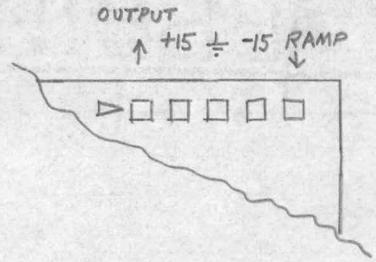
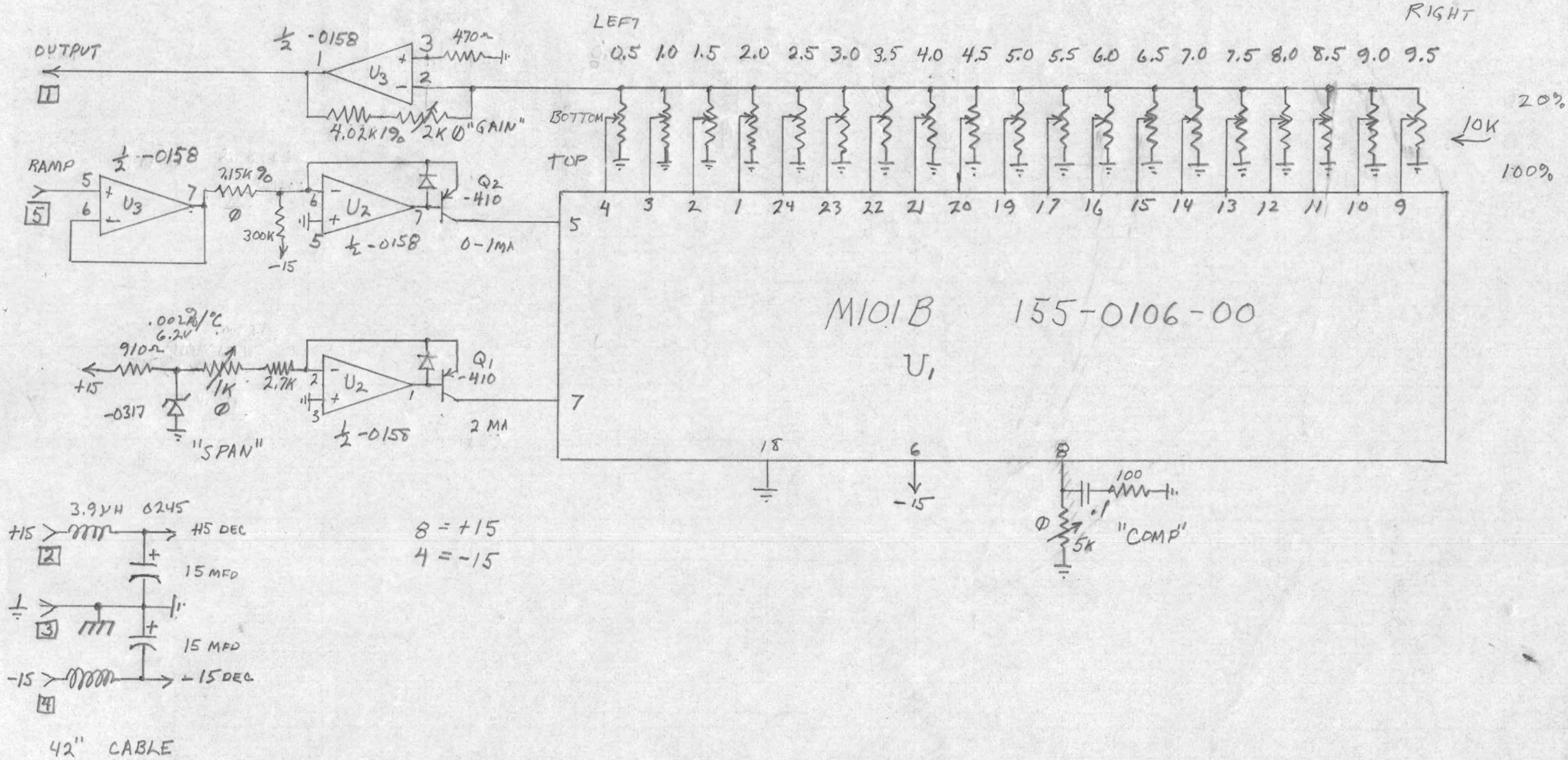
INPUT	GAIN	DRIVE
	100%	0V
	20%	≈ 5V
	0%	≈ 6.25V





