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SOLID STATE AMPERE HOUR INTEGRATOR

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ILLUSTRATIONS

SOLID STATE AMPERE HOUR INTEGRATOR

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One of the problems in evaluating satellite battery packs is to determine the ampere hour efficiency accurately. Normally this is accomplished by recording the current rate on a strip chart recorder. The data is then processed by summation of the area under the curve to determine the ampere hours accumulated. This has always been a slow and cumbersome task where the accuracy depended upon the strip chart recorder and was further aggravated by approximations by the personnel performing the function.

This paper describes a solid ampere hour integrator designed for evaluation of space satellite batteries. The integrator has to meet the following requirements:

- The unit is to accumulate ampere hour capacities over the range of .01 ampere rate to 20 ampere rate (in two ranges).
- The accuracy to be better than ±1 percent.
- The accumulated ampere hours to be read directly.
- An output pulse to be available for operation of an external print-out counter.

Since ampere hours represent the product of current and time then the object is to convert this product into units that may be accumulated with time or to put it another way to convert the ampere rate to pulse rate and accumulate these pulses.

Basically the ampere hour integrator is a current to frequency converter. Figure 1 illustrates a power supply, battery, current to frequency converter, and a counter. The current to frequency converter has an output pulse rate directly proportional to the battery charge current. The counter accumulates the total number of pulses and displays this total thereby indicating the accumulated ampere hours.

The ampere hour integrator discussed here is composed of three basic units:

1. Current transformer.
2. Current to frequency converter.
3. Accumulator.

CURRENT TRANSFORMER

Figure 2 illustrates a basic circuit of the current transformer used. Circuit operation is as follows:

Assuming I_1 is the current to be sensed and is zero at this time, and further assuming Q_1 is on, then the transformer is reset to negative saturation. The degree of saturation is controlled by the limiting resistor R_1. I_2 will be zero during this time interval. Turning on Q_2 will cause the core to go toward positive saturation. During this period a small magnetizing current will be indicated by I_2. (It might be noted that N_2 does not saturate). This current (I_2) will be equal to the magnetizing current when I_1 is zero. Now suppose a current I_1 is applied to N_3 in such a direction as to add to I_m, then I_2 will be composed of the initial magnetizing current plus the reflected current of I_1 which is

$$I_2 = I_m + (N_3/N_2)\ I_1$$

This current will be directly proportional to $I_1 + I_m$. I_m is an undesirable component which cannot be eliminated but whose effects can be minimized.

Figure 3 illustrates a circuit whereby this may be accomplished.

Advantage is taken of the Br and Bm characteristics of the transformer core in this circuit. Bm less Br actually represents a stored inductive charge in the transformer T_1. As a result when Q_1 turns "off" an undesirable voltage spike is developed across the windings of the polarity indicated in Figure 3. This voltage is in excess of E_{cc1} and is clamped at Q_2 by diode D_1. This in turn causes the base emitter of Q_3 to bias in the "off" direction. If capacitor C_1 stores this energy then Q_3 will maintain a cut-off bias when $I_1 = 0$. C_1 is now capable of supplying the magnetizing current necessary for N_2. R_2 is adjusted for an equilibrium balance to drain off the excess stored charges of C_1. Now a current I_1 will be reflected to N_2 and will be the major collector current of Q_3. This in turn will induce a voltage on R_3 directly proportional to I_1 and will be

$$E_{R_3} = \frac{a(N_3/N_2)\ I_1}{2}$$

where E_{R_3} = average DC voltage on R_3
a = alpha of Q_3
N_3/N_2 = turns ratio of the transformer
I_1 = current being sensed

R_3 = DC resistance of R_3

At this point the circuit is a "current to voltage converter". Substituting a uni-junction transistor circuit for R_3 will make this a "current to frequency converter."

For the circuit illustrated in Figure 4, the rate of charge of C_2 will be directly proportional to I_1 and the output pulse rate (F_0) will also be directly proportional to I_1. Either a positive going or negative going output pulse is available at Q_4. This in effect comprises the basic circuit of the current to frequency converter portion of the ampere hour integrator.

Figures 5 and 6 illustrate the complete schematic of the ampere hour integrator. Referring to Figure 5, Q_1 and Q_4 and the associated circuitry compose a Royer oscillator as a clock reference and also as the driver for Q_2 and Q_3 of the current sensing circuit. Since the current sensing is uni-directional, two relays, K_1 and K_2 reverse the sensing direction upon closure of the external contacts of J_3. The relays reverse the low current primary windings of T_2 rather than the high current sensing winding. Uni-junction transistor Q_6 converts the ampere rate to pulse rate. These pulses are fed to Q_8 via resistor R_{10}. Q_7 and Q_8 compose a single shot multivibrator whose "on" time is determined by C_6 and R_{15}. The collector load of Q_8 is either a relay K_3 (for operating an external counter) or the self contained counter of the unit.

