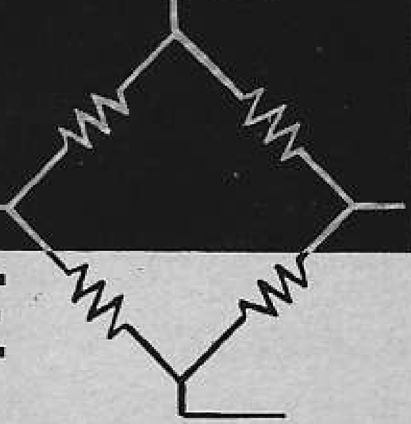
DIVIDE and MULTIPLY with a WHEATSTONE BRIDGE



By FORREST H. FRANTZ, SR.

Properly set up, a Wheatstone bridge becomes a simple calculating machine

ELECTRONIC computers are taking over many of the drudgery jobs in business and engineering. We're all intrigued by the capability, speed and immensity of the giant electronic "brains." Actually they aren't brains, but merely slaves to do drudgery math and record keeping for mankind.

While there's reason for us to be awed by computers, there's no reason to shy away from them and decide they can't be understood. There are simple computer schemes that are easy to understand and duplicate (see "Mr. Math," RADIO-ELECTRONICS, June 1958, page 47). This article describes one you can build in a couple of hours. It uses a simple Wheatstone bridge circuit.

The basic circuit of the Wheatstone bridge is shown in Fig. 1. The resistances in the bridge (A, B, C and D) have a special relationship when meter M reads zero. The relationship is:

$$(1) \qquad \frac{A}{B} = \frac{C}{D}$$

If resistances B, C and D are 10, 20 and 30 ohms, respectively, and the resistance of A is unknown, it may be determined by solving the formula for A and substituting the known values. Thus, multiplying both sides of the equation by B:

$$(2) \qquad A = \frac{BC}{D} = \frac{10 \times 20}{30} = 6.67$$

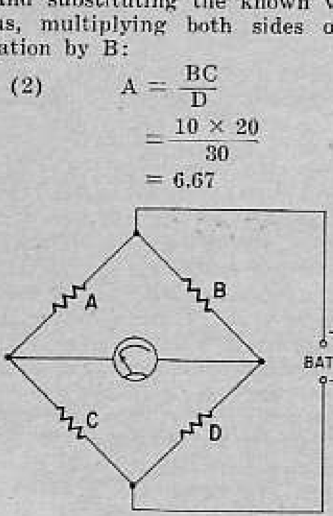


Fig. 1—Basic circuit of a Wheatstone bridge.

In just this way the Wheatstone bridge helps measure unknown resistances, and the dials on the front of the bridge are usually calibrated to give the unknown resistance direct. If we use the Wheatstone bridge principle but use potentiometers with calibrated scales for all four resistances, it's a simple matter to come up with a calculator that can multiply and divide. The circuit of such a device is shown in Fig. 2. The potentiometers are wirewound and must be linear if you want to use linear scales without special calibration. The type specified in the parts list is inexpensive and will give accurate results. The battery supplies voltage to the bridge when either S1 or S2 is depressed. Meter M is the null detector and may be an external meter on the lowest milliampere range if you have a multimeter and wish to economize. S1 is depressed for coarse null; S2 for fine null. This arrangement makes things easy on the meter by minimizing off-scale deflections.

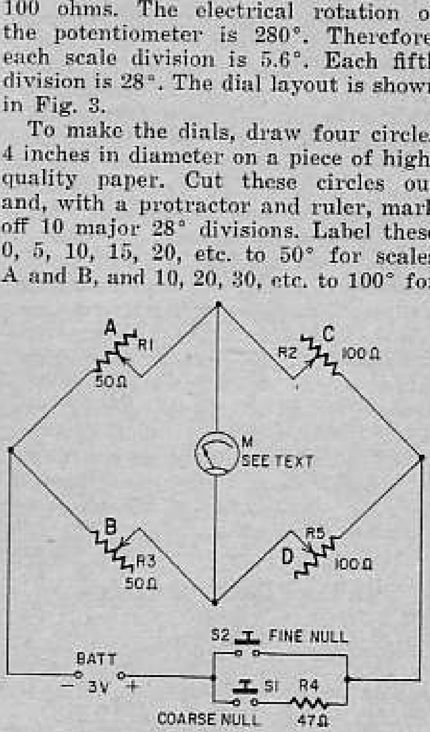
To multiply

Formula (2) can be used to work most problems. To multiply 32 × 36, for example, set 32 on B and 36 on C. Since you want the answer on pot A, you must set D to a multiple of 10 that gets the answer in the range of the A pot. Try setting D at 100. Now, depress S1 and adjust A for coarse meter null. Then depress S2 and adjust A for a fine meter null. Pot A reads 11.5 at null. Multiply by 100 (move the decimal point two places to the right) since pot D divided the problem by 100. The answer is 1,150. If you multiply 32 × 36, the true answer is 1,152. The error is less than 0.2%. In general, the error will not be this small, but it will be reasonably small if you do a good construction job and are careful in setting numbers on the potentiometer dials. Results are comparable with those obtained on an ordinary slide rule. There'll be more examples of how this calculator can be used later.