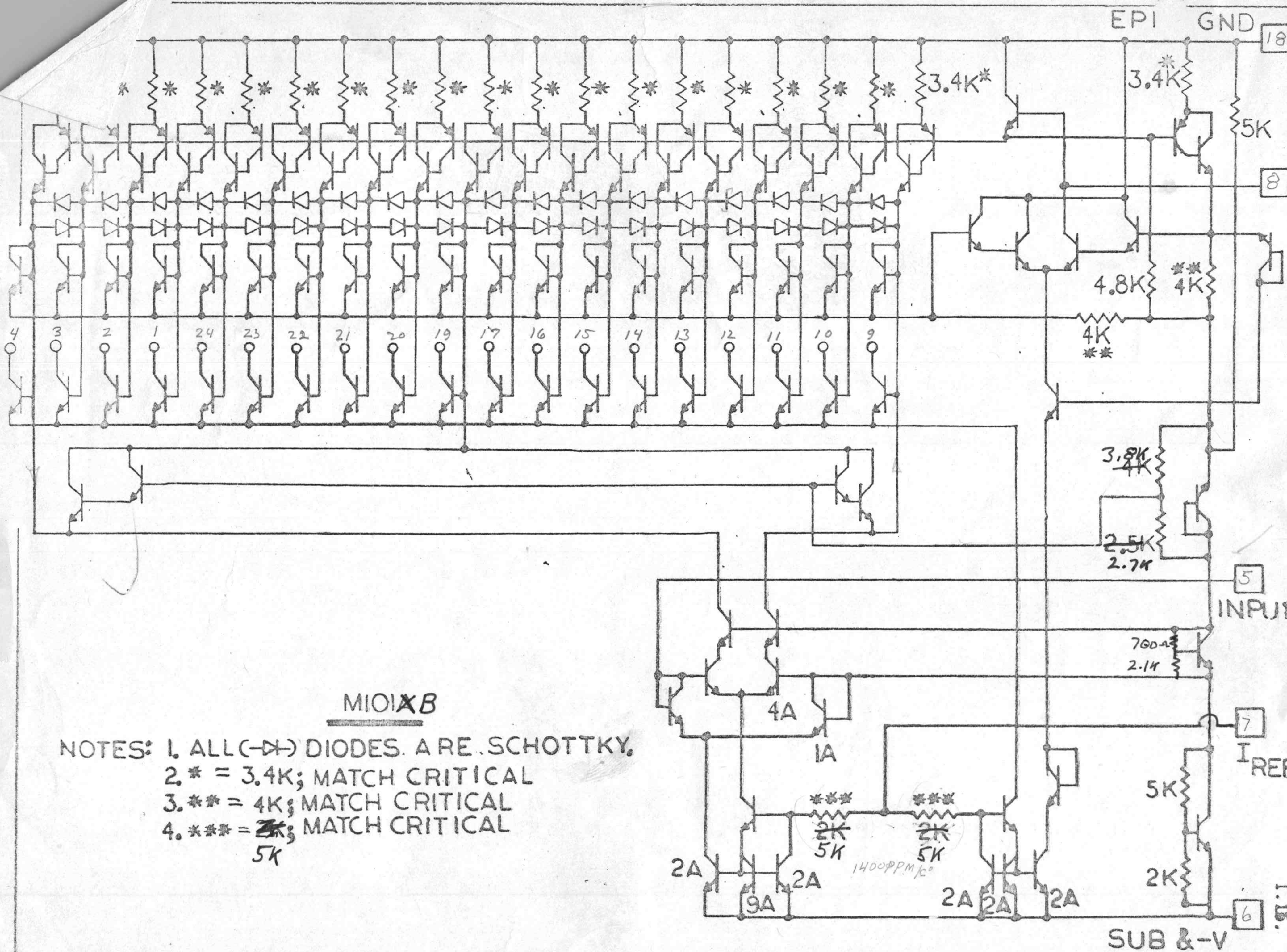
EXTERNAL NORMALIZER

R J McCoy 6-27-73
9-27-73
11-15-73
12-18-73

670-2280

ELECTRICAL CHARACTERISTICS (0°C TO 70°C)

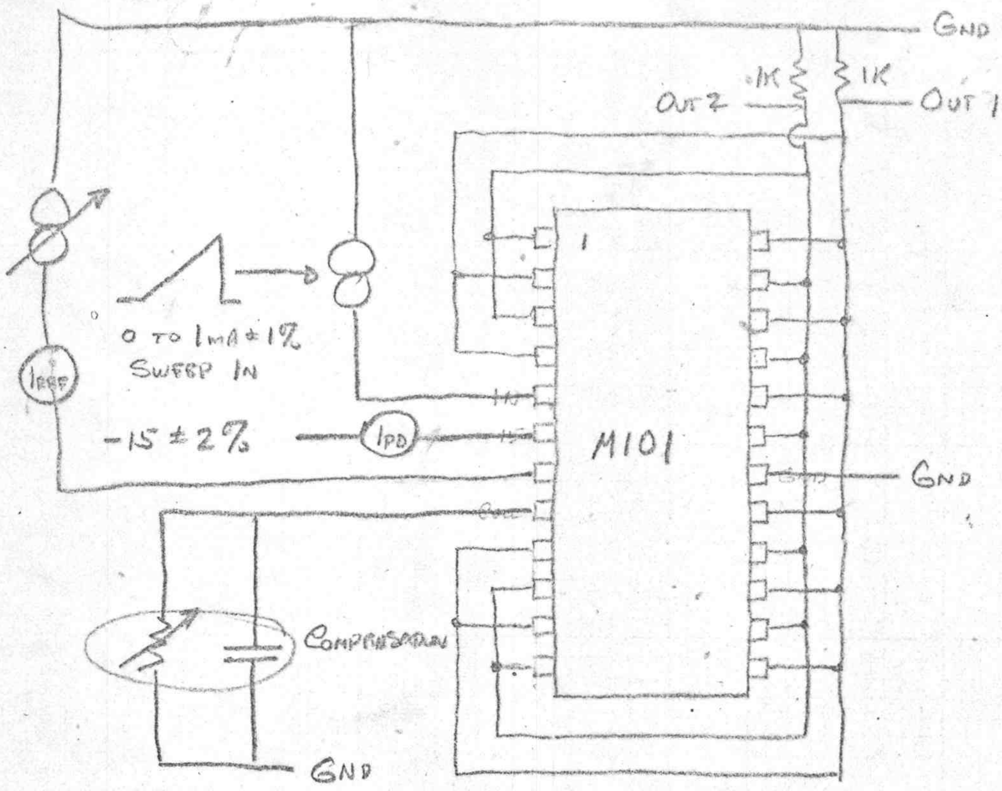
PARAMETER	DESCRIPTION	TEST CONDITION	LIMITS	UNITS
IREF	REFERENCE CURRENT	FIG. 1	1.9 TO 2.1	mA
VOH	MINIMUM OUTPUT HIGH VOLTAGE	FIG. 1 (MEASURE BOTH OUTPUTS)	0.9 TO 1.25	VOLTS
VOL	MAXIMUM OUTPUT LOW VOLTAGE	FIG. 1 (MEASURE BOTH OUTPUTS)	≤ 0.01 (.05) depends on compensation setting	VOLTS
ΔVOH	MAXIMUM VARIATION IN VOH BETWEEN OUTPUTS	FIG. 1 (MEASURE BOTH OUTPUTS)	≤ 0.05	VOLTS
INPUT LINEARITY		FIG. 1 EXPAND 10X HORIZONTALLY & MEASURE HORIZONTALLY BETWEEN OUTPUTS	10 DIVS ± 1 DIV	
IPD	-15 VOLT SUPPLY CURRENT	FIG. 1	≤ 25 mA	