Two current ranges are incorporated in the unit. The high current range is composed of L_1 and one turn winding on $T_2 \cdot L_1$ is necessary to reduce the effects of external circuit impedance upon the current sensor. This range is from 100 milli-ampere rate to a 25 ampere rate. When the low range is used, the total turns (1 + 9) and both inductors L_1 and L_2 are connected in series. This reduces the range by a factor of 10 or 10 milli-ampere rate to 2.5 ampere rate, thus allowing sufficient overlap of the two ranges.

Figure 7 shows a graphical plot of the counting rate vs sensing amperes.

This is a plot of the high current range. The low current range is an exact replica of this plot if the sensing current scale is multiplied by 1/10. The circuit exhibits excellent linearity from .10 ampere rate to 20 amperes with slight non-linearity below and above this range.

CALIBRATION

Calibration of the instrument is rather simple and is accomplished on the low range. C_7, C_8, and C_9 are selected for the desired count at two amperes sensing current (Figure 5). The low end is then checked at a 20 ma. rate. The low end is adjusted by R_8. Once C_7, C_8, and C_9 have been selected, final trim adjustment at the high end is accomplished at the power supply by R_4 (Figure 6). Since a change in range is essentially a change in ampere turns, both ranges are calibrated simultaneously.

Two regulated power supplies are incorporated (Figure 6), 30 volt regulated supply for the current to frequency converter circuit and a 12 volt simple regulator for the counter and relays. This eliminates interaction of the high current of the counter from the current sensing circuits.

The low range accuracy is better than ± 1 percent from 10 ma. rate to a 2 ampere rate and within ± 2 percent up to 2.5 amperes. The same applies to the high range which is 100 ma. rate to 20 ampere rate (± 1 %) and to 25 amperes (± 2 %).

Figures 8, 9, and 10 are pictures of the Ampere Hour Integrator. Figure 8 shows the Ampere Hour Integrator in a 8 x 8 x 5 case. Figure 9 shows the internal construction and Figure 10 shows the Ampere Hour Integrator mounted in a 19 inch rack panel along with a "print out counter".

The addition of the "print out counter" increases the versatility of the unit. As mentioned previously the sensing direction of the Ampere Hour Integrator can be reversed upon closure of external contacts. "Print out" and "reset to zero" of the print out counter can also be controlled from a remote point, thus permitting remote programing of the Ampere Hour Integrator—Print Out Counter combination.

The use of the ampere hour integrator simplified battery evaluation and also permitted more tests to be conducted simultaneously without materially increasing the work load on the personel. Several units have been in continuous operation for over a year and indicate no significant change in calibration or performance.

