# A logarithmic amplifier of wide dynamic range

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# NATIONAL RESEARCH COUNCIL OF CANADA

## RADIO AND ELECTRICAL ENGINEERING DIVISION



# A LOGARITHMIC AMPLIFIER OF WIDE DYNAMIC RANGE

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## ABSTRACT

A logarithmic amplifier is described, which is to be used in a radiometer for recording solar bursts. The amplifier is tuned sharply to 30 c/s. The dynamic range is 90 decibels, and the sensitivity is approximately 2 microvolts. When incorporated into a radiometer, the output of the amplifier is stable to within one decibel of input power for several weeks. Over the temperature range from 28°C to 40°C, the drift in output corresponds to less than 0.5 decibel of input power.

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# A LOGARITHMIC AMPLIFIER OF WIDE DYNAMIC RANGE

- C.A. Giasson -

## INTRODUCTION

One aspect of the program of 2800 mc/s solar observations at the Algonquin Radio Observatory is the recording of solar bursts, which are comparatively short-duration enhancements of solar emission over the daily level. These bursts occur in a wide range of intensities. The more intense bursts, although of less frequent occurrence, are of particular interest. Valuable information is lost if the recording meters are permitted to go off-scale; therefore, it is necessary to compress the input signal to one of the recorders. A logarithmic amplifier is desirable for this purpose because it preserves the structure of the burst.

The radiometer is of the conventional Dicke type [1] in which modulation at 30 c/s is imposed on the radio-frequency signal. The system consists essentially of a crystal mixer, a 30-mc/s intermediate-frequency amplifier with detector, a tuned 30-c/s amplifier, a synchronous demodulator, and a 0-1.5 volt recording meter. The logarithmic response is obtained in the 30-c/s amplifier.

The design specifications for the logarithmic amplifier are imposed by the dynamic range of signals likely to be encountered. The smallest signal that the radiometer will detect corresponds to a change of about 1°K in equivalent antenna temperature. In consideration of the parameters of the mixer and intermediate-frequency amplifier, this corresponds to approximately one microvolt at the input of the logarithmic amplifier. However, somewhat less sensitivity could be tolerated, as the smaller bursts are also monitored on other channels. From past experience, and an estimate of the gain of the antenna used, it is considered that the most intense bursts are unlikely to surpass an equivalent antenna temperature of $10^5$°K. The logarithmic amplifier should, therefore, have a dynamic range approaching 100 decibels. For periods of 24 hours or more the variation in output due to gain instability or drift with temperature change should be less than one decibel of the input power. A deviation of 1 or 2 decibels from the true logarithmic curve could be tolerated, inasmuch as there are other sources of nonlinearity in the radiometer.

Several types of logarithmic amplifier were investigated. In particular, the use of semiconductor diodes as a dynamic load in an amplifier was found impractical because of the excessive change in their characteristics with temperature variation. The method finally used to achieve a nonlinear characteristic was the method of successive detection. The main advantage of this system is that the logarithmic characteristic can be made independent of the variation in tube parameters, and fairly insensitive to temperature drift.

PRINCIPLE OF OPERATION

The system of successive detection makes use of a number of identical stages of amplification, each followed by a detector [2,3]. At low levels of signal, all stages operate in the linear part of their characteristic, but as the signal becomes larger the last stage soon becomes saturated. If the input signal increases further, the other stages become saturated at approximately geometric intervals in input signal level. The detectors, however, contribute, in turn, equal linear increments to the output current. This is accomplished by adding the outputs of the detectors in a common load. For this reason the response of the amplifier is approximately logarithmic.

Since amplitude detectors are used in the present amplifier, the output is insensitive to phase. To retain the phase information, which specifies the polarity of a signal, it would be necessary to replace each diode detector in the amplifier with a synchronous detector.

DESCRIPTION OF AMPLIFIER

The circuit diagram of the amplifier is shown in Fig. 1. The amplifier consists of three essential parts: a frequency selective preamplifier, a logarithmic section, and a d-c amplifier.