The Wheatstone bridge calculator is built onto a 8½ x 12½-inch panel of ⅛-inch Masonite. A wooden base may be attached to it with wood screws if you prefer a vertical panel.

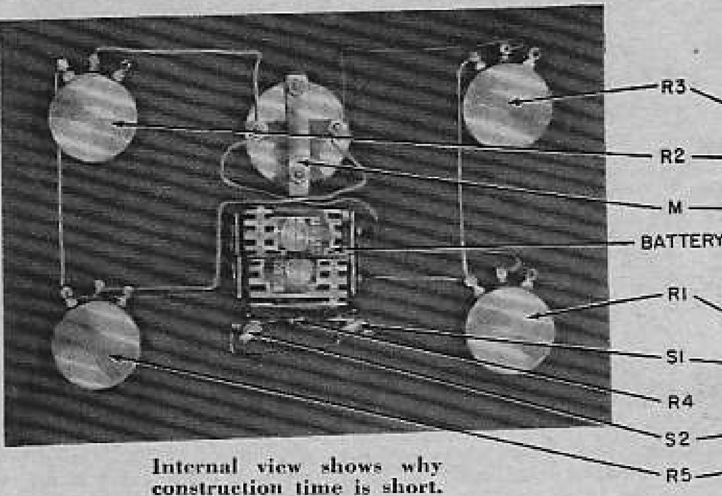
The dial scales are linear and have 50 equal divisions. Every fifth division line is longer than the others. On scales A and B, each division corresponds to 1 ohm of resistance and every fifth division represents a 5-ohm increment with a full-scale value of 50 ohms. On scales C and D, each division represents 2 ohms, each fifth division a 10-ohm increment, and the full-scale value is 100 ohms. The electrical rotation of the potentiometer is 280°. Therefore, each scale division is 5.6°. Each fifth division is 28°. The dial layout is shown in Fig. 3.

To make the dials, draw four circles 4 inches in diameter on a piece of high-quality paper. Cut these circles out and, with a protractor and ruler, mark off 10 major 28° divisions. Label these 0, 5, 10, 15, 20, etc. to 50° for scales A and B, and 10, 20, 30, etc. to 100° for

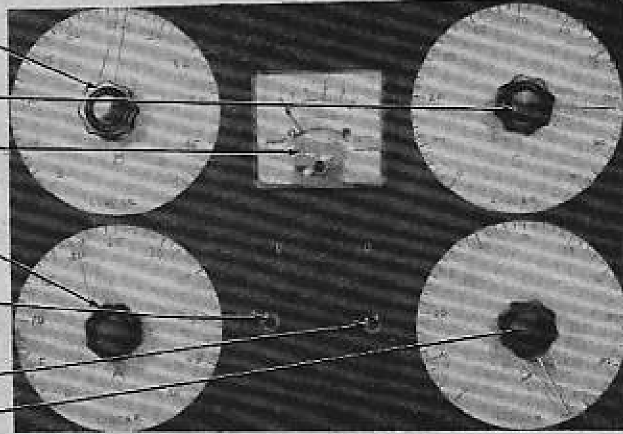


R1, 3—pot, 50 ohms, linear (Clarostat 58C1-50 or equivalent)
R2, 5—pot, 100 ohms, linear (Clarostat 58C1-100 or equivalent)
R4—47 ohms, ½ watt, 10%
BATT—penlight cells (2 in series)
M—0-1-ma meter (Shurite 8300Z or equivalent)
S1, 2—spst pushbutton
Battery holder for two penlight cells
Panel and dials and knobs (see text)
Miscellaneous hardware

Fig. 2—Circuit of the Wheatstone bridge calculator.



Internal view shows why construction time is short.



Closeup of the calculator's front panel.

C and D. Next, fill in the minor divisions 5.6°, 11.2°, 16.8° and 22.4° from the preceding major division. Finally, draw a ⅜-inch center hole, and cut it out. Ink the scales in if you wish. Fasten the dials to the panel with rubber cement. Be sure the panel is clean, and go easy with the rubber cement. *Center* the dials over the potentiometer holes.

Cut the pot shafts to ½ inch. Place a hex nut on each potentiometer bushing before mounting. Adjust the position of this nut till the bushing extends the thickness of a hex nut beyond the front of the panel, and then fasten the front hex nut. This makes the pointer knob ride close to the scale.

The pointer indicators are made by cutting out plastic pointers, scratching a hairline on them with an ice pick, filling the hairline with India ink, and then attaching the pointers to plain knobs with service cement. Be sure the hairline is aligned with the center of the knob sha't hole. Fig. 4 shows the pointer in detail. Fasten the pointer knobs to the pots so that the pointer travels an equal distance beyond the first and last graduation on the scale. The pointer travels beyond the ends of the scale since the potentiometer arm rides over the end connections on the pot.

