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TELEMETERING LIMITER FOR AFCRC AEROBEE BEACON SYSTEM

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TELEMETERING LIMITER FOR AFCRC

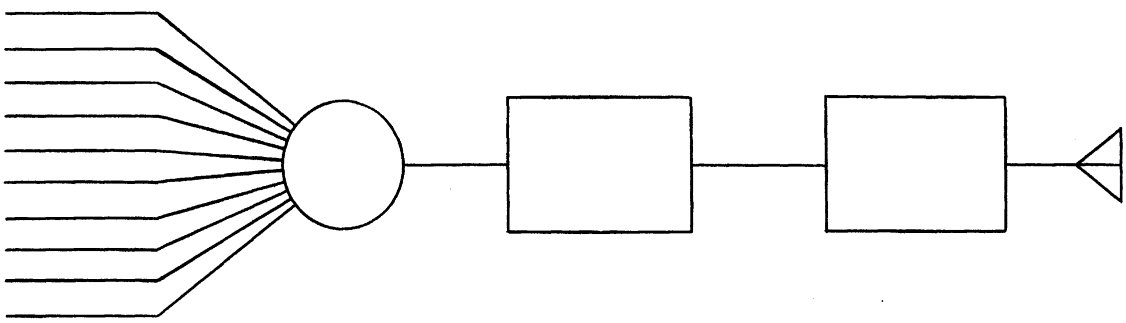
AEROBEE BEACON SYSTEM

I. INTRODUCTION

This technical note will describe a limiter circuit which has been designed for use in connection with the standard U.S. Air Force Cambridge Research Laboratory beacon telemetering system, developed for Aerobee rocket use. Limiter action is necessary to avoid a malfunction of the telemeter when an input voltage greater than 5 volts or less than 0 volts is applied.

II. STATEMENT OF THE PROBLEM

The information system under consideration is diagrammed in Fig.1.



Information signals   Commutator   Limiter   Telemeter

Fig. 1

The commutator permits presentation of many (typically 20) information and calibrating voltages on one telemeter channel. Thus, the output signal of the commutator consists of a sequence of flat-topped pulses, at a rate of approximately 80 per second. Following the commutator is the limiter, which should (a) clip the peaks of any pulses which are over 5 volts and (b) suppress any negative pulses, and in so doing, produce minimum insertion loss.

The use of vacuum-tube amplifiers could conceivably result in very sharp limiting, but their use has been avoided due to problems of linearity and drift. Similarly, the use of relays and vacuum-tube switching circuits has been avoided due to the pulsed nature of the signal, which would require very rapid response in the switching loop. The normal problems of missile instrumentation must be met, including reliabilty, compactness, minimum weight, and resistance to vibration, acceleration, and environmental changes. The specific requirements are as follows:

a. Linearity of transfer characteristic in the range from 0 to 5 volts must be within 0.01 volt, and preferably 0.005 volt.

b. No signals greater than 6 volts or less than -1 volt should appear on the output.

c. Input signals of 25 volts should be considered typical, and an input of 60 volts must not damage the limiter. Negative inputs should be expected.

d. Insertion loss must be very low. Earl investigation fixed 2200 ohms as the maximum permissable series resistance.

e. It is considered that the output impedance of the information source will be less than 5000 ohms; in most cases it will be below 100 ohms.

f. The limiters must accomodate the input impedance of the telemeter, which has been specified as greater than 50,000 ohms.

III. BASIC FORM

The ideal limiter would have a transfer characteristic like that shown in Fig. 2.

