NAA-SR-120
INSTRUMENTATION

A REVERSING LOGARITHMIC DC AMPLIFIER

ATOMIC ENERGY RESEARCH DEPARTMENT

NORTH AMERICAN AVIATION, INC.

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WRITTEN BY:

R. L. CARTER

WORK DONE BY:

R. L. CARTER
R. G. GRAYDON
D. C. WOODS

ATOMIC ENERGY RESEARCH DEPARTMENT
NORTH AMERICAN AVIATION, INC.
P. O. BOX 309 DOWNEY, CALIFORNIA

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REPORT APPROVED BY:

F . E. FARIS, Group Leader, Radiation Effects
J. P. HOWE, Section Chief, Reactor Materials

S. SIEGEL, Associate Director C. STARR, Director

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INTRODUCTION

In the course of devising automatic recording instrumentation for a high temperature Sykes experiment it was necessary to design and build a non-linear differential amplifier. The experiment required the reading of differential voltages which were changing too rapidly for manual operation of a precision potentiometer. At the same time, the precision required in the determination of small differential voltages did not allow on-scale readings for larger values of differential voltages with any known commercially available recording millivoltmeter or potentiometer. A high sensitivity, non-linear, high impedance DC amplifier to permit the application of a continuously recording instrument was designed, built and tested in the spring of 1950.

In the meantime an amplifier with some similar features was placed upon the market by Leeds and Northrup. The non-linear feature of the L & N amplifier, however, is intended primarily for instrument protection. The instrument developed here was designed to have a sufficiently reproducible non-linear response to permit calibration and use for measurements.

PURPOSE

Automatic recording equipment was designed for use with a high temperature Sykes experiment in which calorimetric measurements were to be made to temperatures approaching 2000° C. At such high temperatures, radiation becomes the dominant mechanism for heat transfer. The temperature differences which are used to determine the magnitude of this transfer no longer are directly proportional to it, but must be related by the Stefan-Boltzman law of radiation:

$$\frac{dQ}{dt} = k\,(T_1^{\,4} - T_2^{\,4})$$

$$\simeq 4\,k\,T_1^{\,3}\,(T_1 - T_2) \text{ if } \left|(T_1 - T_2)\right| << T_1$$

where $\frac{dQ}{dt}$ is the rate of heat transfer and T_1 and T_2 are the absolute temperatures of the radiating and receiving surfaces.

It is seen that for a given value of $\frac{dQ}{dt}$, the magnitude of $(T_1 - T_2)$ may vary widely depending upon the temperature at which the measurement is made. If the thermocouples used to measure temperatures are assumed to be linear, $T_1 - T_2$ may be represented by $a\Delta$, where Δ is the differential voltage generated Then

$$\frac{dQ}{dt} = 4\ ak\ T^3 \Delta.$$

The error in this measurement is

$$\delta\ \frac{dQ}{dt} = 4\ ak\ T^3 \delta \Delta.$$

With linear recording instrumentation $\delta\ \Delta$ is generally limited by the instrumentating to some fraction, f, (usually ≥ 0.5 per cent) of the maximum value of the variable, Δ_i, whence

$$\delta\ \frac{dQ}{dt} = \left(\frac{dQ}{dt}\right)_i\ f\ \left(\frac{T}{T_i}\right)^3.$$

One sees that the accuracy with which $\frac{dQ}{dt}$ may be determined diminishes with the cube of the absolute temperature.

If however, the voltage Δ is fed into a logarithmic amplifier in which the output voltage is

$$V = c \log \Delta\ ,$$

then

$$\delta\ V = c\ \frac{\delta \Delta}{\Delta}.$$

Applying the recorder criterion

$$\frac{\delta V}{V_i} = f$$

$$\frac{\delta \Delta}{\Delta} = f \log \Delta_i.$$

The error in the heat transfer measurement is then

$$\delta \frac{dQ}{dt} = 4\,a\,k\,T^3 \Delta\, f \log \Delta_i$$

$$= \frac{dQ}{dt}\, f \log \Delta_i$$

so that the instrumental error in the measurement of the heat transfer rate is independent of the temperature of measurement, depending only on the magnitude of the heat transfer rate, the readability of the recording instrument, and the amplitude of the maximum signal to be recorded.