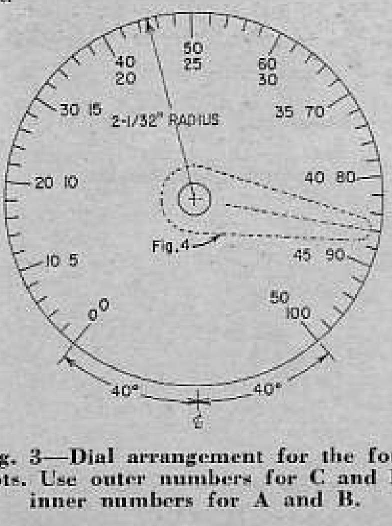


Fig. 3—Dial arrangement for the four pots. Use outer numbers for C and D, inner numbers for A and B.

Mount S1, S2, and the meter, and wire the calculator. Use the photos for guidance. Insert the battery, and you're ready to calculate.

Using the instrument

Here are a few examples of how you can use the calculator. Simple numbers that you can check mentally are used in the first few problems.

• **Problem 1: There's a 40-volt drop V across a 30-ohm resistor R. Compute (a) the current I through the resistor, (b) the power P dissipated.**

Solution:

(*a*) I=V/R, I=40/30. Set 40 on C, 10 on B, 30 on D. The result obtained by adjusting A for meter null is 13.3. Since B was set on 10, the result is 10 times the actual answer. So divide the answer by 10 (move the decimal point one place to the left) to get 1.33. The answer your calculator will give on the problem might look more like 1.31 or 1.35, but accuracy is still better than 2%.

(*b*) P=VI

From the preceding problem, V (30) is set on C. Set I (1.33) × 10 or 13.3 on B, and set D to 100. Adjust A for null. The result is 4.0. Since we multiplied by 10 in setting B and the problem was divided by 100 in setting D, the result on A must be multiplied by 10 to obtain the answer, which is 40. This is reasonably close to the longhand answer (39.9).

• **Problem 2: A car traveled 45 miles per hour for 10 minutes. How far did it go?**

Solution:

Distance = Speed × Time

$$= \frac{45 \text{ miles}}{60 \text{ minutes}} \times 10 \text{ minutes}$$

Set 45 on B, 10 on C, and 60 on D. Adjust A for null. The result is 7.5 miles. In this case, the result on A is the answer because the numbers were set directly on the pots without scale multipliers.

• **Problem 3: Square 35.**

Solution:

Set 35 on B, 35 on C, 100 on D. Adjust A for null. The result is 12.2 on A. This must be multiplied by 100 since the problem was divided by the 100 set on D. The answer from the calculator is 1,220, which is reasonably close to the actual result (1,225).

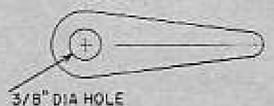


Fig. 4—Diagram of the pointers. Make four from clear plastic; see text for details.

• **Problem 4: Find the square root of 20.**

Solution:

Set 20 on A. Since the square root of 25 is 5, the answer will be near 5. Set B to 50, C to 50, and D to 100. Depress S2 and decrease B and C equally for a null. When B equals C at null, the result on either of them, divided by 10, is the answer. Again the division is required because of the scaling. Although using multipliers and divisors may seem complicated, you'll catch on quickly. The practice actually will help you in your understanding of math.

• **Problem 5: A 30-, 40- and 90-ohm resistor are connected in parallel. What is the total resistance?**

$$R = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$$

Solution:

Set B to 10, C to 100, D to 30 and adjust A for null. You're calculating 1,000/R, and the result on A is 33.3. Write it down.

Leave B at 10, C at 100 and set D to 40. The result of 1,000/R, when A is adjusted for null is 25. Write it down.

Leave B at 10, C at 100 and set D to 90. Adjust A for null and write down the result. It's 11.1.

Add the results of the preceding steps: 33.3 plus 25 plus 11.1 is 69.4. Leave B set to 10, C set to 100 and set 69.4 on D. Adjust A for null. The result on A is 14.4. This is the answer since the numerator-scale multiplier cancelled out the denominator-scale multiplier. Incidentally, I obtained 14.2 as the final answer on my calculator. If you're careless along the way, you may get much further off.

Here's another pointer on getting accuracy. Adjust for a close null. Alternately press and release S2 in getting the fine null to be sure that there's no movement of the meter needle in going from one switch position to the other. If you use a 0–1-ma meter for a null indicator, you can increase the null sensitivity by boosting battery voltage to 6 (four flashlight batteries in series) or by providing a transistor amplifier for the meter.

Once you get the hang of using the calculator with formula (2) (which I used in most of the illustrative problems), explore formula (1) and the formula AD = CD. With a little bit of thought and practice, you can do a lot with this calculator. And you'll increase your skill with mathematics too. END