrated accurately, all steps on all dials can be quickly compared with the corresponding steps on the other instrument and corrections assigned accordingly. Readings should be taken to an interpolated place on the 0. 001 ohm-per-step dial if possible.

When neither URS has been calibrated, the procedure is somewhat more complicated. For each individual 100 ohm step change on the unknown URS, two readings are necessary. The first is the reading for the corresponding step on the second URS. The second is the reading on this same 100 ohm step of the second URS when the URS being calibrated is set to the next lower 100 ohm step with the 10 ohm-per-step dial set on X. Table 4 illustrates an example of this method for calibration of the 100 ohm-per-step dial and setting X on the 10 ohm-per-step dial. The same method could be applied to work on down through the lower dials. However, the method outlined previously for shorting out the twenty step dial is much more convenient if the standard URS is in fair adjustment even though not recently calibrated. Errors of 0. 001 or 0. 002 ohms on the standard URS will result in negligible corrections for the URS being calibrated.

Calibration of the 100 ohm-per-step dial and X step on the 10 ohm-per-step dial also can be accomplished for a single URS by this method using a string of twenty untrimmed 100 ohm resistors. By making the step by step comparison of the X step on the 10 ohm-per-step with each step on the 100 ohm-per-step dial, corrections need not be known to any of the twenty resistors arranged in series.

8. Conclusions

The various methods of URS calibration mentioned here indicate that the user of a URS has available a choice of methods. Still other methods not described here can be used if one has access to a variety of resistance boxes and possibly a slide wire. We can conclude that standards accurately incorporating the unit of resistance are completely unnecessary for accurate URS calibrations. Any moderately well equipped laboratory is in a position to adequately calibrate a URS.

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[2] Thomas, J. L. (Oct. 8, 1948), National Bureau of Standards Circular 470.

[3] Brooks, P. P. B. (March 1, 1962), National Bureau of Standards Monograph 39.

[4] Standards Laboratory Instrument Calibration Technique DR-03, Six Dial Universal Ratio Set, issued by Department of the Navy, Calibration Program. Available for a fee from the Office of Technical Services, Department of Commerce, Washington, D. C.

[5] Peacock, L. W., I. S. A. Proceedings, 1961 Fall Instrument-Automation Conference and Exhibit, Vol. 16 - Part 1, Paper No. 22-61.