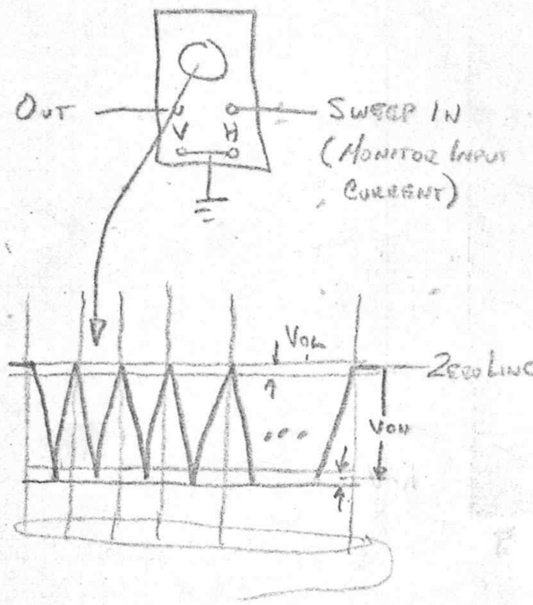


MIOIXB

NOTES: 1. ALL (-▷|-) DIODES ARE SCHOTTKY.
2. * = 3.4K; MATCH CRITICAL
3. ** = 4K; MATCH CRITICAL
4. *** = ~~2K~~ 5K; MATCH CRITICAL

FIG. 1

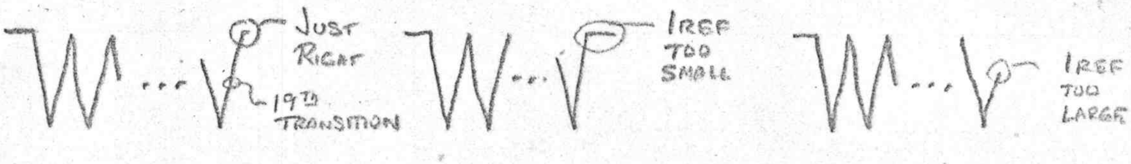




SCOPE GRATICULE LINES

MEASUREMENT PROCEDURE

1. ADJUST VCC TO 15 ± 2% VOLTS
2. ADJUST INPUT SWEEP TO 0 TO 1mA ± 1%
3. ADJUST IREF UNTIL 19TH TRANSITION IS JUST COMPLETE –



4. ADJUST COMPENSATION FOR MAX AMPLITUDE UNTIL JUST BEFORE TALLEST PEAKS (USUALLY NEAR CENTER OF SWEEP) START TO FLATTEN
5. RECHECK 3, THEN 4, THEN 3 ETC.
6. LEAVE IREF ADJUSTED AS ABOVE WHEN MAKING ALL MEASUREMENTS

