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.

Sequence	e_{in}	e_b	S-1	Relation	e_v
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.

(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].

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 and "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 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. The following example will describe how that is done.

The operator initially sets S-1, S-2, the direction memory, and the counters. Typically S-1 is set to +, S-2 is set to $e_b = 0$, the direction memory is set to "increase" and the counters are reset to "no count". This set of initial conditions is obtained by pressing a single reset button. If the Lobetrol is operated without these initial conditions, the "dull conscience" mentioned above will sense a "wrong" combination and will find the input voltage with a "proper" combination of switch and counter positions. It takes some time for the conscience to act, however.

When a voltage of, say, 2.5V is connected to the input, the voltmeter indicator will move to V, close the "V" switch, and:

1. A resetting impulse is applies to the "Zero" counter,
2. A count is registered on the "V" counter,
3. An impulse is sent to S-1 to reverse its polarity,
4. An impulse is sent to S-2 to increase e_b one step from 0 to 2V.

Now $e_{in} = 2.5V = e_b - e_v$, $e_b = 2V$, $e_v = -0.5V$, and the voltmeter indicator will move down-scale.

When the voltmeter indicator passes zero, the "zero" switch will operate and:

1. Reset the "V" counter,
2. Register a count on the "Zero" counter,
3. Change S-1 to + polarity.

Now $e_{in} = e_b + e_v = 2.5V = 2V + 0.5V$.

The indicator will move to 0.5V. The potential, $e_{in} = 2.5V$, is indicated by the positions of S-2, S-1, and the voltmeter indicator.

When e_{in} is reduced to zero, the voltmeter indicator will move below zero, again closing the "Zero" switch, and thus:

1. Send a resetting impulse to the "V" counter,
2. Register a count on the "Zero" counter - the second and each subsequent count on a counter sends an impulse which reverses the position of the switch in the direction memory, therefore, S-2 is changed to "decrease",
3. Change S-1 to - polarity.

Now $e_{in} = 2V - e_v = 0$, and, therefore, $e_v = 2V$.

When the voltmeter indicator passes V, the "v" switch will:

1. Reset the "Zero" counter,
2. Register a count on the "V" counter,
3. Change S-1 to + polarity,
4. Step e_b to zero (the direction memory switch is in the decrease position).

Now $e_{in} = 0 + e_v$, ev = 0, and the voltmeter indicator moves to zero.

Because the "Zero" and "V" switches are set to operate slightly below zero and slightly above V, the switches will remain in the above condition.

If, now, 1.5V is applied to the input, $e_{in} = 1.5V = 0 + e_v$, and $e_v = 1.5V$. The voltmeter indicator will move past V thus operating the "V" switch which will:

1. Send a resetting impulse to the "Zero" counter,
2. Change S-1 to - polarity,
3. Register a count on the "V" counter - this is the second count since reset and an impulse is sent to change the memory to "increase".
4. Step S-2, increasing e_b to 2V. The stepping impulse through the direction memory is delayed to permit the counter to act on the memory before S-2 is stepped. The impulse to S-1 is also delayed to prevent a sudden change in the voltage applied to the voltmeter.

Now $e_{in} = 1.5V = e_b - e_v = 2V - e_v$, $e_v = 0.5V$, and the indicator moves to 0.5V.

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 is 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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3. UCRL Drawing 3V8665, Magnetic Measurements Lobetrol Schematic.

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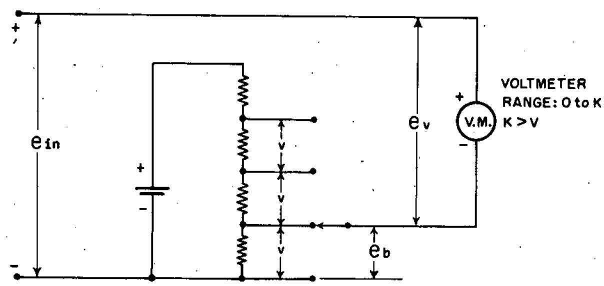

FIGURE 1

SIMPLE SCALE EXPANSION (ZERO SUPPRESSION) CIRCUIT.