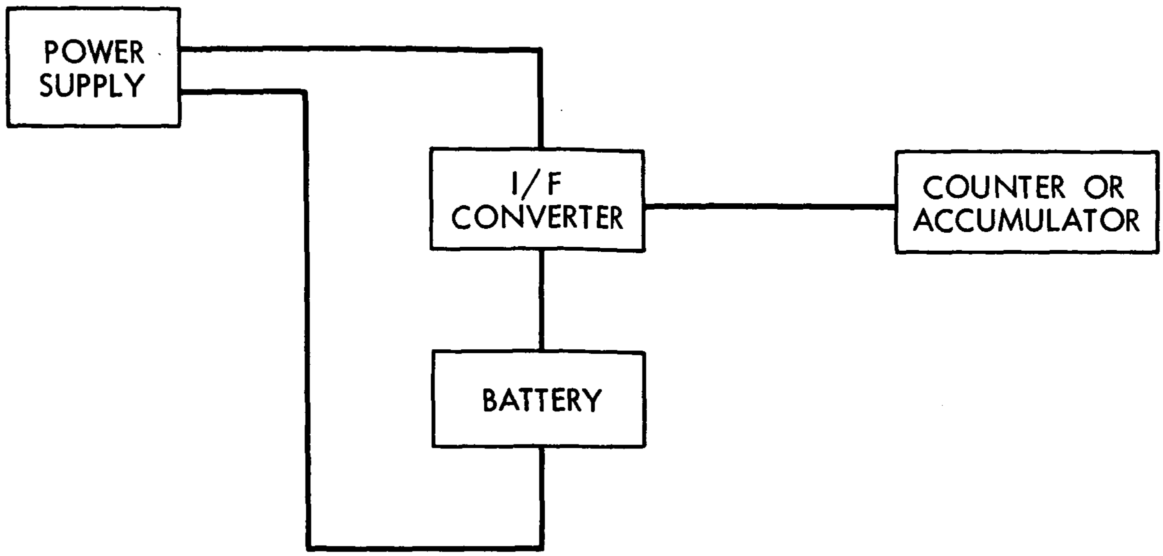

Figure 1 - Block Diagram of Ampere Hour Integrator

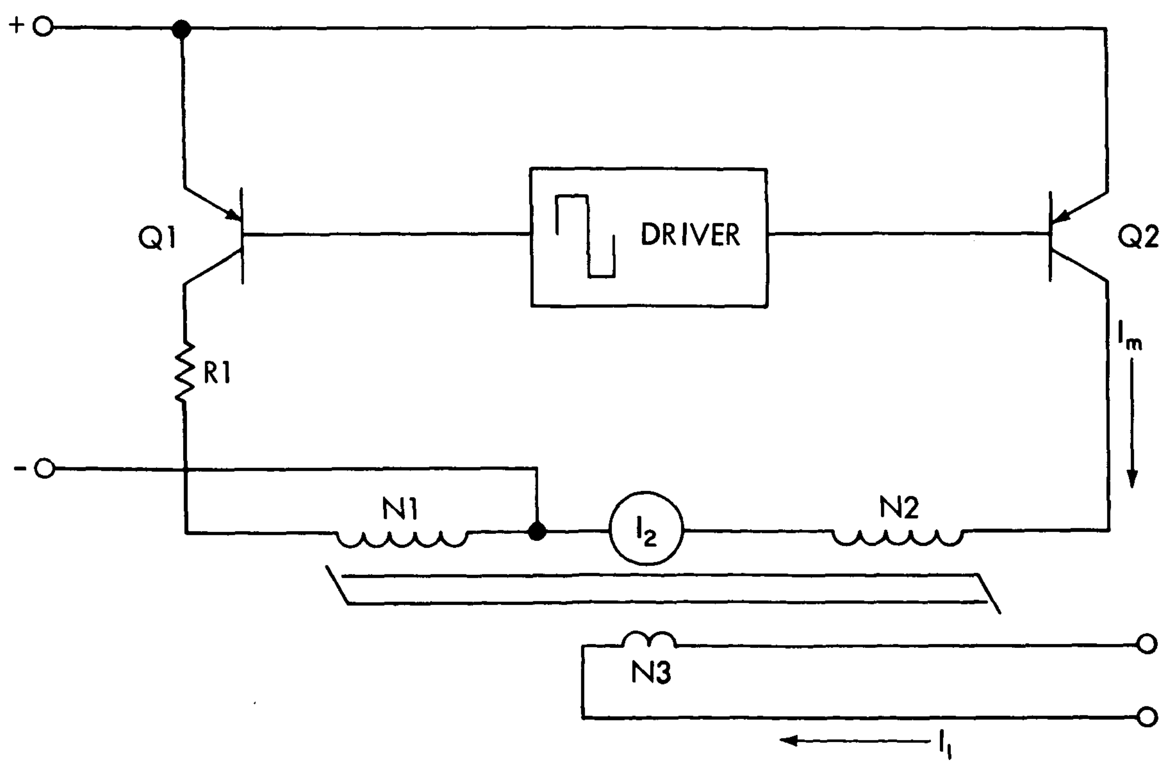