Eng Proposal

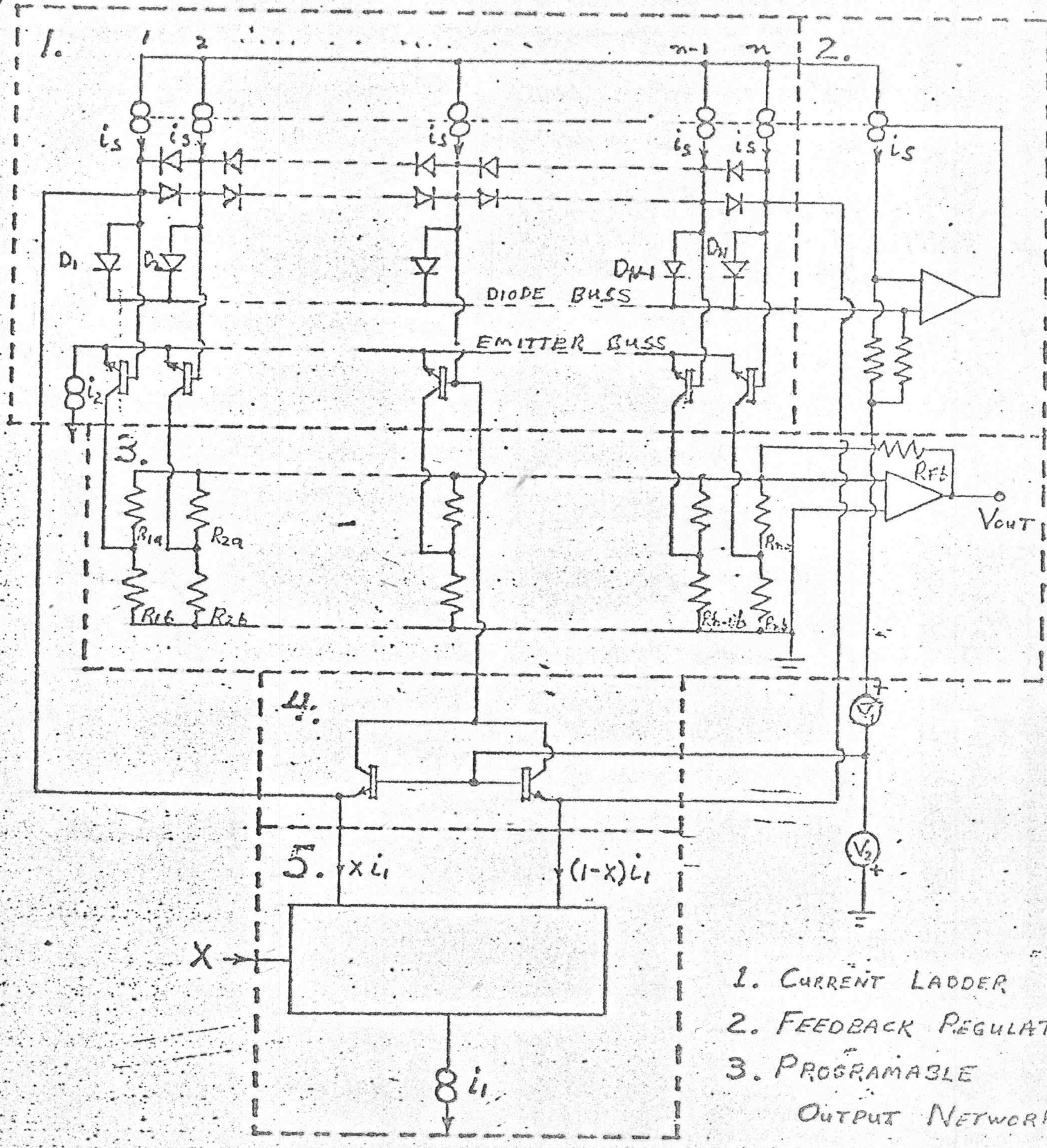
ATTACHMENT

John Pace

1. The invention is a technique for making a programable function generator, suited to, but not restricted to, construction in integrated circuit form. It produces an output current or voltage which is a programable function of an input voltage or current at n evenly spaced values of the input voltage or current. For values of the input signal between the n points, the output is a linear interpolation between the output values at the nearest points. The programing of each point is independent of all other points, and the output at any point can be established by the ratio of two resistors.

Included is a technique for making compensated current sources for integrated circuits.