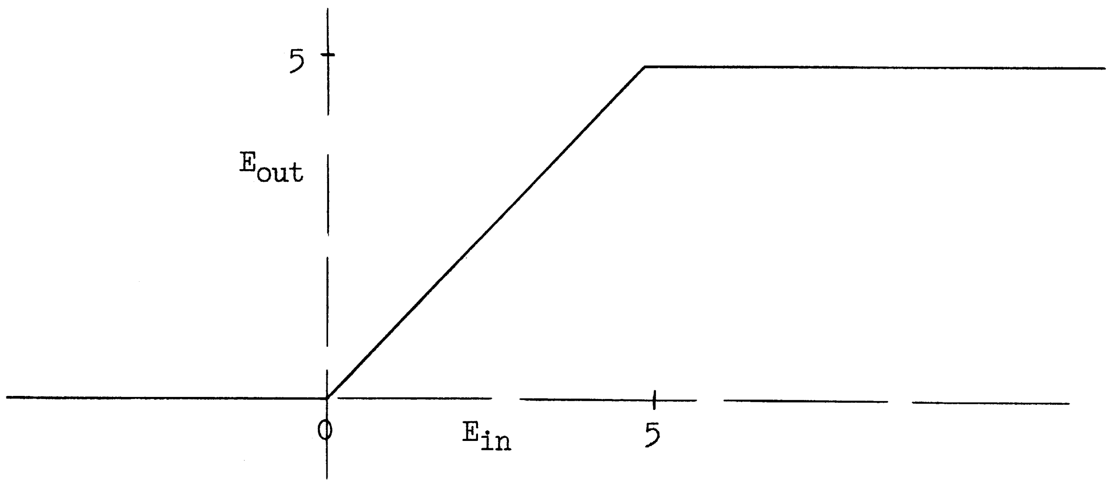


Fig. 2

If perfect diodes and a 0-impedance 5 volt source were available, this curve could be realized by the circuit of Fig. 3.

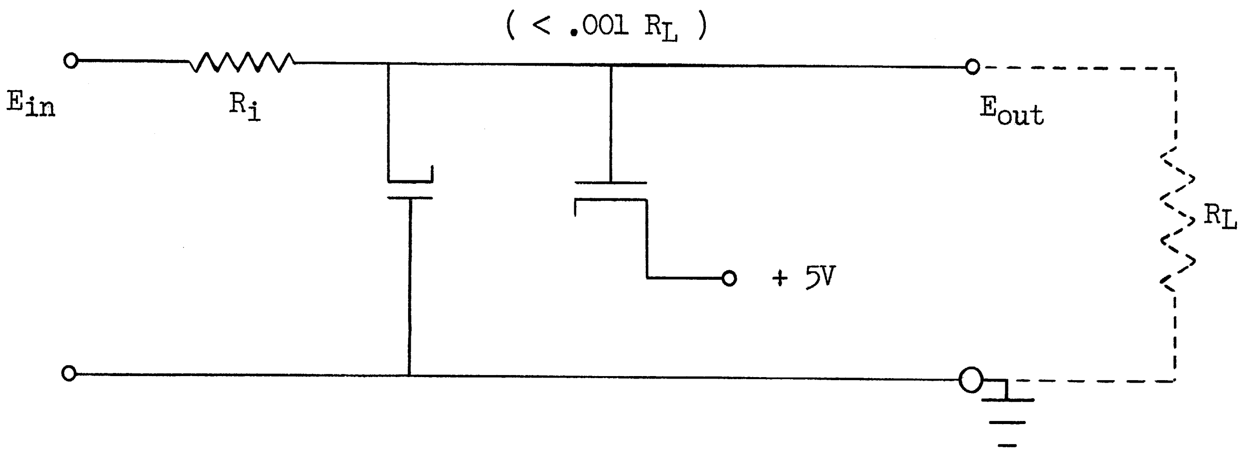


Fig. 3

The principal impedimentae to the realization of an ideal circuit are:

1. Current which flows when the voltage applied to the diode is in the reverse direction. This could be either forward and decreasing with voltage as in a vacuum diode, or reverse and increasing

with voltage as in a semiconductor diode. This current develops an error voltage across the series input resistor (and the source output impedance, which is very low in all cases where extreme accuracy is required).

2. Forward resistance of the diode, which develops a voltage that increases the apparant bias level.

3. Internal resistance and temperature variations of batteries which can be used as 5-volt bias sources.

IV. CHOICE OF COMPONENTS

Thermionic Diodes

The first limiters built here and flown in early missiles used subminiature vacuum diodes, Sylvania type 5647, which have the advantage of zero reverse current under any condition. However, the random thermionic energy of the electrons as emitted from the cathode with zero anode voltage, or even with a small negative voltage, causes forward current. Experimental data show that a negative bias of 0.4 to 0.6 volt is required to reduce the current below a few microamperes, which is necessary for proper operation of the limiter. The use of a slightly reduced filament voltage logically lowers this figure to 0.3 or 0.4 volts. There is significant variation from one tube to another in this respect.

The large-signal forward resistance of the 5647 is approximately 150 to 200 ohms, according to the manufacturer's specifications.

The complete circuit of this earlier limiter is shown in Fig. 4 and its transfer characteristic in Fig. 9.

