Title
EXTENDING THE RANGE OF A SELF-BALANCING RECORDING POTENTIOMETER WITHOUT REDUCING RESOLUTION

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ABSTRACT

The combination of our "Lobetrol" (an assembly of relays, switches, etc.) with a commercial recorder (such as Leeds and Northrup Type G Speed-O-Max) constitutes a self-balancing, indicating and recording potentiometer whose range is a multiple of the range of the commercial recorder. The resolution of the combination is equal to the resolution of the recorder.

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BASIC EXPANSION CIRCUIT

Consider the simple scale expansion circuit in Fig. 1. Here $e_{in} = e_b + e_v$, e_b is the "bucking potential" and e_v is the potential at the voltmeter terminals. If $e_b = nV$ (where n is any integer from zero to n inclusive), and if the voltmeter scale covers the range from zero to V, any e_{in} between zero and (n + 1) V can be measured.

The circuit we use is shown in Fig. 2, in which $e_{in} = e_b \pm e_v$. When $e_b = 2nV$ (n as above) and the voltmeter scale covers the range from zero to V, any e_{in} between -V and (2n + 1) V can be measured. This circuit differs from the one shown in Fig. 1 in that: (1) for a given number of steps, twice the range is covered, and, more important, (2) with a slow voltmeter (such as a self-balancing potentiometer) the indication of e_{in} is interrupted only while the switches are moving from one position to another. (In the system of Fig. 1, the indication is interrupted while the voltmeter indicator moves from V to zero or from zero to V, when e_b is stepped.)

The following is an example of the operation of our expansion system (Fig. 2).

Increase e_{in} from zero to 2.5V.

Sequence	e_{in}	e_b	S-1	Relation	e_v
1	0	0	+	$e_{in} = 0 + e_v$	0
2	$0 < e_{in} < V$	0	+	$e_{in} = 0 + e_v$	$0 < e_v < V$
3	V	0	+	$e_{in} = 0 + e_v$	V
4	Reverse S-1, Step increase S-2 to 2V.				
5	V	2V	-	$e_{in} = 2V - e_v$	V
6	$V < e_{in} < 2V$	2V	-	$e_{in} = 2V - e_v$	$V > e_v > 0$
7	2V	2V	-	$e_{in} = 2V - e_v$	0
8	Reverse S-1.				
9	2V	2V	+	$e_{in} = 2V + e_v$	0
10	$2V < e_{in} < 3V$	2V	+	$e_{in} = 2V + e_v$	$0 < e_v < V$
11	2.5V	2V	+	$e_{in} = 2V + e_v$	.5V
Now reduce e_{in} to zero.					
12	$3V > e_{in} > 2V$	2V	+	$e_{in} = 2V + e_v$	$V > e_v > 0$
13	2V	2V	+	$e_{in} = 2V + e_v$	0
14	Reverse S-1.				
15	2V	2V	-	$e_{in} = 2V - e_v$	0
16	$2V > e_{in} > V$	2V	-	$e_{in} = 2V - e_v$	$0 < e_v < V$
17	V	2V	-	$e_{in} = 2V - e_v$	V
18	Reverse S-1, Step decrease S-2 to zero.				
19	V	0	+	$e_{in} = 0 + e_v$	V
20	$V > e_{in} > 0$	0	+	$e_{in} = 0 + e_v$	$V > e_v > 0$
21	0	0	+	$e_{in} = 0 + e_v$	0

The above sequence can be generalized as follows:

(a) When the voltmeter reaches its lower limit, reverse its polarity.

(b) If e_{in} is increasing and the voltmeter reaches its upper limit, reverse its polarity and increase e_b one step.

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(c) If e_{in} is decreasing and the voltmeter reaches its upper limit, reverse its polarity and decrease e_b one step.

In Fig. 3, a curve (a) is repeated on narrow charts (b, c). The system of Fig. 1 results in a series of offset segments of the original curve (Fig. 3b). The Fig. 2 method folds the curve between the lines $e_v = 0$ and $e_v = V$ (Fig. 3c).

AUTOMATIC SCALE EXPANSION

The circuit of Fig. 1 lends itself readily to automatic scale expansion. If the voltmeter is equipped with switches which operate at zero and at V, operation of the "V" switch indicates that e_{in} is increasing (de/dt is positive) and calls for $e_{b_2} = e_{b_1} + V$ (S-2 steps up). Operation of the "Zero" switch (indicating de/dt is negative) calls for $e_{b_4} = e_{b_3} - V$ (S-2 steps down). This method is being used successfully with a slowly varying input. A one hundred times scale expansion, recording resistance thermometer has been described by D. C. Stull[1]. A. J. Williams of Leeds-Northrup Company has described a preliminary commercial model of the Stull instrument[2].