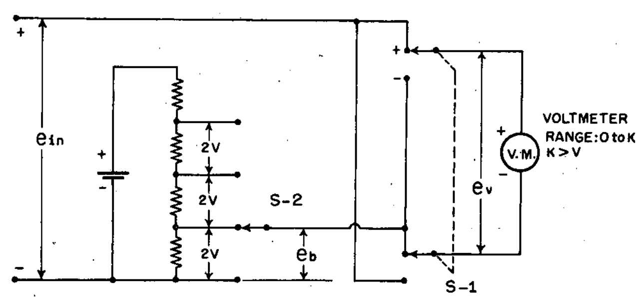

FIGURE 2

"UP AND DOWN" SCALE EXPANSION CIRCUIT.

MU-4817

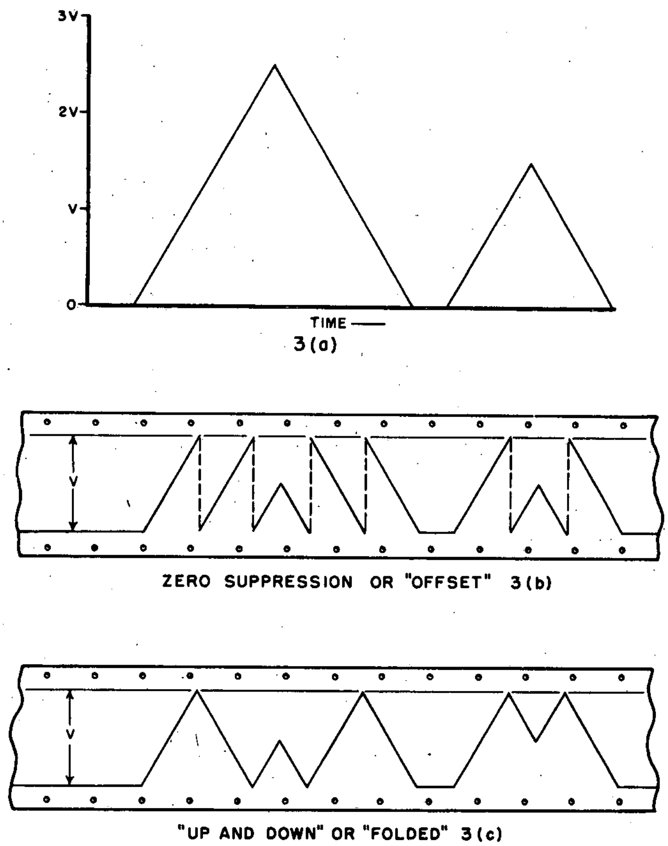

FIGURE 3
HOW NARROW CHARTS DISPLAY HIGH RESOLUTION DATA.