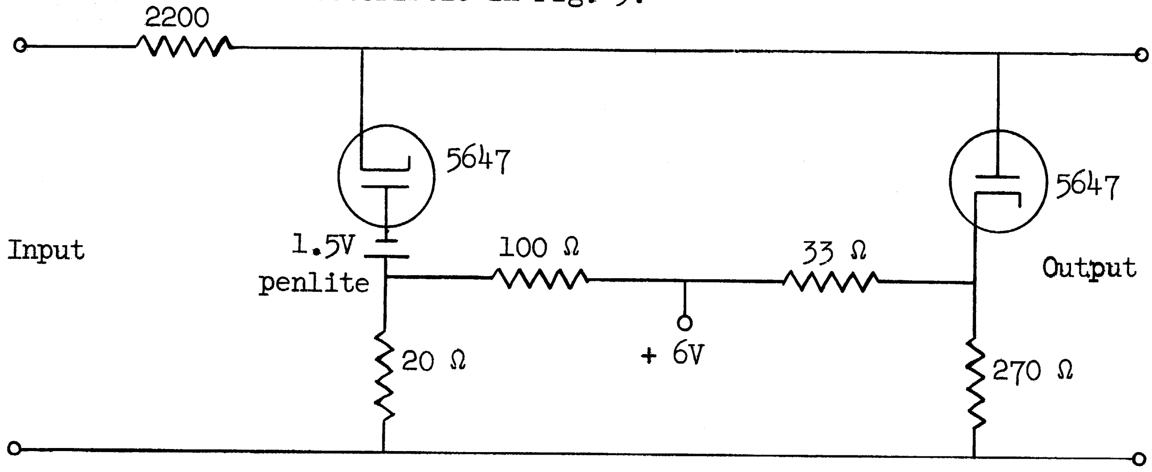


Fig. 4

A somewhat involved bias system was necessary to obtain biases of approximately 5.5 and -0.5 volt (Fig. 4) to overcome the "contact potential" current discussed above. It was based on the 6-volt source available in the missile, and led to serious problems to be discussed in the section on bias sources.

Semiconductor Diodes

If germanium diodes are considered, the question of reverse current becomes important; it has been found that with presently available diodes, the back current, rather than the insertion loss, determines the maximum allowable value of series resistor R_i. In the range of 0 to 5 volts the diodes are in a low-current condition; the equivalent network is shown in Fig. 5.

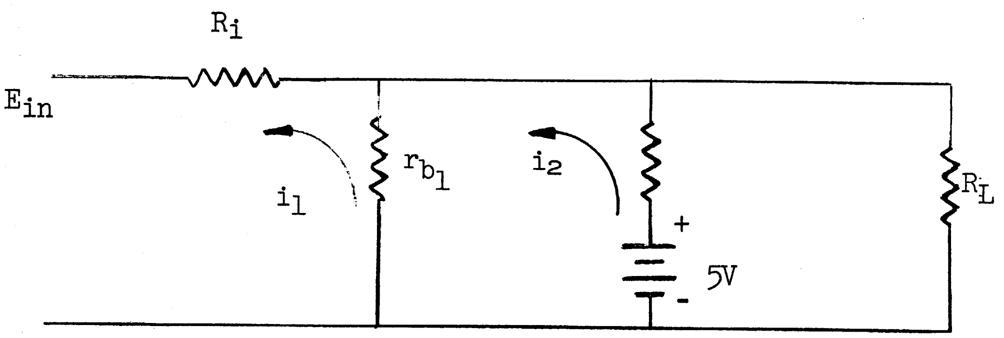


Fig. 5

In this case r_{b_1} and r_{b_2} are very large, and nonlinear. Since an error is caused by the current through R_i, and r_{b_1} and r_{b_2} are much greater than R_i, it can be seen that:

$$E_{error} = (i_1 + i_2)\,R_i = \left(-\frac{E_{in}}{r_{b_1(E)}} + \frac{5-E}{r_{b_2(5-E)}}\right) R_i \qquad (1)$$

$$= \left[\frac{5}{r_{b_2(5-E)}} - E\left(\frac{1}{r_{b_1(E)}} + \frac{1}{r_{b_2(5-E)}}\right)\right] \qquad (2)$$

The subsubscript on r_b indicates the voltage at which the nonlinear resistance has been measured. The current drawn by the load resistance R_L has been neglected. For simplicity of thought, the problem will be considered with a grounded input, since this is a condition of maximum error (see Fig. 7) if the diodes are similar in characteristics. In this case r_{b_1} is large compared with R_i, and therefore can be neglected. Accordingly, the error is given by simple voltage-divider action as shown in Fig. 6.

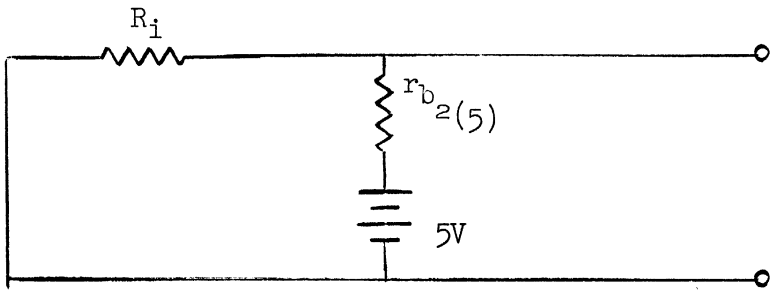


Fig. 6

Data-reading considerations allow a maximum error of 0.005 volt. Typical diodes of good quality (Hughes type 1N100 is an example) can be obtained in which the reverse current at room temperature is specified to be less than 5 microamperes at 5 volts. Thus for the specified allowable error, a 1000-ohm series resistor is indicated. Consideration of the forward characteristics then shows the limiting features of the device.