Figure 4 is a generalized schematic representation of a device which operated S-1 and S-2 of Figure 2 automatically. We call this automatic device a Lobetrol. The Lobetrol senses and responds to the conditions a, b, and c listed under Basic Scale Expansion Circuit. Condition "a" is met by reversing the position of S-1 each time the "Zero" switch is operated (at $e_v = 0$). When the "V" switch is operated (at $e_v = V$ +) the Lobetrol must decide whether condition "b" or condition "c" applies, and act accordingly. If S-1 is in normal (plus) position and the voltmeter pointer is moving toward "V" an increasing e_{in} (input voltage) is indicated. Therefore, if S-1 is <u>plus</u> when the V switch

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(c) If e_{in} is decreasing and the voltmeter reaches its upper limit, reverse its polarity and decrease e_b one step.

In Fig. 3, a curve (a) is repeated on narrow charts (b, c). The system of Fig. 1 results in a series of offset segments of the original curve (Fig. 3b). The Fig. 2 method folds the curve between the lines $e_v = 0$ and $e_v = V$ (Fig. 3c).

AUTOMATIC SCALE EXPANSION

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In the circuit of Fig. 2, the sign of de/dt is indicated by the initial positions of S-1 and S-2 and the sequence of operating the "Zero" and "V" switches. A continuing sequence of V, Zero, V, Zero, V, Zero, etc., indicates constant sign of de/dt. When either switch is operated twice without the operation of the alternate switch interposed, a change in the sign of de/dt is indicated. Also, each additional operation of the switch under the above conditions corresponds to an additional change of sign of de/dt.

Figure 4 is a generalized schematic representation of the subject of this discussion. We call the automatic device which operates S-1 and S-2 of Fig. 2 a "Lobetrol" (from "lobe" and "control" - it's not much of a brain, just a small lobe - a few habits, a one item memory, a dull conscience)[3].

The Lobetrol senses the responds to the conditions a, b, and c listed under Basic Scale Expansion Circuit. Condition "a" is met by reversing the position of S-1 each time the "Zero" switch is operated (at $e_v = 0$). When the "V" switch is operated (at e_v + V+) the Lobetrol must decide whether condition (b) or condition (c) applies, and act accordingly. If S-1 is in normal (plus) position and the voltmeter pointer is moving toward "V" an increasing e_{in} (input voltage) is indicated. Therefore, if S-1 is <u>plus</u> when the V switch is closed S-1 is reversed and S-2 is stepped up. If S-1 is minus and the voltmeter pointer is moving toward V a decreasing e_{in} is indicated. Thus if S-1 is minus when the V switch is closed S-1 is reversed and S-2 is stepped down.

A relay controlled by the position of S-1 chooses either the step-up or the step-down mechanism and the operation of this relay is delayed to prevent a change in choice while S-2 is stepping.

THE SELF-BALANCING RECORDING POTENTIOMETER

The voltmeter we use in the scale expansion system is a self-balancing, recording potentiometer (commonly called a recorder). Recorders are being mass-produced by several manufacturers and are built with a variety of characteristics. Specifications of the instruments we use with this scale expanding accessory include:

Range:	-1 through zero to + 11 millivolts.
Accuracy:	better than 0.25 percent.
Chart width:	approximately 10 inches.
Maximum pen speed:	10 inches per second.

The elements of a recorder are displayed schematically in Fig. 5. The amplifier (in the position of the galvanometer in the usual potentiometer circuit) senses the direction of unbalance and drives the motor in the direction to correct the unbalance. The chart is driven by a choice of:

1. Synchronous motor
2. Synchro
3. Balancing motor (such as drives the pen).

Leeds and Northrup Company refers to the direction of motion of the pens in their Speed-O-Max recorders as the "x" direction; thus the chart moves in the "y" direction. With a synchronous motor drive, $y = kt$. The pen position is proportional to the input voltage, $x = k_1 e_x$. Thus $e_x(t)$ (input voltage as a function of time) is plotted.