Figure 2 - Current Transformer Circuit

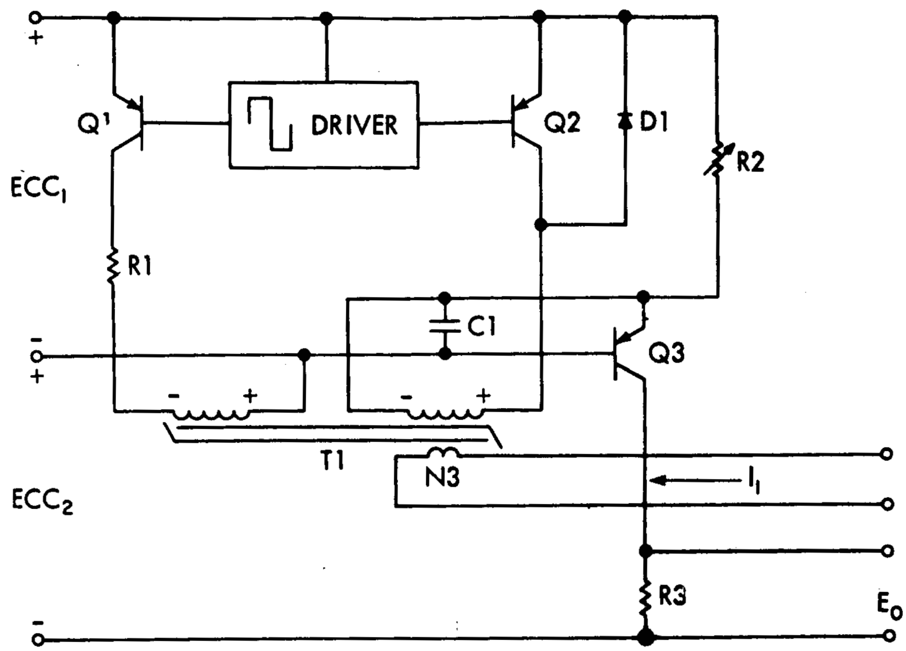

Figure 3 - Current to Voltage Converter

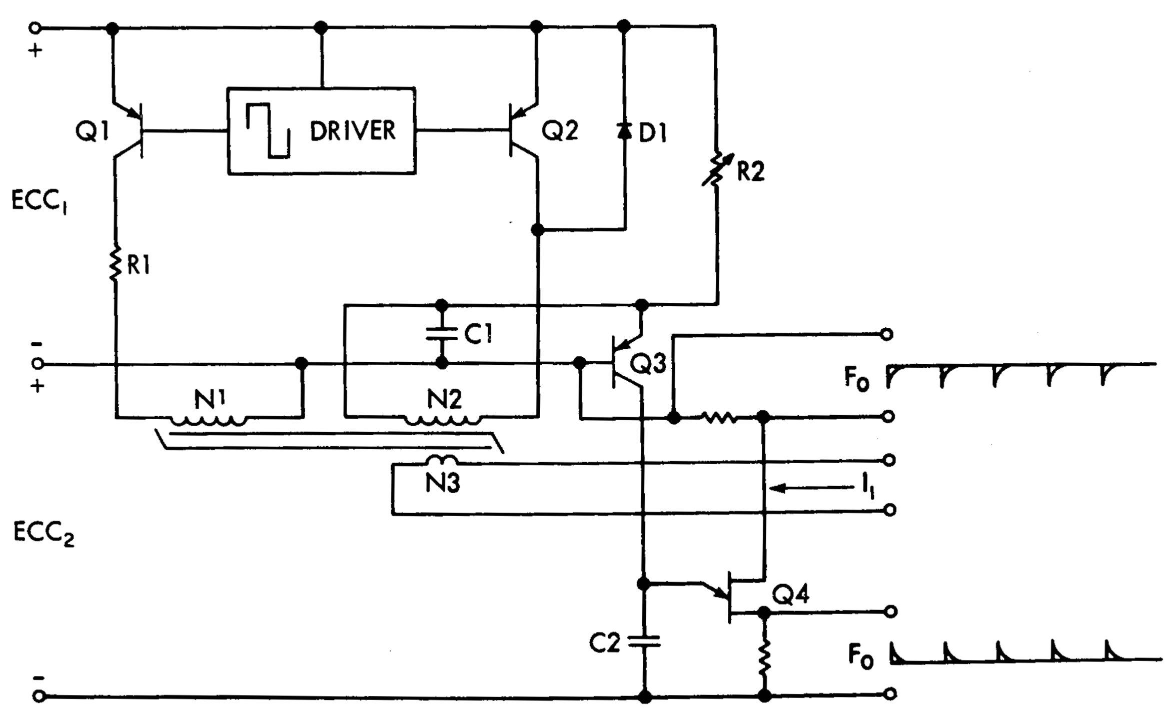