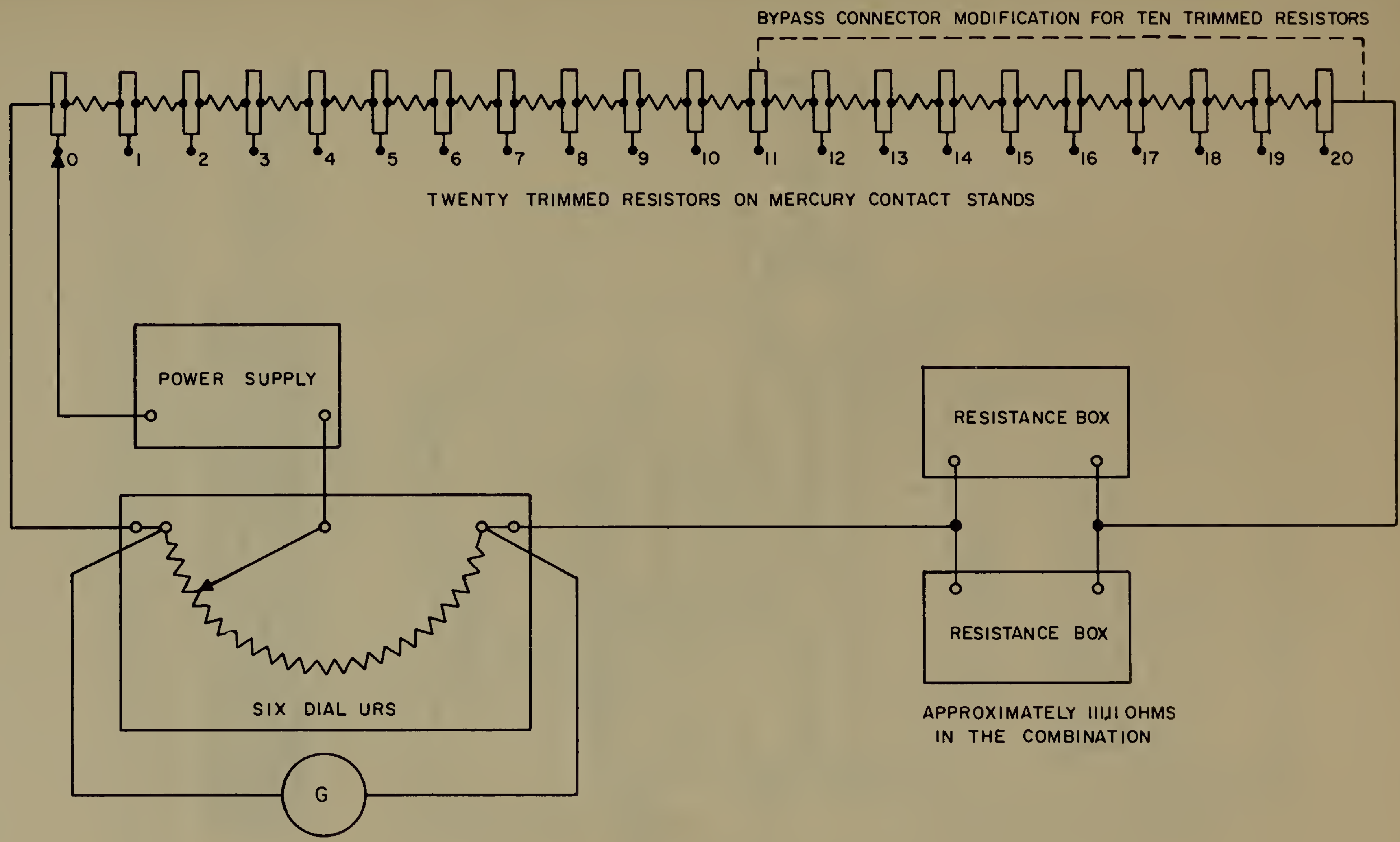

FIG. I. SCHEMATIC ARRANGEMENT FOR CALIBRATION OF A UNIVERSAL RADIO SET USING TWENTY TRIMMED RESISTORS. (UNTRIMMED RESISTORS MAY BE USED IF CORRECTIONS ARE KNOWN.)