The newer high-conductance diodes offer the highest forward-to-back current ratio available (see Table I); thus the type 1N100, which appears to be the best at low voltages, was selected for use in the limiter. Three of these diodes have been tested and show conformity to the manufacturer's specifications, as tabulated.

TABLE I

DIODE CHARACTERISTICS AT 1 VOLT FORWARD AND 5 VOLTS REVERSE

Diode Number	Reverse Current at -5 volts, microamperes	Maximum Forward current at 1 volt, milliamperes	Temperature, °C
1N48	10.5 (exp)	4.0 (mfr. spec)	25
1N48	23.5 (exp)	-	41
1N69	5.7 (exp)	4.0 (mfr. spec)	25
1N69	12.7 (exp)	-	41
1N34	8.9 (exp)	-	25
1N63	13.2 (exp)	3.0 (mfr. spec)	25
1N63	30.8 (exp)	-	41
1N100 No. 1	1.4 (exp)	26 (exp)	25
1N100 No. 2	3.9 (exp)	35 (exp)	25
1N100 No. 3	4.5 (exp)	26 (exp)	25
1N100 (mfr. spec)	5.0 (max.)	20 (min.)	25
1N100 No. 3	14.7 (exp)	-	42

Generally, the diode which has the highest ratio of r_{b_5} to r_{f_1} should be selected. R_i then can be determined from error and insertion-loss considerations.

The effect of high temperature on the back resistance is rather large. Experimental data show that at 42°C, few diodes can be expected to have currents less than 5 microamperes at -5 volts. (See Table I)

A typical instrumentation provides periodic calibration to permit the desired accuracy of data interpretation. In this calibration system, four of the commutator segments are devoted to fixed-voltage signals, of 0.00, 1.35, 2.70, and 4.05 volts respectively. Reference to Fig. 7b shows that at elevated temperatures, assuming a diode of minimum allowable quality, this system employing four reference levels will limit the determinable error caused by the limiter circuit to less than a millivolt except between 0 and 1.3 volts. The sharp curvature of the diode characteristic (diode No. 1) near 0 volts causes the largest error. If a high-quality diode is used here, the error can be reduced to a maximum of 3 millivolts at 42°C and 0.8 millivolt at 25°C as shown in Fig. 7a. At the 5-volt end of the range, the hump in the error curve (with calibration) is much less pronounced, since the bias voltage is normally a few tenths of a volt over 5 volts, and most of the rapid change in the diode characteristic curve is very close to 0 volt. At low temperatures, the bias voltage may drop to 5 volts. However, at low temperatures, the diode back current, and thus the error, is greatly reduced, so the accuracy is still high over this part of the scale. This is indicated in the data of Fig. 7.

If there is a selection of diodes available, the units with the lowest reverse current at -5 volts will give the least error, and thus should be selected. This characteristic is especially valuable in regard to the diode which is biased at 0 volt.

V. BIAS SOURCE

Of the several ways of providing a reference bias voltage of 5 volts, one possibility mentioned earlier is the use of a voltage divider in conjunction with a N-T-6, (6-volt) battery. This arrangement would have a very low apparent impedance without significant current drain from the battery. For example, if 10- and 50-ohm arms were used across 6.3 volts, the bias would be 5.25 volts at an 8.3-ohm impedance. Unfortunately, experience has shown that the available voltage under load of the N-T-6 battery decreases rapidly with decreasing temperature, to a value as low as 5.5 volts. Thus, to be safe in the design of the voltage divider, it must be arranged to produce 5 volts with an input voltage of 5.5 volts.