Figure 4 - Current to Frequency Converter

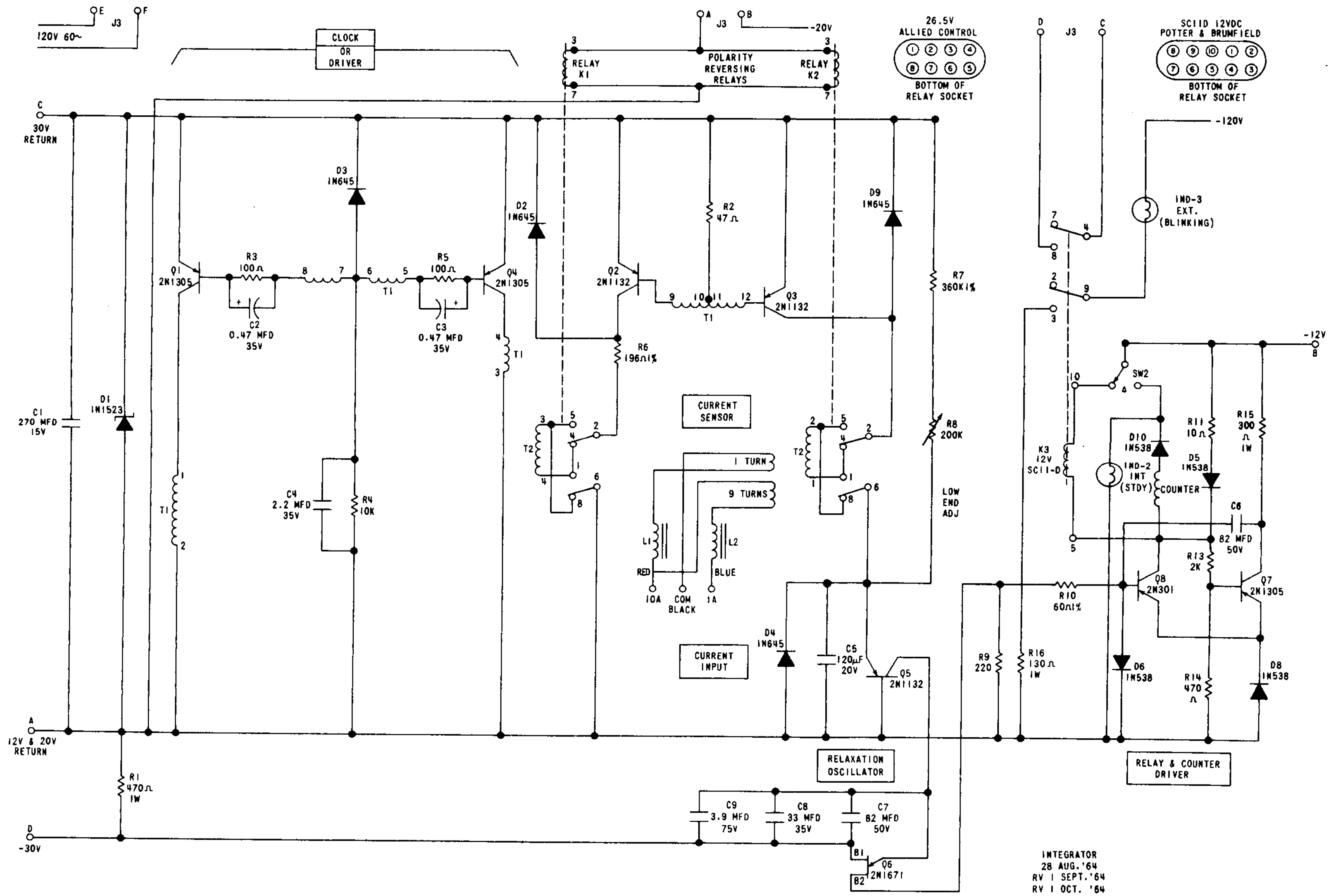

Figure 5 - Schematic - Ampere Hour Integrator