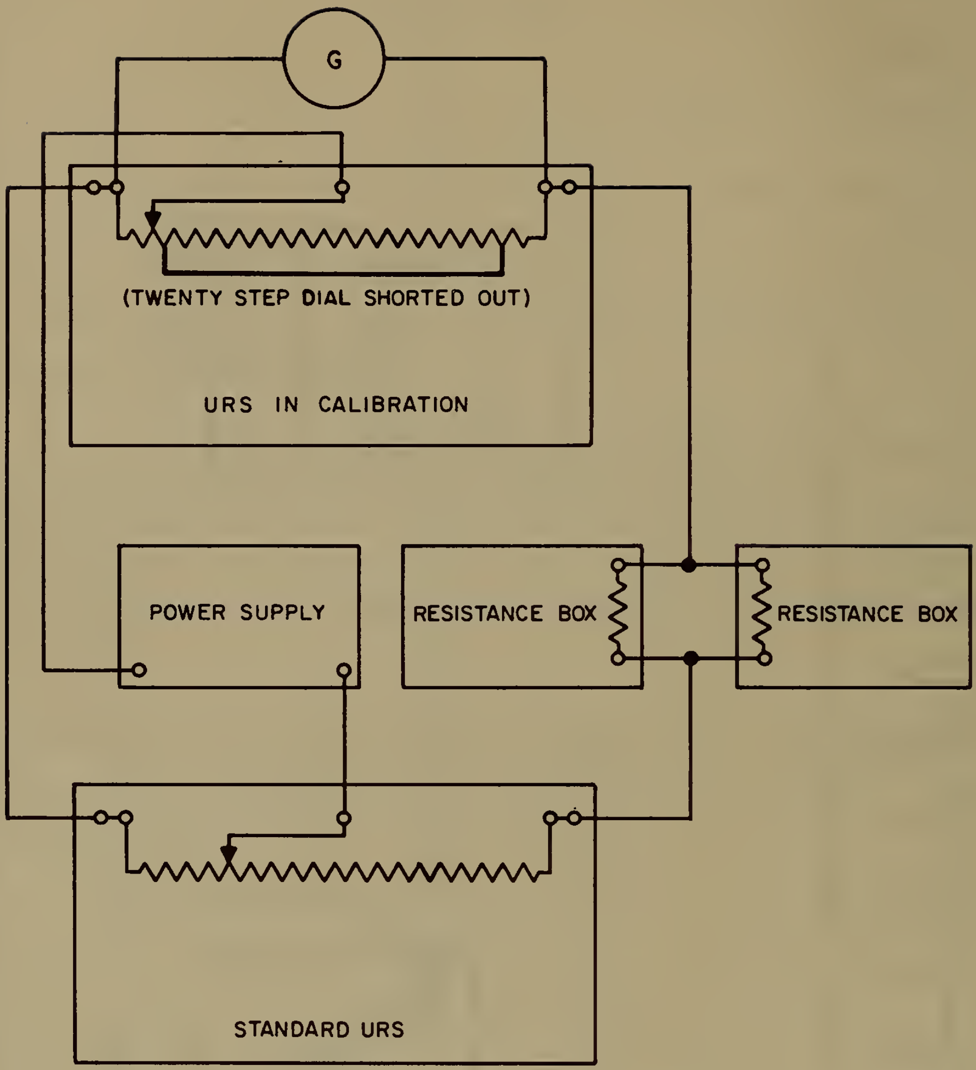

FIG. 2. CALIBRATION OF THE TEN STEP DECADES OF A URS IN A DIRECT READING ARRANGEMENT. COMBINED RESISTANCE OF RESISTANCE BOXES IS ABOUT 110 OHMS FOR URS READING DIFFERENCE OF 2,000,000 FOR THE 10 OHM-PER-STEP DECADE.