MU-4818

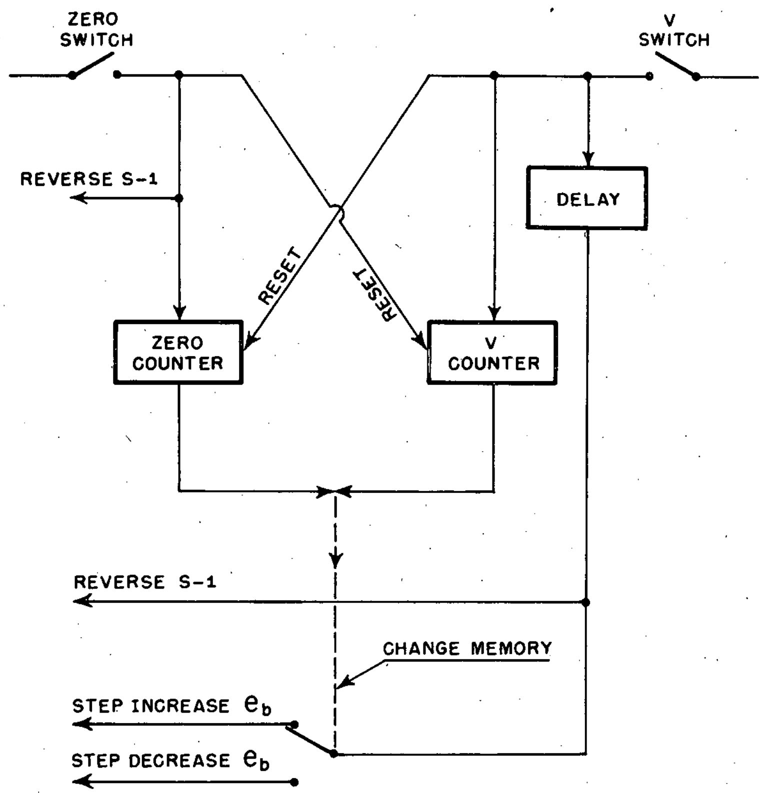

FIGURE 4

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

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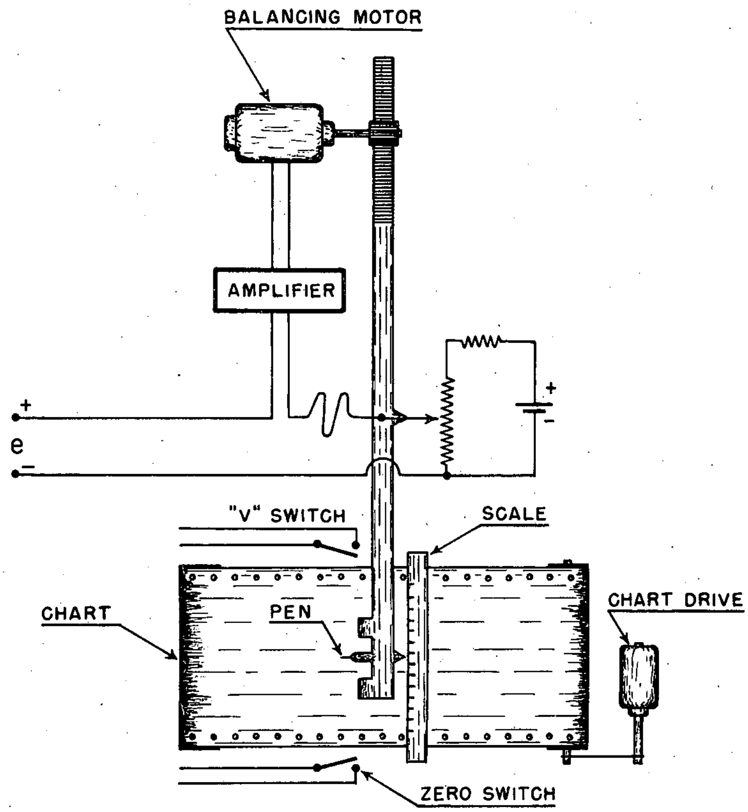

FIGURE 5

ELEMENTS OF SELF-BALANCING RECORDING POTENTIOMETERS.

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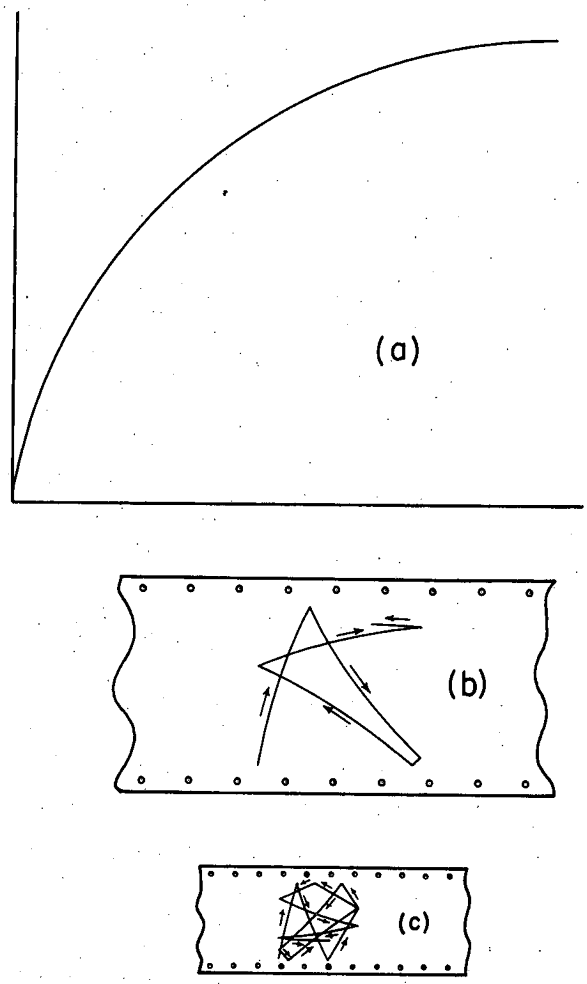

FIGURE 6

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

MU-4821