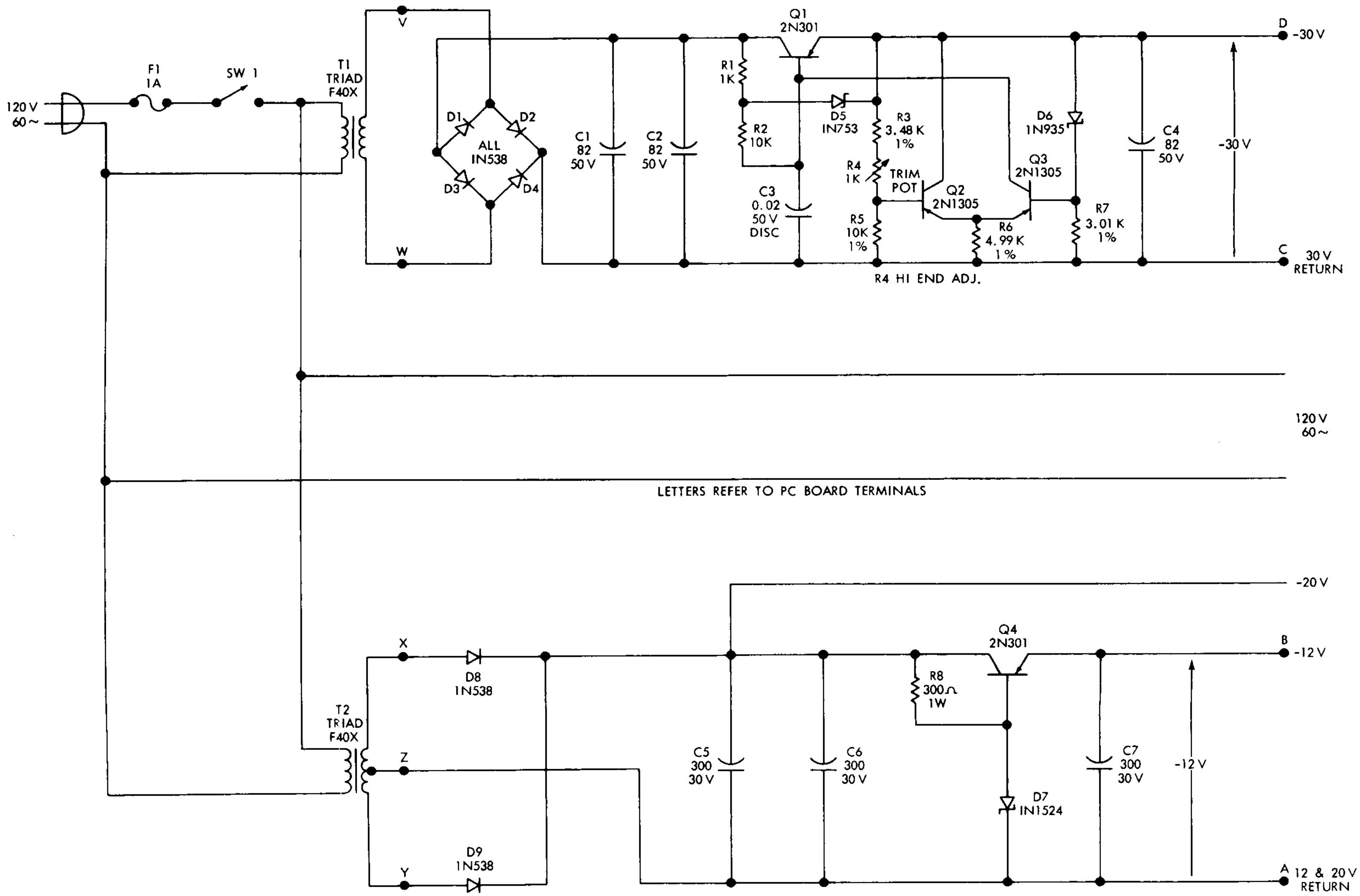

Figure 6 - Integrator Power Supply

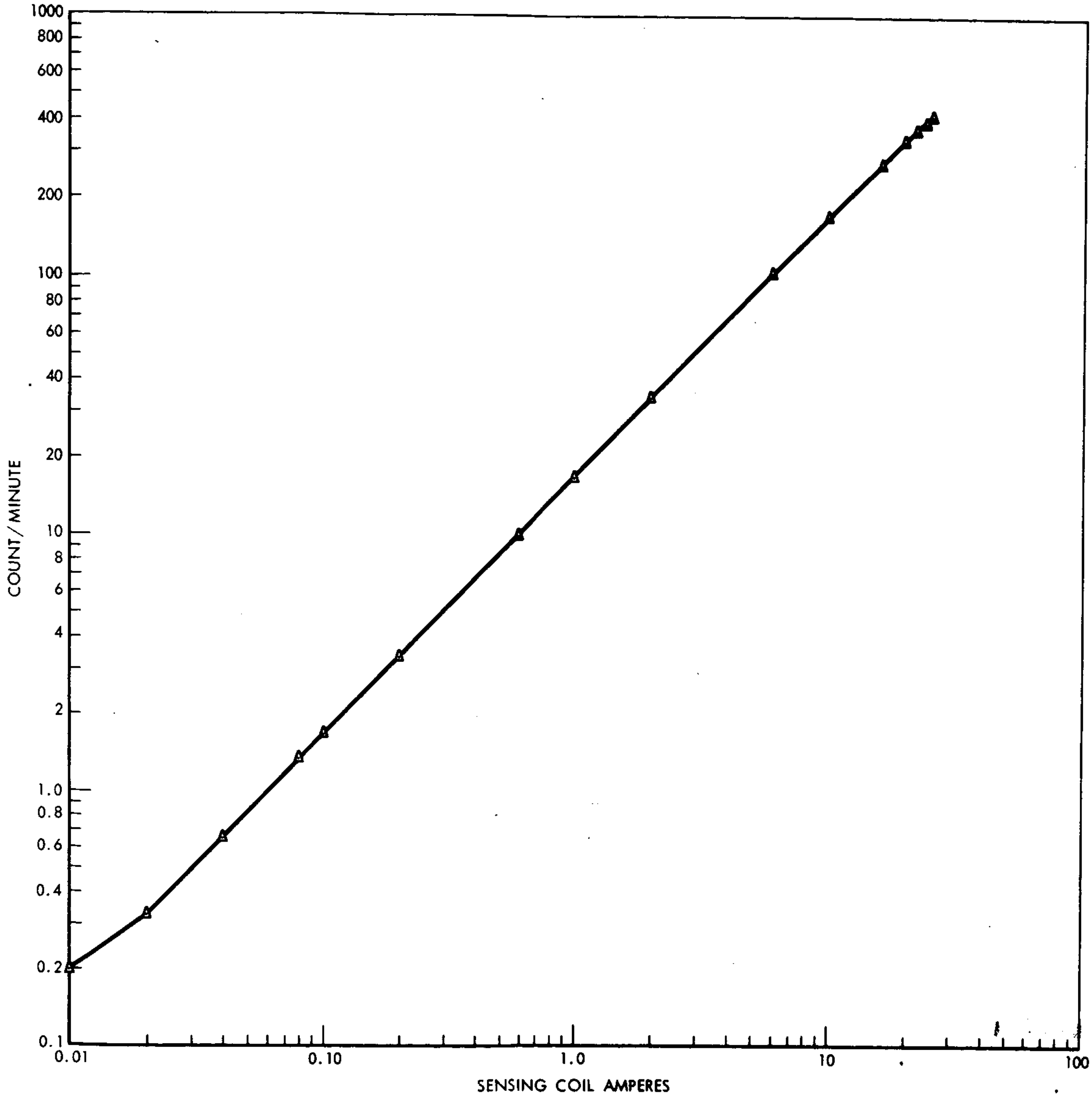

Figure 7 - Count Rate vs Current