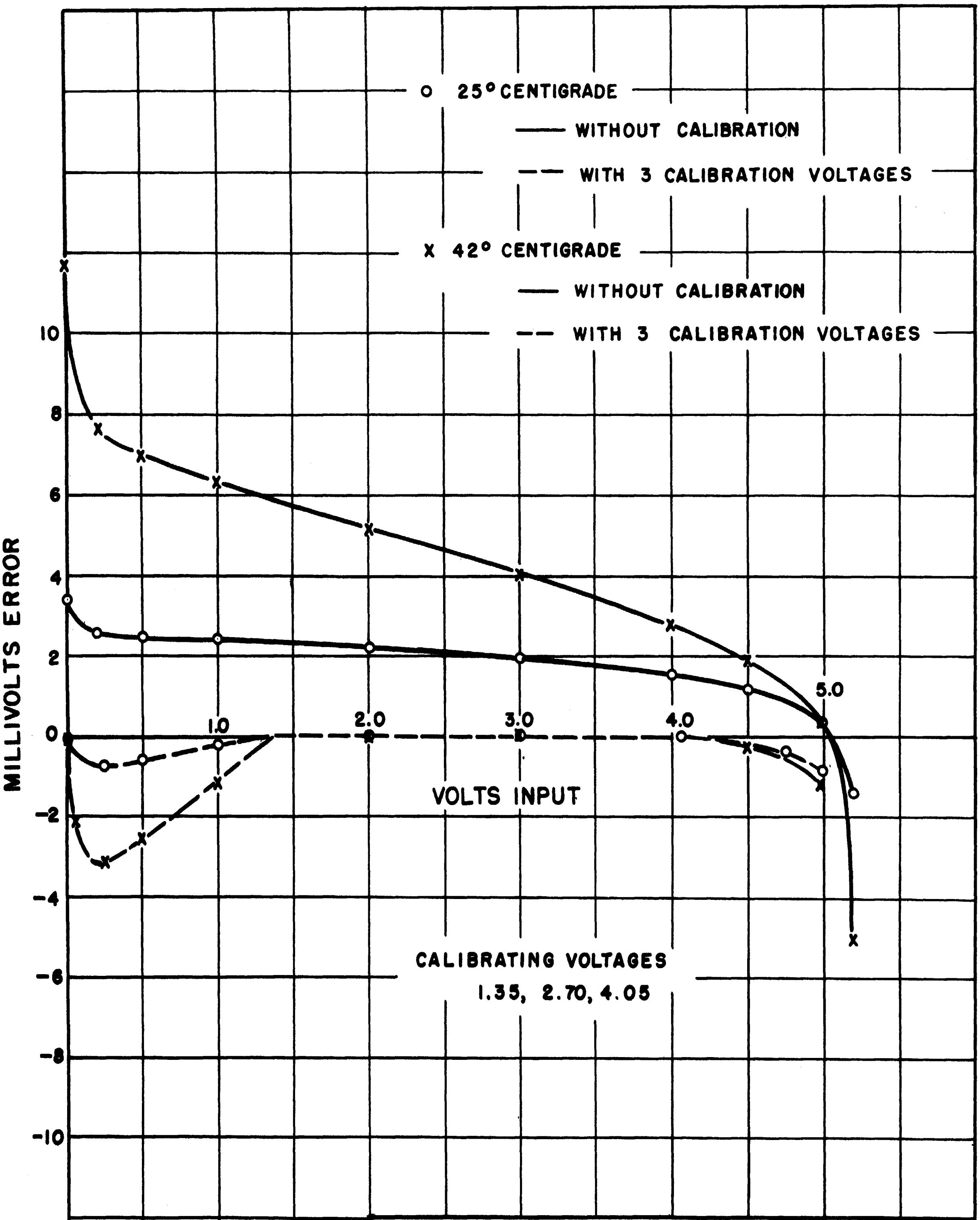


FIG. 7a
MAXIMUM
ERROR IN LIMITER DUE TO
DIODE BACK CURRENT
(BEST DIODE)