When the chart is driven by a synchro, the position of the chart equals $k_2\theta$, where θ is the angular position of the transmitting synchro. A rack and pinion can be used to convert "s" (distance) into angle "θ" so that $e_x(\theta)$ or $e_x(s)$ may be plotted.

When the chart is coupled to a self-balancing potentiometer, similar to the system driving the pen, $y = k_3 e_y$ and $e_x(e_y)$ is plotted. We use this combination to draw magnetization curves automatically. A motor drives a potentiometer in the magnet current regulator circuit to increase the current uniformly; a 200 millivolt shunt in series with the magnet winding is the source of e_y, while e_x is the voltage drop in a bismuth resistor whose resistance is a function of magnetic field. A curve equivalent to a 48 inch by 48 inch graph can easily be folded within an 8 inch square when both e_x and e_y are expanded with Lobetrols. See Fig. 6.

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2. A. J. Williams, Jr., Electronic Recorder With Range and Precision Adequate for the Platinum Resistance Thermometer, Communication and Electronics (AIEE), No. 2, p. 289, Sept. 1952 (includes a bibliography).
3. UCRL Drawing 3V8665, Magnetic Measurements Lobetrol Schematic.

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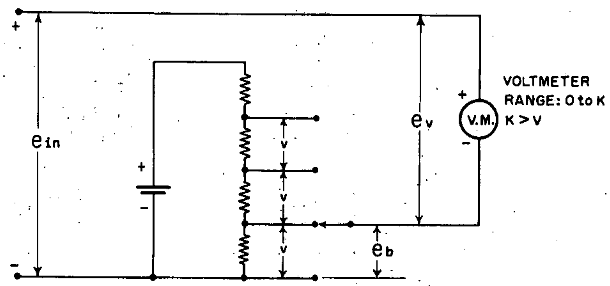

FIGURE 1

SIMPLE SCALE EXPANSION (ZERO SUPPRESSION) CIRCUIT.

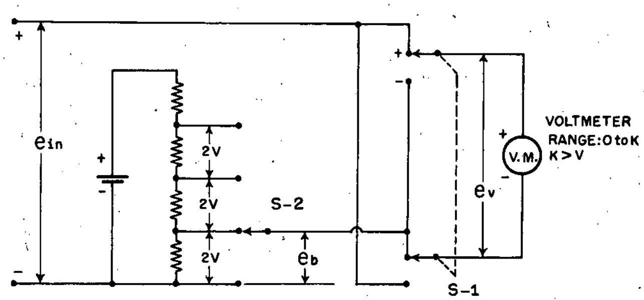

FIGURE 2

"UP AND DOWN" SCALE EXPANSION CIRCUIT.

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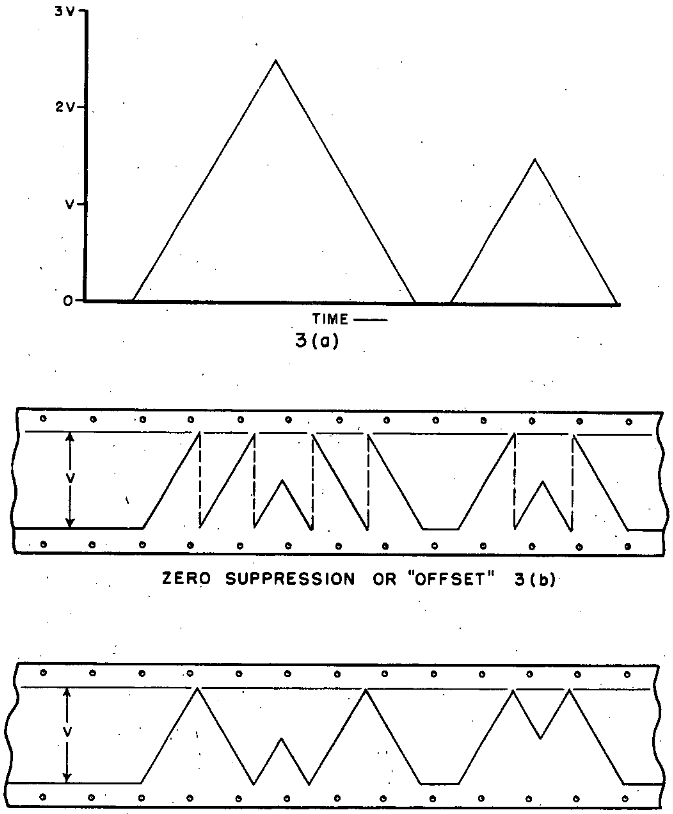

3(a)

ZERO SUPPRESSION OR "OFFSET" 3(b)

"UP AND DOWN" OR "FOLDED" 3(c)

FIGURE 3
HOW NARROW CHARTS DISPLAY HIGH RESOLUTION DATA.