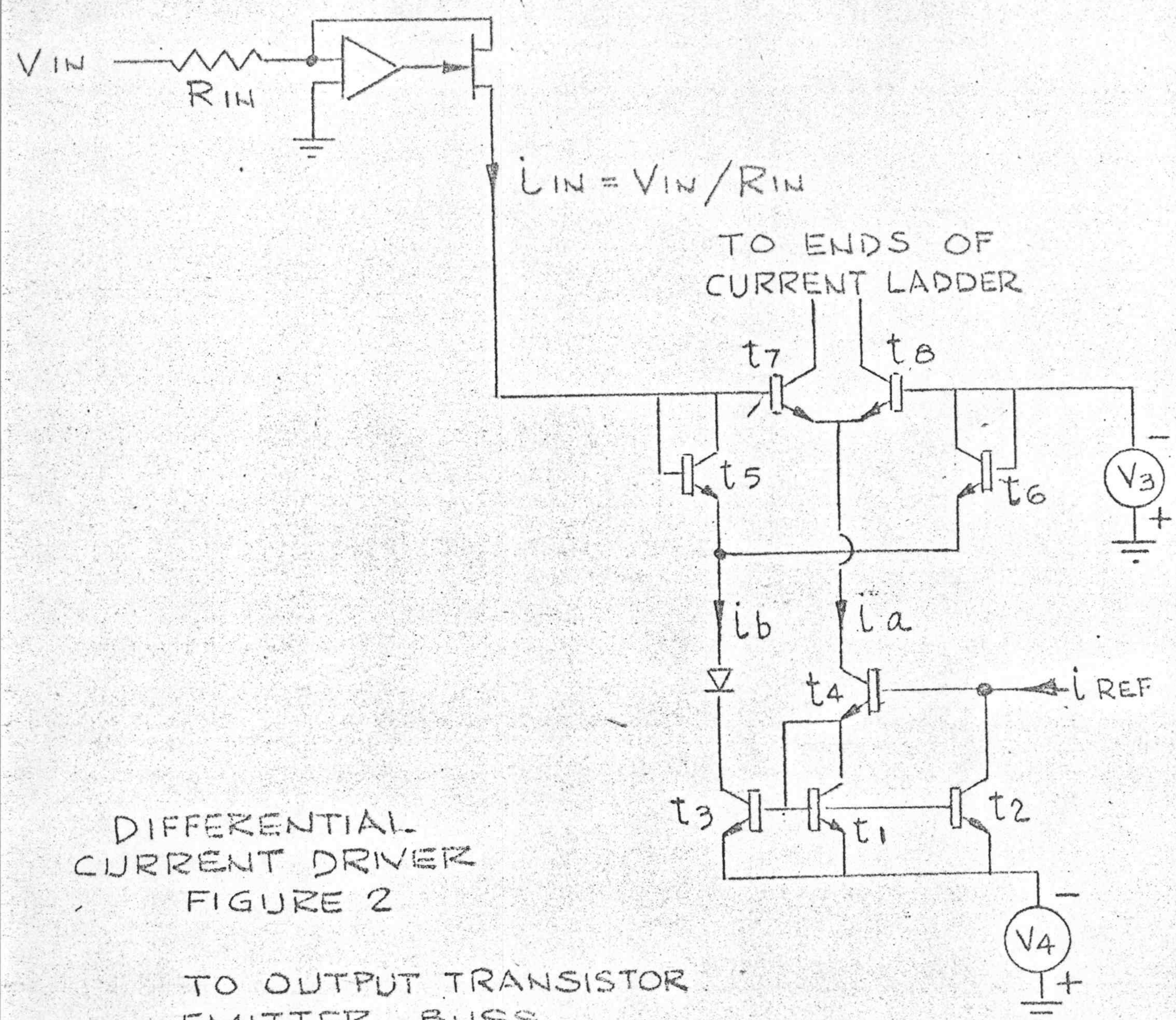
PROGRAMABLE FUNCTION
GENERATOR SYSTEM



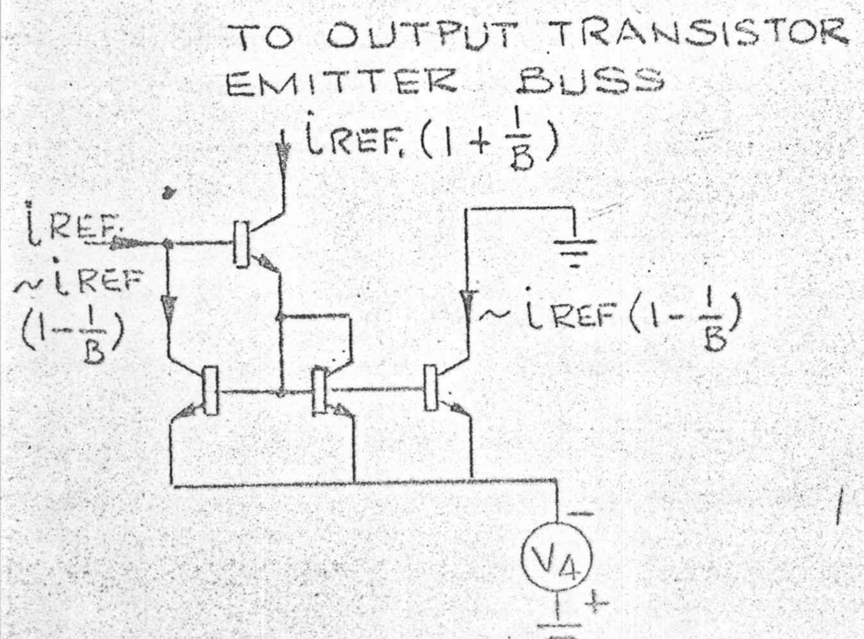
1. CURRENT LADDER
2. FEEDBACK REGULATOR
3. PROGRAMABLE OUTPUT NETWORK
4. VOLTAGE LIMITER
5. DIFFERENTIAL CURRENT DRIVER

Figure 1

John W. Pace
9-29-71



DIFFERENTIAL CURRENT DRIVER
FIGURE 2



COMPENSATED CURRENT SOURCE
FIGURE 3

3. The system is outlined in Figure 1. Block number 1 of the drawing is a current ladder. It consists of n identical current sources, the outputs of which are connected to each other horizontally by pairs of diodes. Each current source output also drives the anode of a diode (which may be a diode-connected transistor), the cathode of which goes to a common buss, and to the base of a transistor whose emitter is also connected to a buss.

Block number 2 is a regulator consisting of a current source identical to those in block number 1, a pair of matched resistors, and a differential voltage amplifier whose output controls the amount of current delivered by the current sources. The regulator's function is to maintain the total current ladder equal (or nearly equal) to the current from one current source.