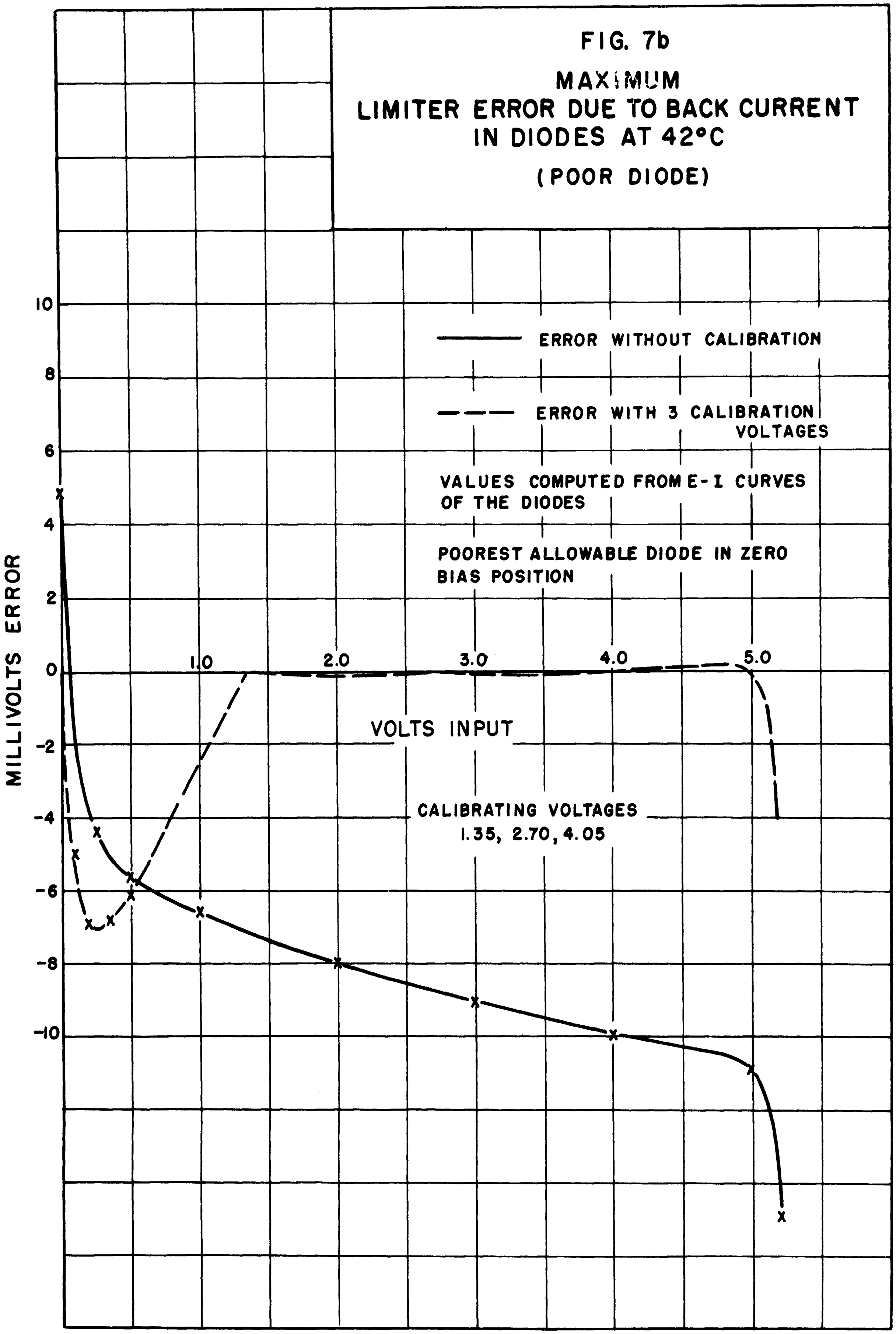


FIG. 7b
MAXIMUM
LIMITER ERROR DUE TO BACK CURRENT
IN DIODES AT 42°C
(POOR DIODE)
ERROR WITHOUT CALIBRATION
ERROR WITH 3 CALIBRATION VOLTAGES
VALUES COMPUTED FROM E-I CURVES OF THE DIODES
POOREST ALLOWABLE DIODE IN ZERO BIAS POSITION
MILLIVOLTS ERROR
10
8
6
4
2
0
-2
-4
-6
-8
-10
1.0
2.0
3.0
4.0
5.0
VOLTS INPUT
CALIBRATING VOLTAGES
1.35, 2.70, 4.05

Correspondingly, if the battery voltage is 6.3 volts, the bias voltage will be 5.7 volts. Since the resultant bias voltage determines the point at which limiting commences, it is important to select a stable supply source.

For these reasons, the use of a different type of bias battery was considered. Four series-connected Mallory RM-1 mercury cells, with an open-circuit voltage of 5.36 volts were selected after preliminary investigation. RM-1's were chosen in preference to other mercury cells because they appear to hold their voltage above 1.25 volts for a longer time under load.

Under anticipated circuit use an overload (limiting action) will force current through the battery in the reverse direction. Some tests were made and it was found that the battery will polarize under the influence of a reverse current, allowing the terminal voltage to rise to as much as 1.6 volts per cell. This would be the case in the limiter if one or two of the information channels became overloaded to 20 or 25 volts. To overcome this effect, a constant "preload" is put on the battery to insure that the current will not, in general, reverse. With a drain of 15 milliamperes, the bias is very close to 5.2 volts with an internal impedance of about 10 ohms for the four cells at room temperature.

If several limiters are to be used, they can be supplied from a common battery source, in which case the use of the RM-12 would be indicated. This cell is roughly the same electrically as three RM-1's in parallel; thus it should be preloaded to approximately 45 ma. With this system, the bias source would then be capable of handling simultaneous overloads on three channels. The lower internal impedance of the larger cells likewise enhances the desired limiting function.

The foregoing discussion has been on the basis of using this system at room or higher temperatures. In actual use of the limiter, at the Holloman range it is possible that temperatures may go to as low as 0°C. This will have three effects on the limiter.