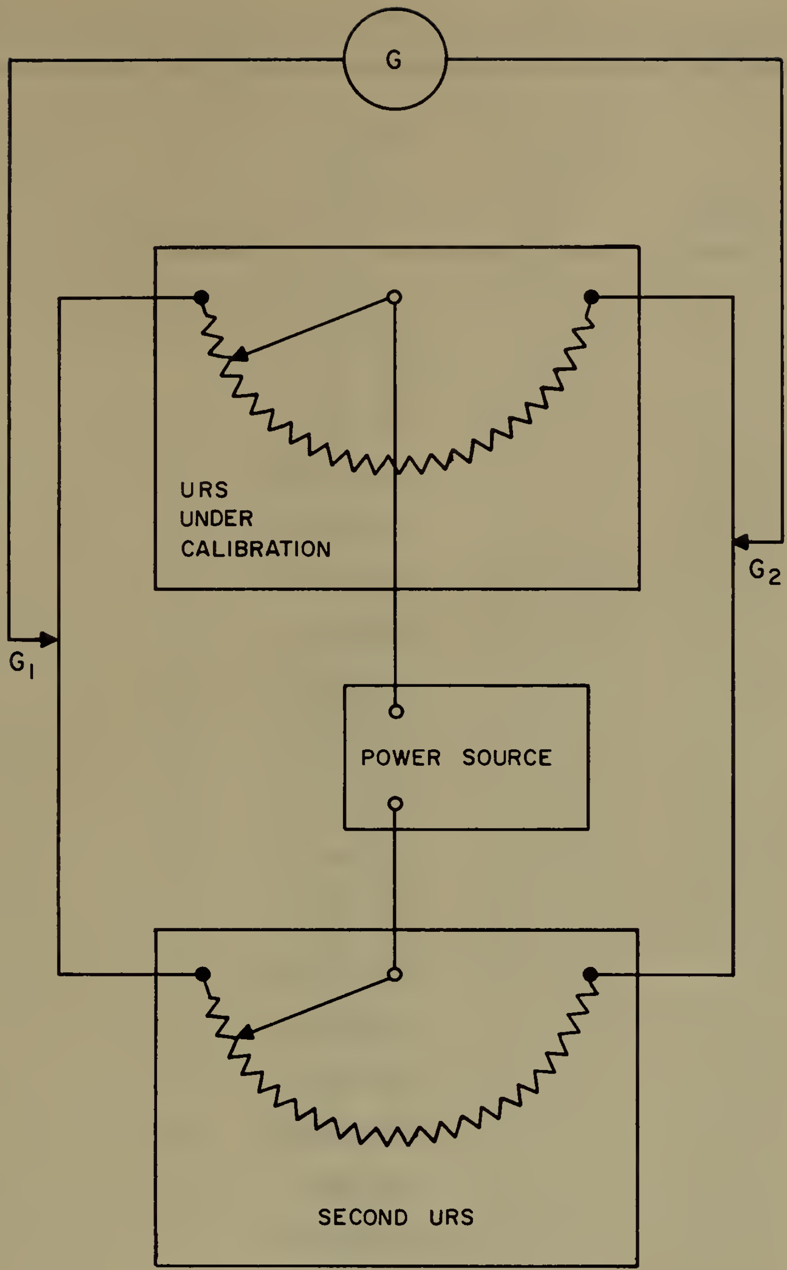

FIG. 3. ARRANGEMENT FOR CALIBRATION OF THE 100 OHM-PER-STEP DIAL AND THE X STEP ON THE 10 OHM-PER-STEP DIAL OF A URS BY MEANS OF A SECOND URS.

Table 1. Example of calibration data for URS twenty step dial and X step on 10 ohm-per-step dial using twenty trimmed resistors

Power Supply Connection Point	URS Reading	Correction
0	0.0032	0.0000
20	2000.0032	0.0000
1	100.0037	-0.0005
1*	X0.0018*	+0.0014*
2	200.0039	-0.0007
3	300.0041	-0.0009
4	400.0043	-0.0011
5	500.0038	-0.0006
6	600.0035	-0.0003
7	700.0033	-0.0001
8	800.0030	+0.0002
9	900.0028	+0.0004
10	1000.0026	+0.0006
11	1100.0027	+0.0005
12	1200.0024	+0.0008
13	1300.0020	+0.0012
14	1400.0026	+0.0006
15	1500.0034	-0.0002
16	1600.0039	-0.0007
17	1700.0043	-0.0011
18	1800.0038	-0.0006
19	1900.0036	-0.0004
20	2000.0032	0.0000

* Data for X step on 10 ohm-per-step dial.

Table 2. Example of calibration data for URS 100 ohm-per-step dial and X step on 10 ohm-per-step dial using twenty untrimmed resistors. Correction to each resistor in terms of the mean of the group is known to a part per million.

Resistor Number	Correction in ppm compared to mean of group	Summation of corrections	Power supply connection point in use	Computed Reading for a perfect URS	Actual URS Reading	Correction to URS
			0	0.0113	0.0113	0.0000
			20	2000.0113	2000.0113	0.0000
1	- 6	- 6	1	100.0107	100.0112	-0.0005
"	"	"	1*	X0.0107*	X0.0093*	+0.0014*
2	+ 5	- 1	2	200.0112	200.0119	-0.0007
3	-10	-11	3	300.0102	300.0111	-0.0009
4	+21	+10	4	400.0123	400.0134	-0.0011
5	+ 1	+11	5	500.0124	500.0130	-0.0006
6	-17	- 6	6	600.0107	600.0110	-0.0003
7	-14	-20	7	700.0093	700.0094	-0.0001
8	+13	- 7	8	800.0106	800.0104	+0.0002
9	-10	-17	9	900.0096	900.0092	+0.0004
10	+10	- 7	10	1000.0106	1000.0100	+0.0006
11	- 5	-12	11	1100.0101	1100.0096	+0.0005
12	+17	+ 5	12	1200.0118	1200.0110	+0.0008
13	- 3	+ 2	13	1300.0115	1300.0103	+0.0012
14	0	+ 2	14	1400.0115	1400.0109	+0.0006
15	+10	+12	15	1500.0125	1500.0127	-0.0002
16	- 9	+ 3	16	1600.0116	1600.0123	-0.0007
17	+ 2	+ 5	17	1700.0118	1700.0129	-0.0011
18	+ 4	+ 9	18	1800.0122	1800.0128	-0.0006
19	- 1	+ 8	19	1900.0121	1900.0125	-0.0004
20	- 8	0	20	2000.0113	2000.0113	0.0000

* Data for X step on ten ohm-per-step dial.