The possibility of exothermal reactions occuring during the Sykes experiment made essential the incorporation of provisions for measuring signals of either sign. The amplifier has therefore to be linear for small signals.

CHARACTERISTICS

A breaker-type DC amplifier has been built having approximately the following transfer characteristics:

$$V_{out} = c_1 \log V_{in} \qquad (+\,50 \text{ mv} > V_{in} > 0.1 \text{ mv})$$

$$V_{out} = c_2 V_{in} \qquad (+\,0.1 \text{ mv} > V_{in} > -0.1 \text{ mv})$$

$$V_{out} = c_1 \log(-V_{in}) \qquad (-50 \text{ mv} < V_{in} < -0.1 \text{ mv})$$

This was designed for applications requiring the continuous recording of differential voltages of values up to 20 millivolts of either polarity, but requiring that small voltages be accurately readable down to the microvolt level. It has been found that the introduction of range-changing switches into a system of the necessary sensitivity led to transient effects of objectionable duration.

The amplifier (Fig. 1) has the following features:

1. High input impedence (1 megohm)
2. High discrimination against 60 cycle line pick-up interference (60 db)
3. Insensitivity to stray voltages existing between input leads and ground

4. Maximum voltage gain of 10,000 for small signals, automatically reduced to 100 for large signals of either polarity

High imput impedence allows the amplifier to be used in place of a sensitive potentiometer in connection with a high resistance thermocouple circuit. The power drawn from the voltage source at small voltage levels is of the same order of magnitude as that drawn by a potentiometer in the process of sensing null balance. The power drawn by the amplifier at higher signal levels is correspondingly greater, leading to approximately the same fractional voltage error, where the sensitivity limit of the null balance detector in a potentiometer would lead to a constant voltage uncertainty, growing fractionally smaller for large readings. If the resistance of the thermocouple circuit is not greater than 1000 ohms, the error due to current flow is less than 0.1 per cent.

In the application to which this instrument was put, high-level 60 cycle fields were present near the thermocouple, resulting in interfering signals of the order of several millivolts. In order to reduce this signal to the level of microvolts, a low pass filter was needed. It was found that an LC filter could not readily be used because of the difficulty in providing adequate shielding for the inductors against stray 60 cycle fields. At the same time it was desired to maintain a DC signal response time of no longer than 1 second. A four-stage cascaded RC filter was found satisfactory for this purpose.

The complete isolation of the input circuit from ground prevents disturbances due to voltages existing between the measured circuit and ground. This permits the use of one leg of the differential thermocouple as a common lead in a second thermocouple circuit used to measure temperature, with no appreciable interaction between the measuring circuits. Residual voltage due to small asymmetries in the input circuit are balanced out by means of the zeroing adjustment which precedes the filter network.

THE CIRCUIT

The DC voltage appearing at the output of the filter is alternated by means of one arm of a double-pole double-throw synchronous-motor-driven breaker and the resulting voltage amplified by about 150 in the 5693 preamplifier stage, then applied to the three 6BA6 stages of variable-mu amplification. Here the maximum gain is kept low through the use of small-sized plate resistors. The output from the last 6BA6 stage is fed through a 6J6 phase-inverting power stage, and the resulting push-pull signal divided into two channels. The first channel leads to the second arm of the double-pole double-throw synchronous breaker and is filtered to provide high impedence DC output voltage of the same polarity as the input voltage. The second channel feeds a full wave 6AL5 twin diode rectifier. After filtering, the resulting voltage is always negative but of the same amplitude as the output voltage. This voltage is added to a fixed minimum bias furnished by a 4.5 volt battery and is supplied to the grids of the 6BA6's through decoupling filters. Such a feed-back results in a gain suppression leading to overall gain characteristics which are approximately logarithmic at high input signal levels, but which become linear at low input signal levels. This arrangement permits the compression of large signals of either polarity for ease of recording, yet allows one to record a DC signal of the same polarity as the input signal. A switch is provided so that the amplifier may be used as a linear DC amplifier at its maximum gain.