Block number 3 is the programable output network which consists of current dividers R_{1a} and R_{1b} through R_{na} and R_{nb}. Each divider splits the current from a transistor's collector between ground (or some other reference voltage) and, in this case, the input of an operational amplifier which converts the current into a voltage.

Block number 4 is a voltage limiter which is used to prevent the voltage from either end of the current ladder to the diode or emitter buss from exceeding the reverse breakdown voltage of the base-emitter junctions. This regulator permits the current ladder to be longer (that is, n is larger) and therefore there can be more programing points than otherwise would be possible. The voltage regulator functions by diverting current from the center of the current ladder when the voltage at one of the ends of the ladder gets negative enough to turn on one of the regulator transistors, thus preventing the voltage at that end from going much more negative until the regulator transistor is saturated.

Block number 5 is a differential current driver. Its function can be explained as follows: Let the input to the system be X and let X take on any value from 0 to +1. Let i_1 be a constant source of current. Then the differential current driver will (in this case) sink currents of (Xi_1) and $(1-X)i_1$ for driving the ends of the current ladder.

Figure 2 shows one way in which a differential current driver has been realized for use in an integrated circuit. An operational amplifier circuit converts an input voltage of 0 to V_{in} max to a current of 0 to i_{in} max. A precision reference current, i_{ref}, is fed into a current mirror circuit. Let $i_{ref} = i_{in}$ max. Let the β of all transistors be the same. By design, let i_a be some constant factor, y, times as great as i_{ref}. Then the collector current of transistor t_2 is equal to $i_{ref} - i_a/\beta$:

$$i_{c2} = i_{ref} - \frac{i_a}{\beta}$$

Also, if the transistors t_2 and t_3 are identical and have the same collector voltage, then their collector currents will be the same:

$$i_b = i_{c2} = i_{ref} - \frac{i_a}{\beta}$$

Thus, the current source i_b will very nearly compensate for the fraction of i_{in} which is diverted to transistor t_7's base, so as i_{in} varies from 0 to i_{ref}, the current $i_a - i_a/\beta$ will move very linearly from the collector of t_8 to the collector of t_7. This system effectively compensates for the errors normally created by finite β of the transistors, and by the variations of that β with temperature.

Refer to Figure 1: The best way to understand the operation of the system is to first imagine that X = 1, so that all the current to the differential current driver is coming out the left end of the current ladder and none is coming out the right end. Since the current sources in the current ladder have been regulated to force the current in the diode bus to equal the current from one current source, i_s, then

$$i_1 = (n - 1)\, i_s,$$

and the output of the n'th current source is all passing through D_N to the diode buss. The voltage at the anode of D_N also appears at the base of the corresponding transistor. As we move to the left from D_N, we find that the voltages at the anodes of the diodes and at bases of the transistors get progressively more negative because the current from the other current sources must pass through a string of diodes as it moves to the left. Since the transistor on the right side of the current ladder has the most positive base, the current i_s will pass through its collector to the junction of programing resistors R_{na} and R_{nb}.

Next, assume that the input X has decreased to the point where a current $i_s/2$ is flowing out the right side of the current ladder and a current $(n-1)\, i_s - i_s/2$ is flowing out the left side. Then a current $i_s/2$ is flowing through diode D_N to the diode buss, so a current $i_s/2$ must be flowing through diode D_{N-1} to satisfy the regulator. The transistor bases connected to D_N and D_{N-1} will then be at the same potential, so i_2 will be split evenly between the two transistors; $i_2/2$ will go to R_{na} and R_{nb}, and $i_2/2$ will go to $R_{(n-1)a}$ and $R_{(n-1)b}$. The output voltage will be

$$V_{out} \cong R_{Fb} \cdot i_2 \left(\frac{R_{nb}}{2(R_{na} + R_{nb})} + \frac{R_{(n-1)b}}{2(R_{(n-1)a} + R_{(n-1)b})} \right).$$

Now imagine that X decreases even further such that a current equal to i_s flows out the right side of the current ladder. Almost all of this current will come from the first current source. The anode of diode D_{N-1} will be the most positive in the string, so all of its associated current source i_s will flow through it. Therefore, all of i_2 will go to the junction of $R_{(n-1)a}$ and $R_{(n-1)b}$. The output voltage will be

$$V_{out} \cong R_{Fb} \cdot i_2 \cdot \left(\frac{R_{(n-1)b}}{R_{(n-1)a} + R_{(n-1)b}}\right).$$

As X varies from 1 down to 0, the current i_2 moves linearly from one current divider to another, from left to right, and the output will vary in a manner established by the ratios of R_{1a} and R_{1b} through R_{na} and R_{nb}.

Obviously, if B is finite in the transistors, a fraction of i_2 will be lost to the bases; that is

$$V_{out} \alpha\ i_2 \cdot \left(\frac{1}{1 + \frac{1}{\beta}}\right).$$

To prevent the output from changing with temperature because of β variation with temperature, the circuit in Figure 3 was used for i_2 to compensate for the β term. The function of this circuit is the same as the current source for the differential current driver.