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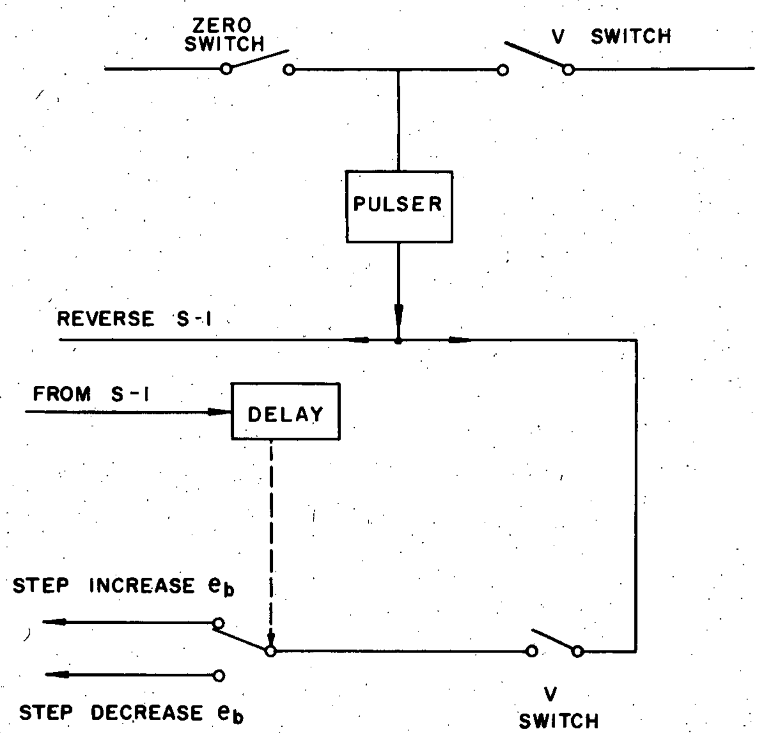

Fig. 4---Schematic Representation of Lobetrol's System for Automatic Range Extension.

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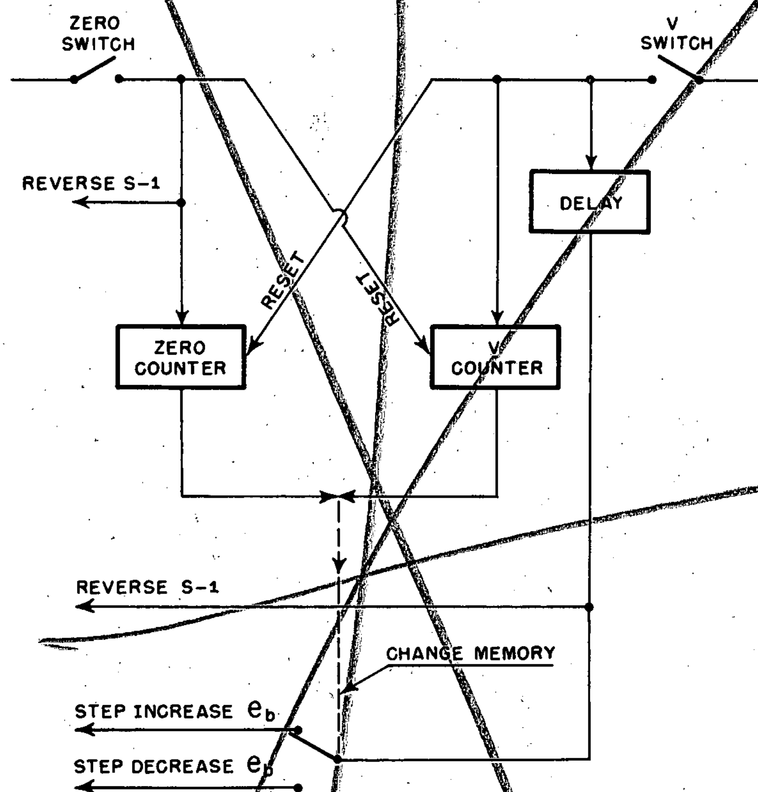

FIGURE 4

SCHEMATIC REPRESENTATION OF LOBETROL'S SYSTEM FOR AUTOMATIC RANGE EXTENSION.