The preamplifier includes V1, V7, V8, V10, and is tuned to 30 c/s for rejection of the power-line frequency and its harmonics. It has an over-all gain of approximately 20 decibels and it includes a sensitivity control R8. The selectivity characteristic is obtained in two identical synchronous stages. Each one is comprised of a cascode amplifier, V7 or V8, a cathode follower, V10A or V10B, and an asymmetrical, parallel, twin-T network TT1, or TT2 which is connected between the lower grid of the cascode amplifier and the output of the cathode follower. The cathode follower conveniently provides the high Q that is required. It isolates the output of the cascode amplifier from the input of the twin-T network, thus allowing a higher value of the plate load resistor. In order to prevent any loading of the output of the twin-T network, the grid is biased through the network by two mercury cells connected in series.

The logarithmic section of the amplifier consists of five identical stages, comprising V2 to V6, each consisting of a type-12AX7 high-mu twin-triode. The first triode provides amplification, and the second one, in diode connection, is used for detection. The voltage gain from the grid of one tube to the next grid is approximately eight.

The outputs of each of these stages are added in a resistive load, R31 and R32 in series, and the sum is applied to the d-c amplifier (V9) which constitutes the third section of the circuit. V9 is a type-6SN7 twin-triode. Potentiometer R31 is a gain