Table 3. Calibration data for the ten step decades of a URS

Dial setting of URS in calibration	Reading of the standard URS	Reading difference	Correction to dial settings
0000.000	0.034		
X0.000	2000.062	2000.028	0.0014
00.000	0.034	0.000	0.0000
10.000	200.038	200.004	+0.0002
20.000	400.042	400.008	+0.0004
30.000	600.045	600.011	+0.0006
40.000	800.047	800.013	+0.0006
50.000	1000.050	1000.016	+0.0008
60.000	1200.055	1200.021	+0.0010
70.000	1400.056	1400.022	+0.0011
80.000	1600.059	1600.025	+0.0012
90.000	1800.061	1800.027	+0.0014
X0.000	2000.062	2000.028	+0.0014
0.000	0.034	0.000	0.0000
1.000	20.032	19.998	-0.0001
2.000	40.036	40.002	+0.0001
etc.			

Table 4. Example of calibration of the 100 ohm-per-step dial and X step on the 10 ohm-per-step dial on a URS with the aid of a second URS. (Circuit arrangement shown in Figure 3.)

*Reading of URS undergoing calibration	Reading of second URS	Reading Differences	Summation of Differences	Summation that would result if all twenty URS steps were equal	Correction for the corresponding URS step	
0.0000	0.0060					
2000.0000	2000.0060					
100.0000	100.0063	-0.0024	-0.0024	-0.002165	-0.0002	1
X0.0000	100.0087					
200.0000	200.0049	-0.0021	-0.0045	-0.004330	-0.0002	2
1X0.0000	200.0070					
300.0000	300.0054	-0.0021	-0.0066	-0.006495	-0.0001	3
2X0.0000	300.0075					
400.0000	400.0043	-0.0020	-0.0086	-0.008660	+0.0001	4
3X0.0000	400.0063					
500.0000	500.0052	-0.0018	-0.0104	-0.010825	+0.0004	5
4X0.0000	500.0070					
600.0000	600.0051	-0.0027	-0.0131	-0.012990	-0.0001	6
5X0.0000	600.0078					
700.0000	700.0059	-0.0019	-0.0150	-0.015155	+0.0002	7
6X0.0000	700.0078					
800.0000	800.0074	-0.0015	-0.0165	-0.017320	+0.0008	8
7X0.0000	800.0089					
900.0000	900.0075	-0.0028	-0.0193	-0.019485	+0.0002	9
8X0.0000	900.0103					
1000.0000	1000.0073	-0.0030	-0.0223	-0.021650	-0.0006	10
9X0.0000	1000.0103					

1100.0000	1100.0075	-0.0023	-0.0246	-0.023815	-0.0008	11
10X0.0000	1100.0098					
1200.0000	1200.0062	-0.0023	-0.0269	-0.025980	-0.0009	12
11X0.0000	1200.0085					
1300.0000	1300.0076	-0.0013	-0.0282	-0.028145	-0.0001	13
12X0.0000	1300.0089					
1400.0000	1400.0060	-0.0022	-0.0304	-0.030310	-0.0001	14
13X0.0000	1400.0082					
1500.0000	1500.0062	-0.0024	-0.0328	-0.032475	-0.0003	15
14X0.0000	1500.0086					
1600.0000	1600.0067	-0.0025	-0.0353	-0.034640	-0.0007	16
15X0.0000	1600.0092					
1700.0000	1700.0050	-0.0030	-0.0383	-0.036805	-0.0015	17
16X0.0000	1700.0080					
1800.0000	1800.0051	-0.0027	-0.0410	-0.038970	-0.0020	18
17X0.0000	1800.0078					
1900.0000	1900.0062	-0.0011	-0.0421	-0.041135	-0.0010	19
18X0.0000	1900.0073					
2000.0000	2000.0060	-0.0012	-0.0433	-0.04330	0.0000	20
19X0.0000	2000.0072					
0.0000						

$+0.0433 \div 20 = +0.00216$ { This is the correction to X step on 10 ohm-per-step dial }

* By adjusting G_1 and G_2 in Figure 3 so that the zero and 20 step readings are reversed for the two ratio sets it is possible to calibrate the URS by setting the second URS on 0.0000, 100.0000, 200.0000, etc. and reading the first URS at points such as 0.0080, 100.0073, X0.0049, 200.0091, 1X0.0070, etc. Care must be exercised to see that the correct signs (+ or -) are applied properly in making the computations.

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