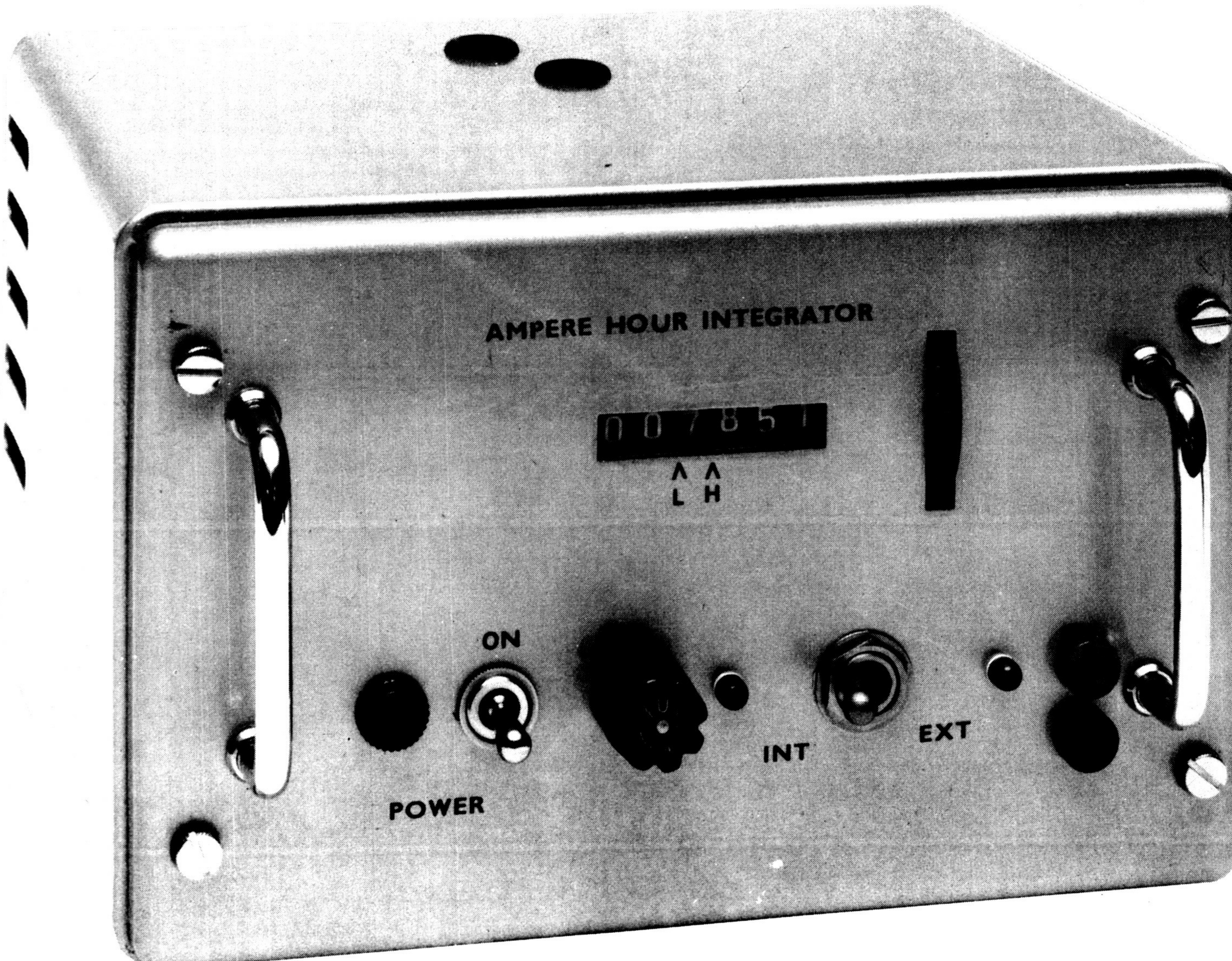

Figure 8 - Ampere Hour Integrator

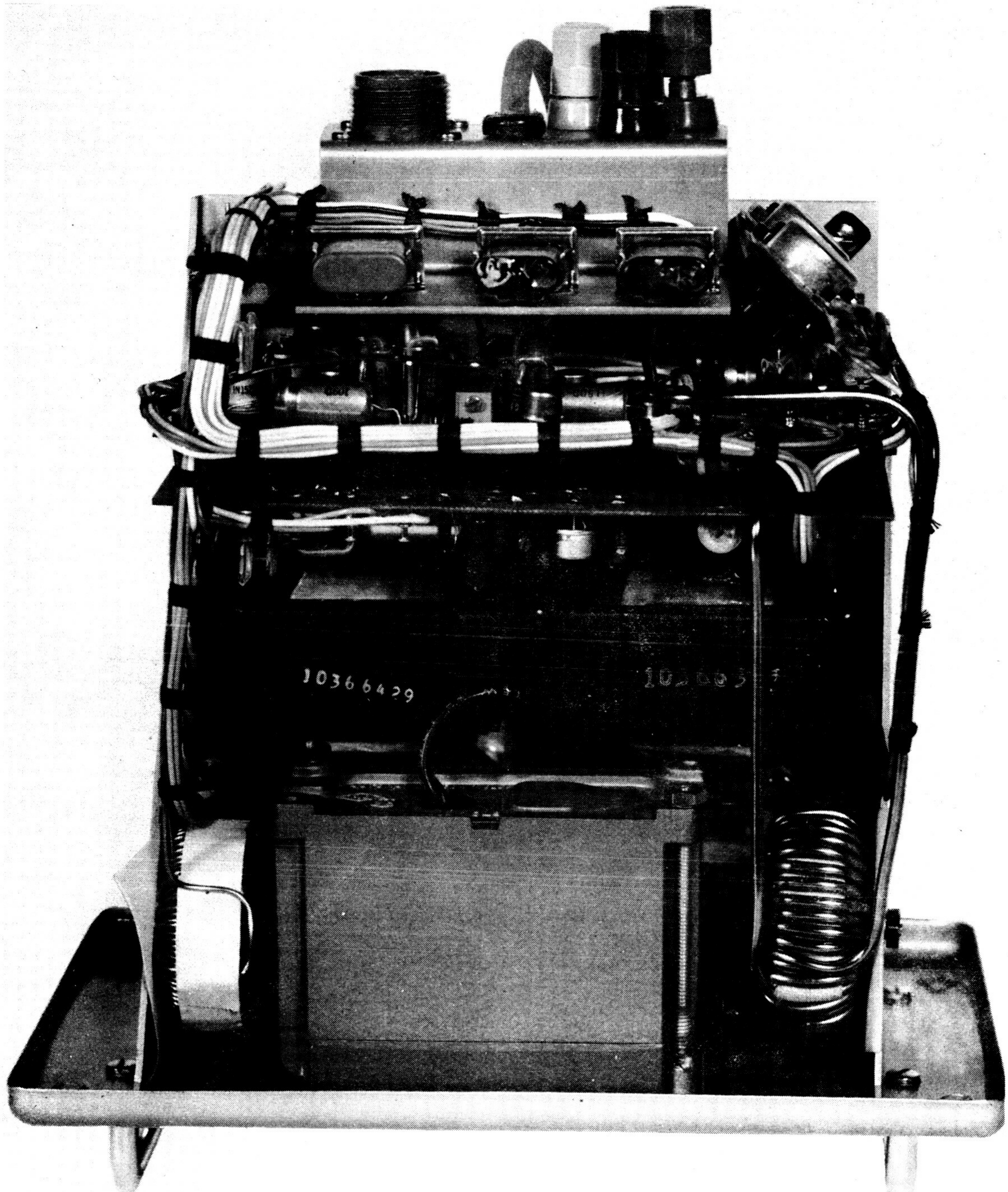

Figure 9 - Internal