Other methods of making programable function generators include diode function generators, servo motor driver switches, cams, and drums, and digital memory systems with analog-to-digital and digital-to-analog converters. The diode-type generators are difficult to program and do not have independent adjustments at each program point. They are usually somewhat sensitive to temperature variations. They do have the advantage of adjusting the positions of the "break points", and they are relatively fast. The servo motor systems are usually large, expensive, slow, and they consume considerable power. They can have the advantage of very smooth and versatile transfer functions. The digital systems tend to be expensive in that they require A to D and D to A converters and a digital memory unit. They also have a disadvantage in that the output will vary in discrete steps. The programable function generator described in this disclosure has the advantage of being small and inexpensive - Blocks 1, 2, 4, and 5 in Figure 1 can be put into one or more integrated circuits. It also consumes little power and responds to relatively fast changing input signals. The programing is conveniently done by resistor ratios, and each point is independent of the others. This lends itself to computer programing and other means of precisely, rapidly changing the function. Use with precise 10 turn potentiometers could take advantage of the accuracy and linearity of the system which could be used for simulating many nonlinear functions, as well as linearizing many nonlinear systems.

The inventive features of this system are:

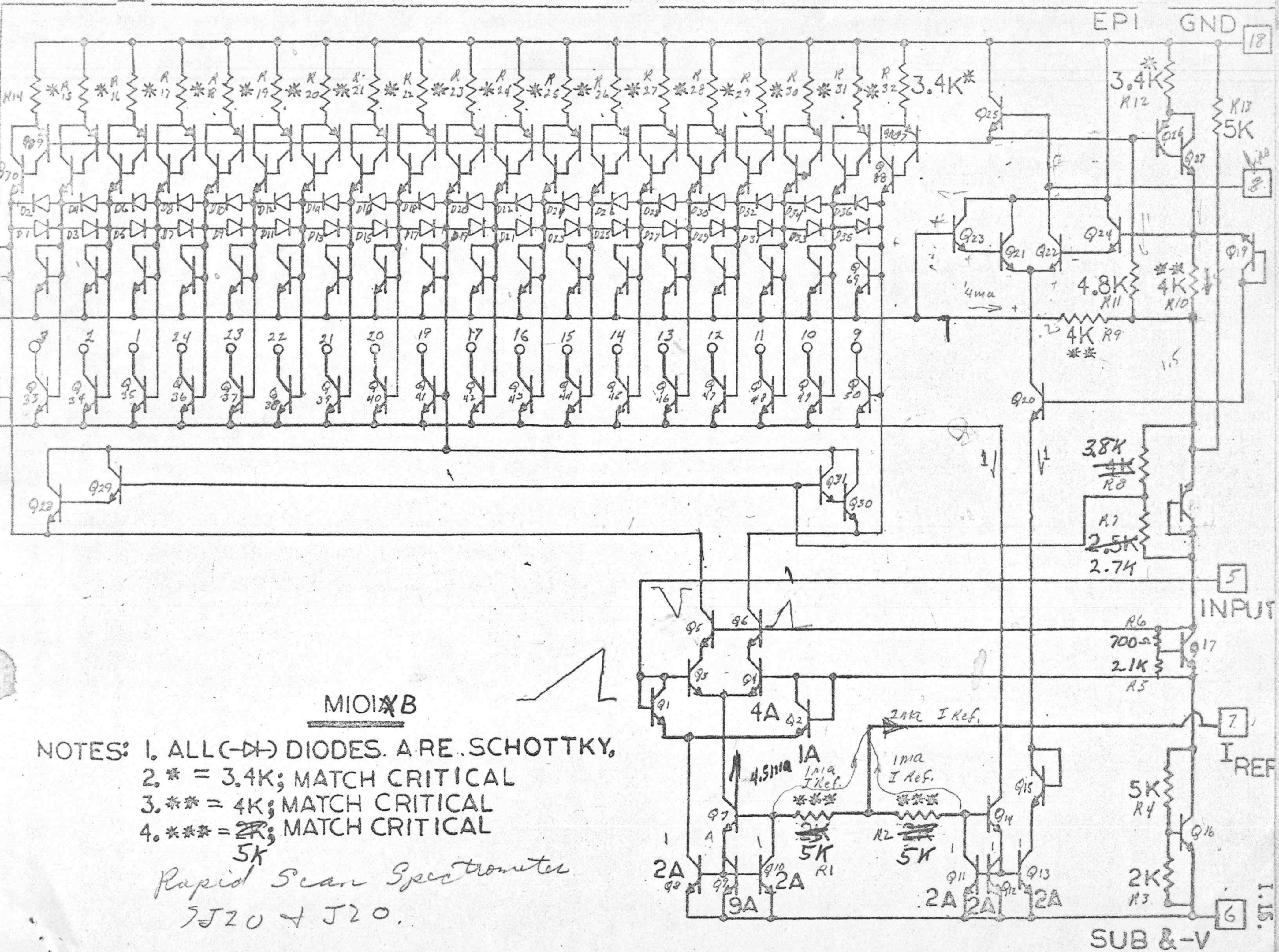
1. The use of current divider resistors and transistors in conjunction with a current ladder to form the unique type of programable function generator. (Invented by Barrie Gilbert) (Disclosure already filed.)

2. The use of a feedback regulator with typical current source to make the system stable, accurate, and very independent of the common mode current from the differential current driver. (Invented by John Pace.)