Calibration of the amplifier is made through the use of a portable potentiometer as a source of voltage. Because of the high input impedence of the amplifier, no significant current is drawn and the setting of the potentiometer can be taken as the applied voltage. It is necessary to shunt out the potentiometer galvanometer since the emf generated during microscopic swings of the coil is of several microvolts amplitude. Figures 2 and 3 are plots of the output voltage vs input voltage for the amplifier, obtained by calibration with a potentiometer.

In order to achieve stability without sluggishness in automatic gain adjustment, pains were taken to decouple the plate circuit from the bias circuit. Voltage regulator tubes are used for this purpose. Time for half adjustment of the gain to a new signal level is approximately 0.5 second. Long period gain stability is achieved through use of an electronically regulated power supply. A DC source for heater voltage is necessary because AC operation results in a hum level which obscures signals at a level of 100 microvolts.

As designed, the amplifier is intended to be used with a high impedence recording device. If a recording potentiometer or a low impedence recorder is used, a push-pull cathode follower may be used for impedance transformation.

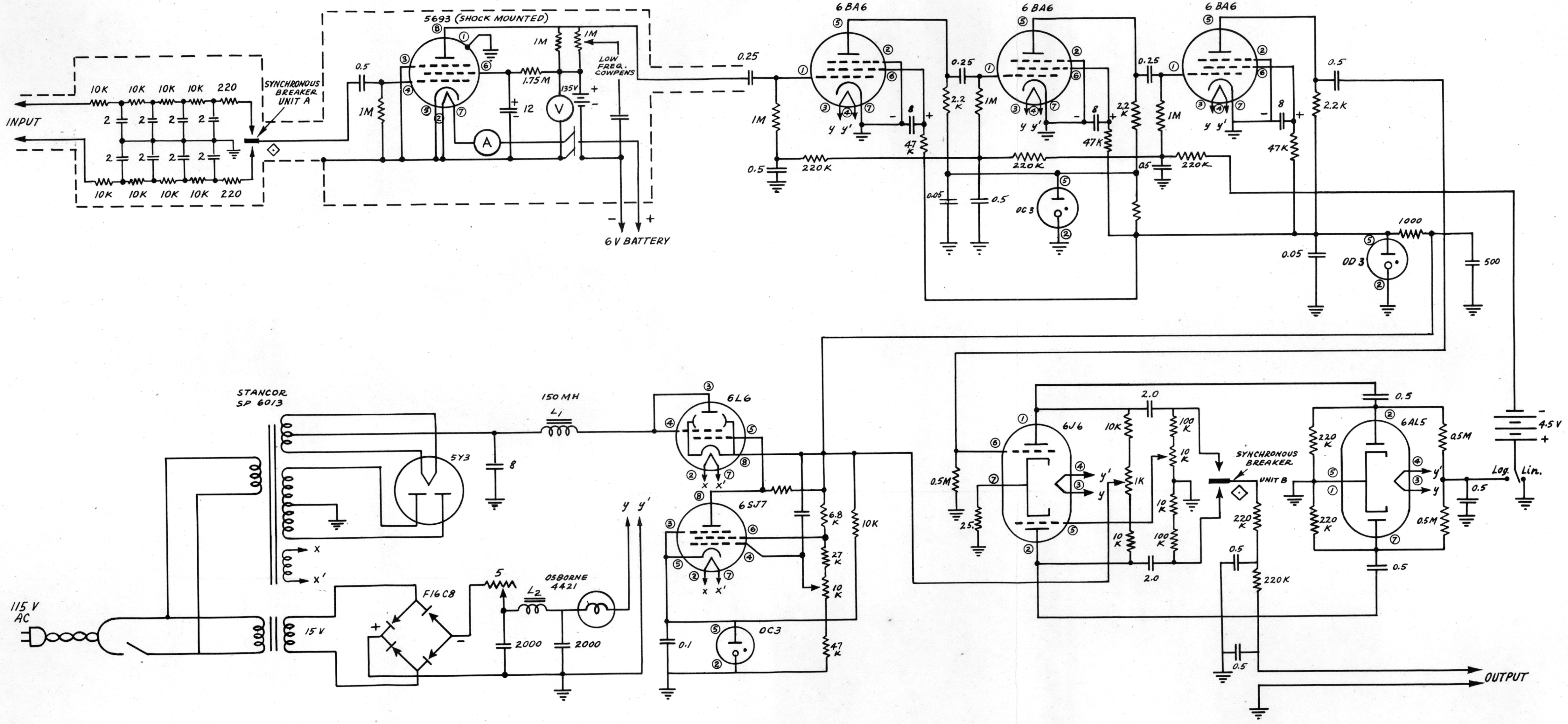

Fig. 1. Reversing Logaritamic DC Amplifier

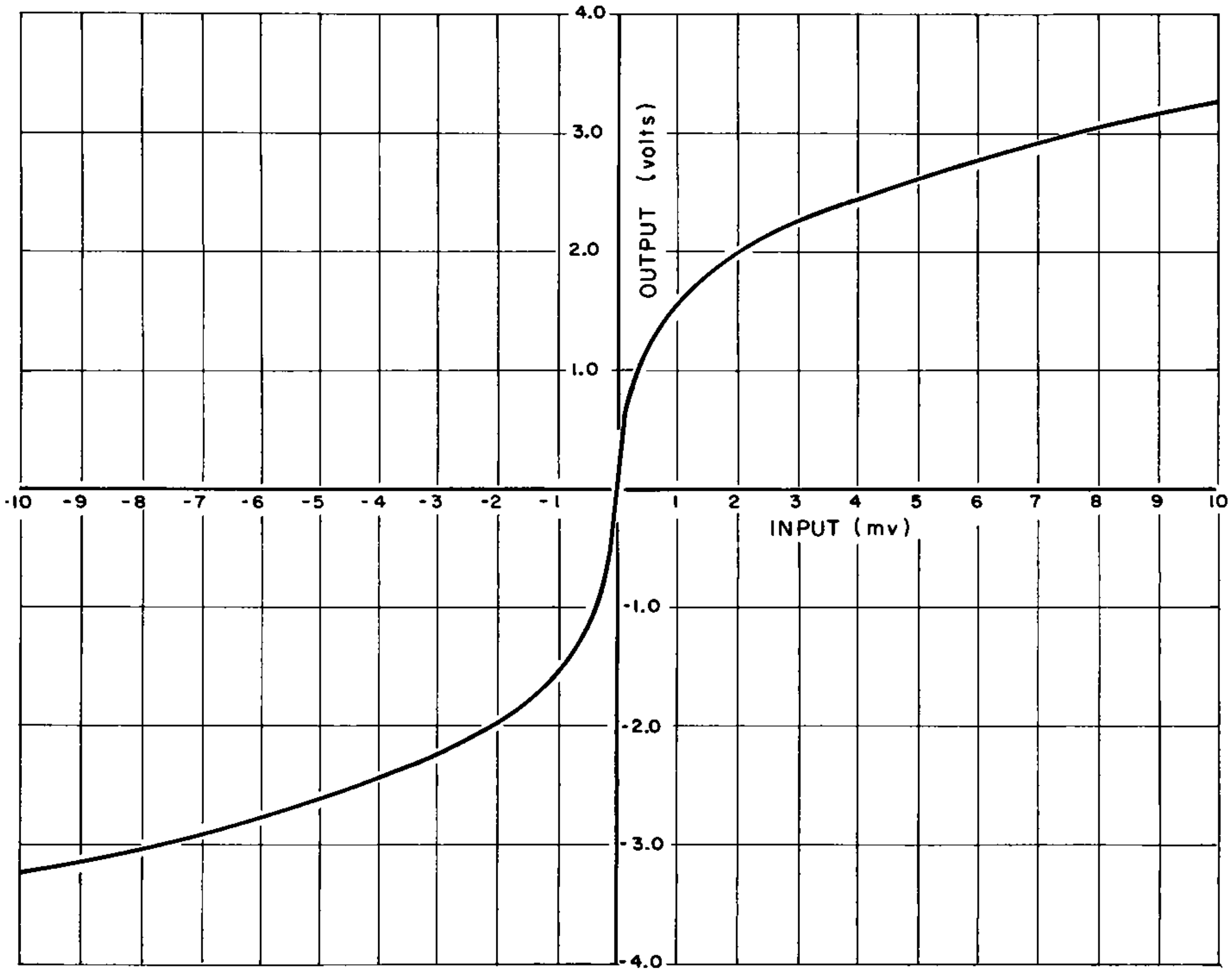

Fig. 2. Linear Plot of Amplifier Output Voltage vs Input Voltage

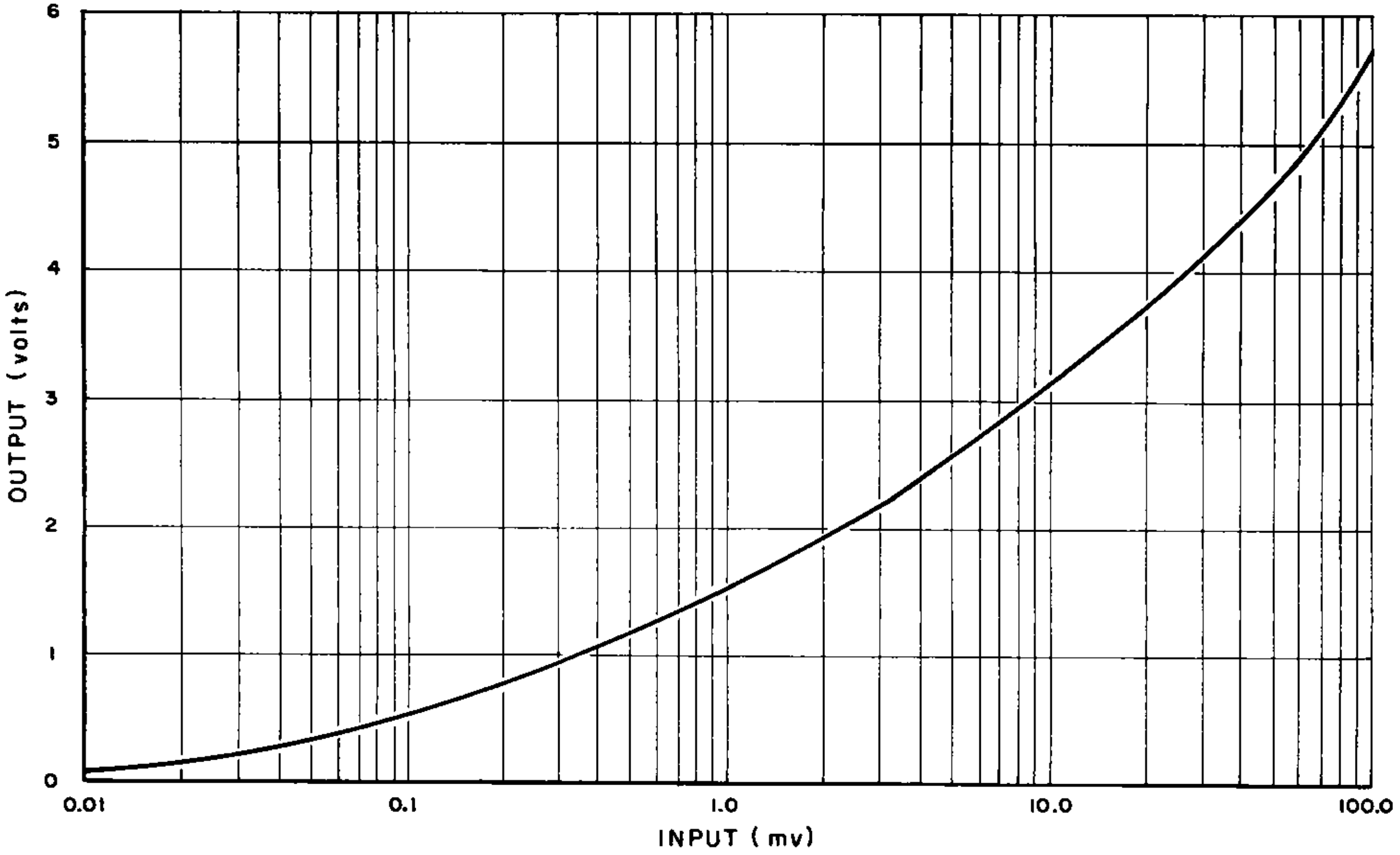

Fig. 3. Logarithmic Plot of Amplifier Output Voltage vs Input Voltage