View - Ampere Hour Integrator

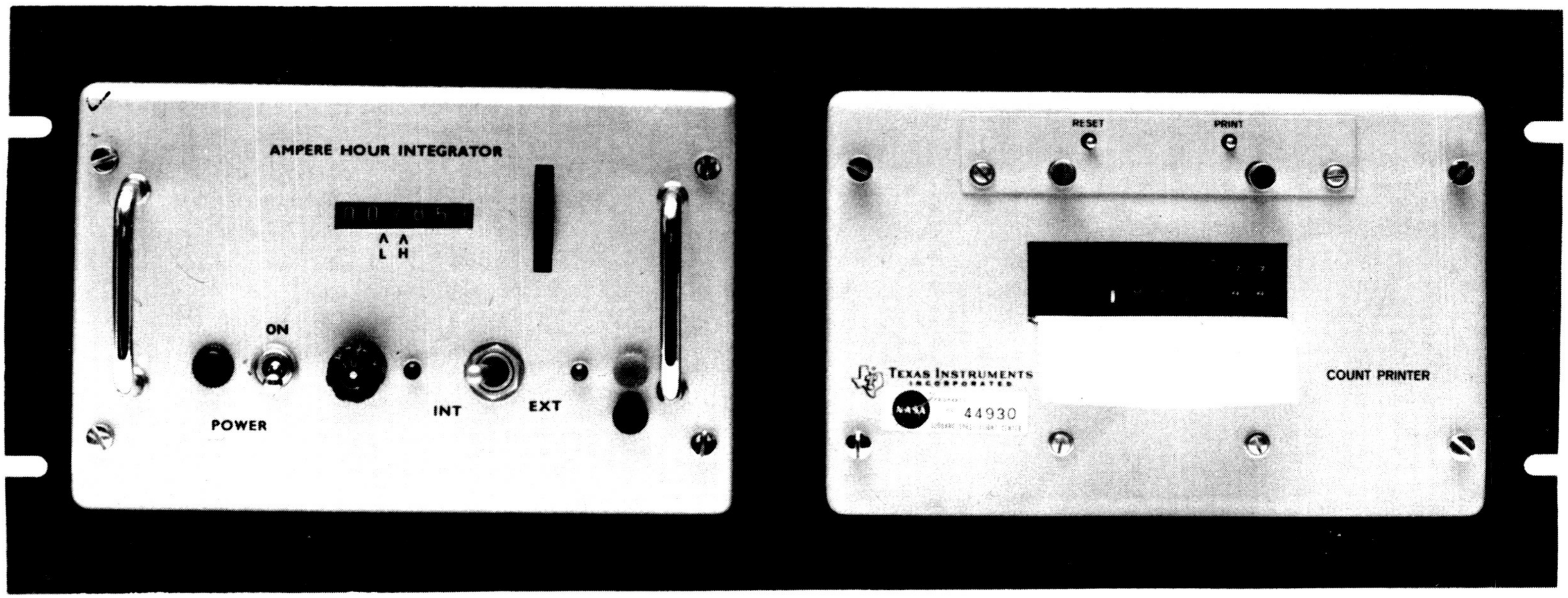

Figure 10 - Ampere Hour Integrator and Print Out Counter in a 19 inch Panel