3. The use of the voltage limiter circuit to make possible a longer current ladder and more programing points. (Invented by John Pace.)

4. The technique for making current sources on integrated circuits with outputs which are, to a good approximation, equal to the input current with an added or subtracted factor proportional to $1/\beta$ or Y/β (where Y is a constant and where β is the common emitter current gain of the transistors) as shown in Figures 2 and 3. (Invented by John Pace.)

4. The exact dates of conception of these inventions are not recorded. The feedback regulator, voltage limiter, and current sources were conceived between the months of March and August 1971. Each of these circuits were tested in breadboard function generators during this period. An integrated circuit function generator employing these circuits has been designed and is, as of December 14, 1971, being fabricated. The schematic diagram for this integrated circuit is dated 9-20-71, revised 9-28-71. My assistant, William C. Stutzman, has witnessed these inventions and their realization in practice. Others with whom the circuits were discussed shortly after conception are Mike Metcalf and George Wilson of Integrated Circuits, Engineering, Tektronix. No engineering notebook was kept.



MI01XB

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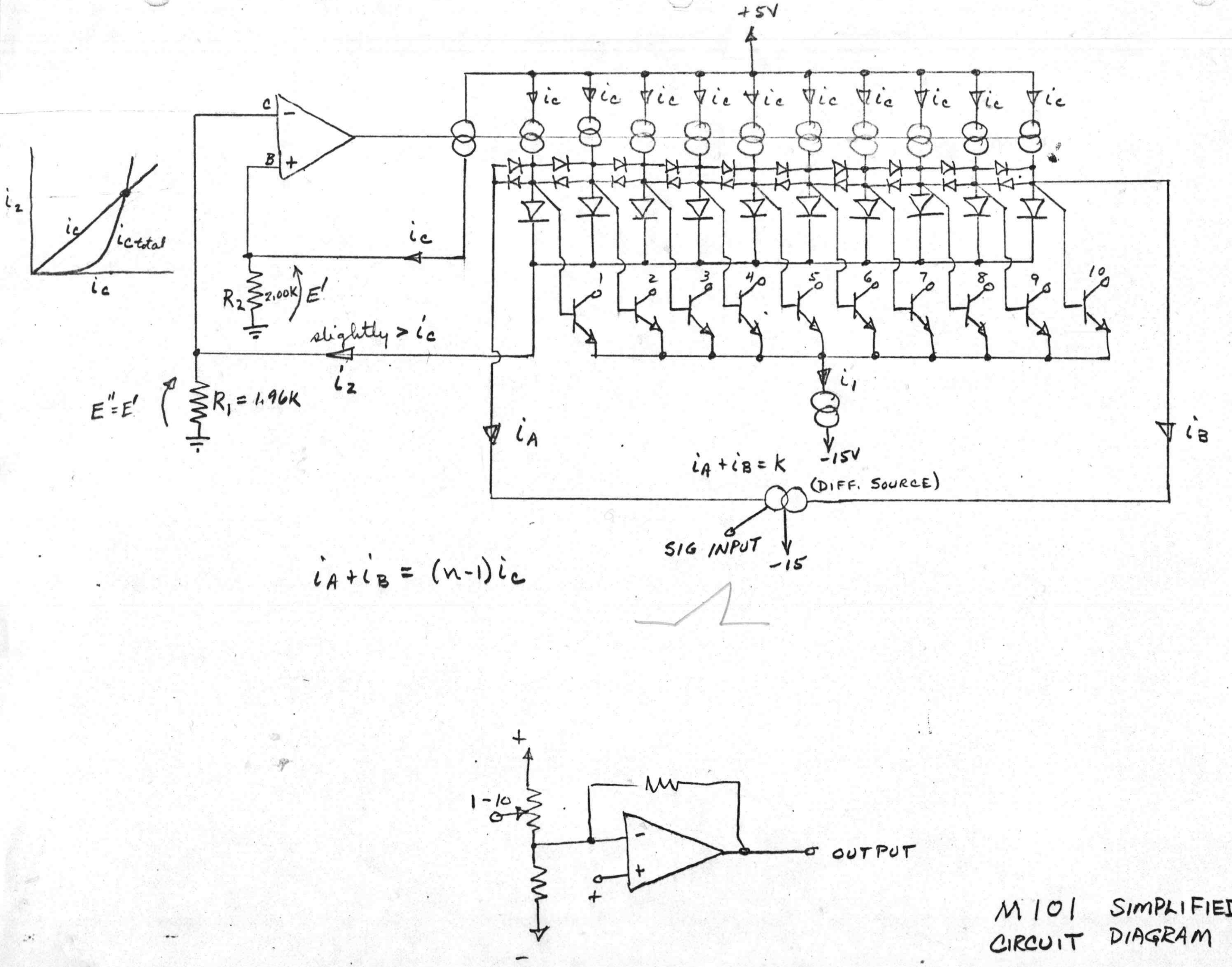
3. ** = 4K; MATCH CRITICAL
4. *** = ~~2K~~ 5K; MATCH CRITICAL

Rapid Scan Spectrometer
SJ20 + J20.

1.15.



M101 SIMPLIFIED CIRCUIT DIAGRAM