1. An increase in the back resistance of the diodes will decrease the already small error due to back current.

2. An increase in the forward resistance of the diodes will make the limiting a little less sharp. However, this effect is much smaller than that on the back resistance, and will raise the output voltage only a few tenths of a volt for input voltages as high as 30 volts.

3. A marked decrease in the efficiency of the Mallory mercury cells at lowered temperature indicates that the preloading cannot be as great as stated, if use is contemplated at 0°C.

Experiments conducted near freezing temperatures indicate that a load of 240 ohms per cell (5 ma) instead of 80 ohms (15 ma) will insure that the bias stays above 5 volts for about 5 to 6 hours of battery life, at this temperature. This was determined on an intermittent-use basis, using 30-minute "on" periods.

Experiments have also determined that if forward and reverse currents are passed alternately through the cell, so that the net charge passed is approximately zero, the cell will not change noticeably in potential, even at low temperatures. This means that the battery loading resistance can be made higher without distortion due to polarization.

The use of standard carbon-zinc "penlight" (or larger) cells was also considered. However, preliminary tests at 0°C indicated that the internal impedance of the cells became so large as to preclude their use in the limiter circuit.

Thus, the choice of mercury cells for a given system is a function of the number of overloaded channels and the extent of the overload. The significant quantity is the current that must be delivered by the cell to equalize the reverse current. If this amount is 5 ma or less, the RM-1 may be used. If it is greater than 5 ma, the RM-12 batteries must be used.

In our application, many of the input signals are calibrating voltages, and other signals which cannot overload; thus the use of the RM-1 is feasible.

On the basis of these considerations, a limiter was built (for low-temperature use) with 1N100 diodes and four RM-1 mercury cells for bias. The series resistor of 1000 ohms was selected as a compromise between optimum limiting and minimum back-current errors.

The final circuit is shown in Fig. 8 and its transfer characteristic is shown in Fig. 9, compared with that of the earlier limiter of Fig. 4. This circuit meets all the specifications except that of 6-volt maximum output at 25 volts input. It was decided that this was acceptable