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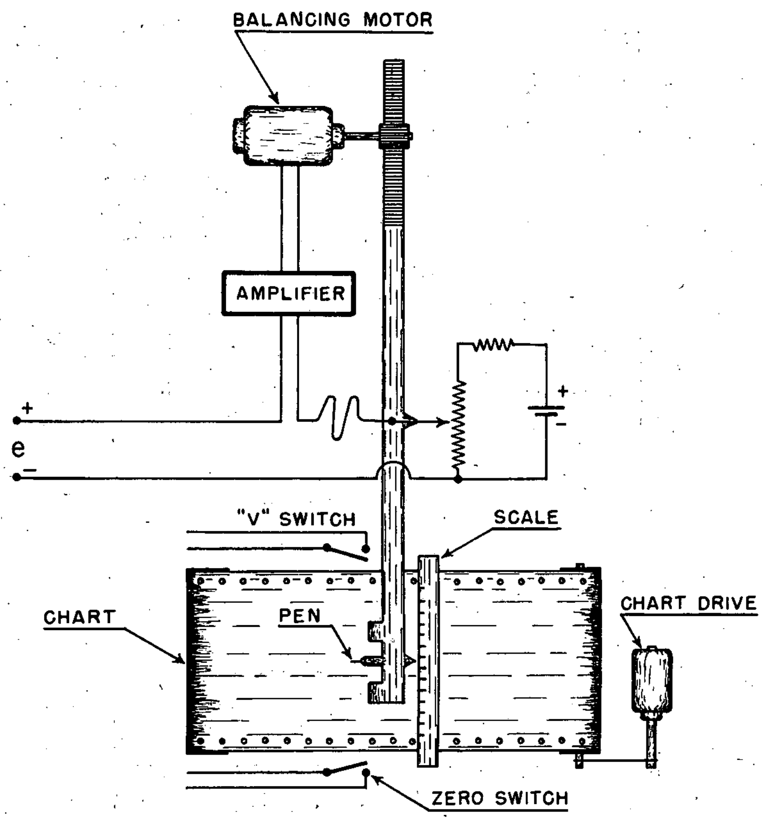

FIGURE 5

ELEMENTS OF SELF-BALANCING RECORDING POTENTIOMETERS.

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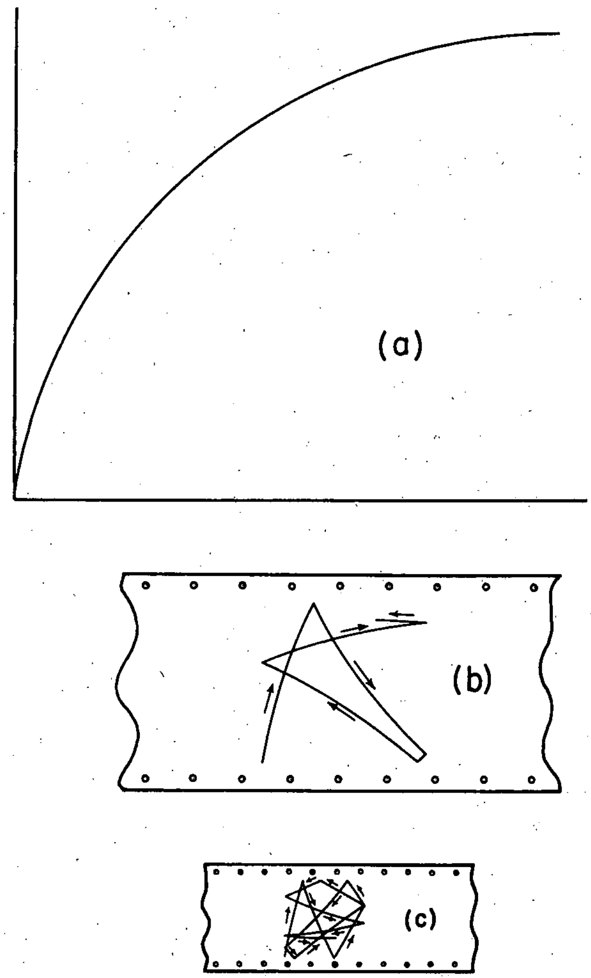

FIGURE 6

COMPARISON OF CONVENTIONAL AND FOLDED PLOTS
(THE RESOLUTION IS THE SAME IN a, b AND c)

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