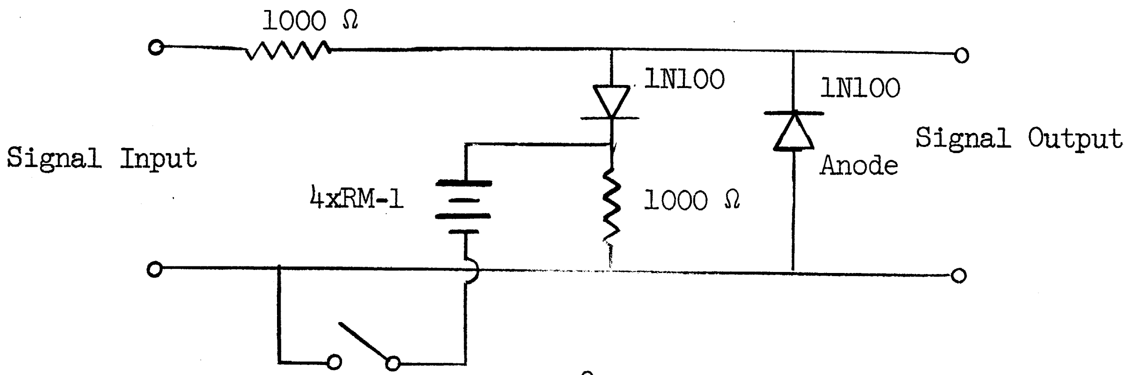


Fig. 8

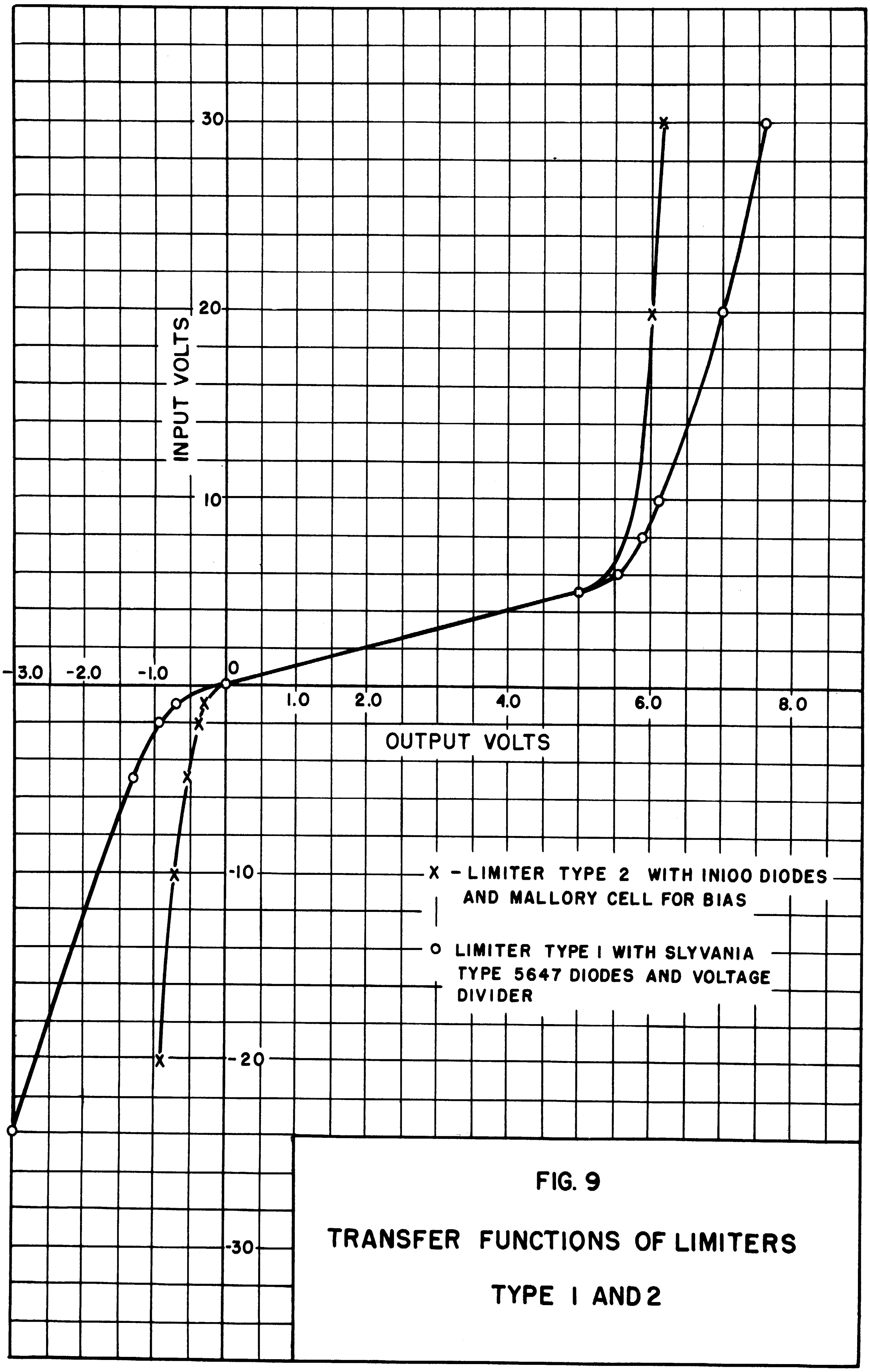


FIG. 9

TRANSFER FUNCTIONS OF LIMITERS

TYPE I AND 2

for the sake of higher accuracy. If a more stable and exact 5-volt supply were available, the limiting could be made sharp enough to meet this requirement. A 60-volt input pulse will seriously polarize the battery, resulting in an increased bias and poorer limiting until the cells can recover; however it will not damage the limiter, thus fulfilling the specifications in this respect. In addition, it will not interfere with the transmission of information, which is unaffected by moderate changes in the bias voltage.

The use of RM-12 cells for a bias supply is recommended if two or more limiters are to be flown in a missile. One set of four such cells is adequate for three limiters when operated as discussed above.

The diodes selected, Hughes type 1N100, are hermetically sealed and thus should be subject to a minimum of environmental change. Their extremely small size is advantageous, and their mechanical ruggedness is high compared to that of vacuum tubes. With the present instrumentation it is not possible to exceed their maximum current ratings of 30 ma dc and 300-ma surge.

VI. CONCLUSION

This technical note has presented the steps in the design of a limiter for use with a specified telemetry system, capable of limiting signals in excess of 5 volts positive and greater than 0 volts negative. A circuit has been designed which is superior to that originally used in this application. The merits of new limiter as compared with its predecessor are as follows:

1. Much sharper limiting, especially at high values of input voltage.

2. Freedom from effects due to interaction through common batteries from other instrumentation in the missile. It should be noted that even if several limiters are operated from one bias battery, interaction will only occur between signals greater than 5 volts, where accuracy is not a consideration.

3. Avoidance of vacuum tubes with their higher failure probabilities and need for filament supply.

4. Improved low-temperature performance, by using seperate lightly loaded bias batteries, instead of the heavily loaded storage-battery source used previously.

In view of these facts, this limiter is considered a desirable unit for use with the specified telemetry system where the signal may be commutated with widely varying input voltages.