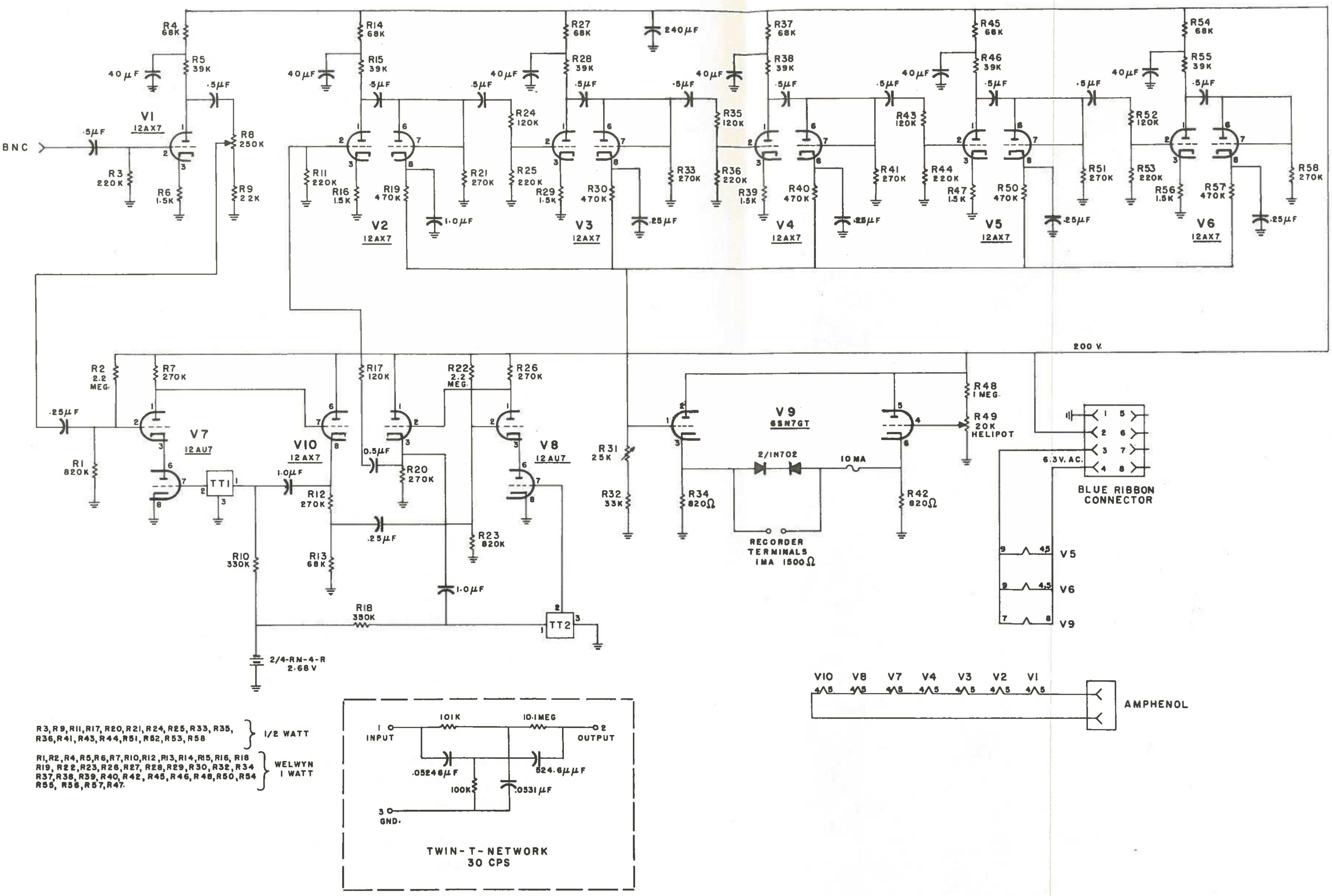


FIG. 1 CIRCUIT DIAGRAM OF LOGARITHMIC AMPLIFIER

control which is normally adjusted to allow the full logarithmic range of the amplifier to be displayed on a 0-1 milliampere 1500-ohm recording meter. However, it enables one to expand the scale when signals of lower intensity are to be recorded. Potentiometer R49 in the grid circuit of V9B provides control of the zero level of the recorder. The output to the recorder is taken between the two cathodes of V9. The zener diodes shown across the output terminals protect the meter against overload.

In order to keep the level of hum low, the filaments of all tubes (except the last three, V5, V6, V9) are fed in series from the direct-current supply shown in Fig. 2. This supply is operated from regulated power, and provides approximately 86 volts, with less than 60 millivolts of ripple.

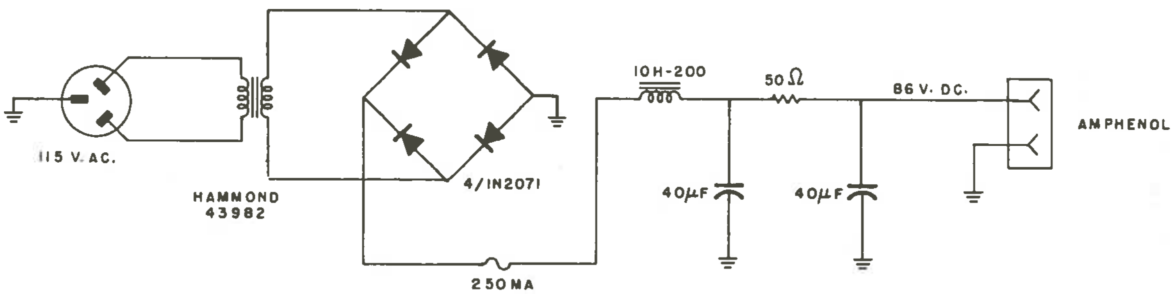


FIG. 2 CIRCUIT DIAGRAM OF D-C HEATER SUPPLY

## CHARACTERISTICS OF AMPLIFIER

The measured response curve of the amplifier is shown in Fig. 3. The logarithmic range extends over about 90 decibels, for an input signal up to $10^5$ microvolts. The amplifier could, for some purposes, be operated for an additional 10 db before complete saturation occurs, but the recovery time would be very much increased, and consequently, for the present application, the logarithmic range is restricted to 90 decibels. When used in the radiometer, effective antenna temperatures up to $10^5$ °K can be monitored, and the main requirement has, therefore, been fulfilled.

The logarithmic range begins at an input signal level of about 5 microvolts although the ultimate sensitivity, as limited by the level of flicker noise and 60 c/s pickup in the first stage, is about 2 or 3 microvolts. These results were obtained from tests with an audio oscillator at the input. However, in the radiometer, in spite of the twin-T filter, there is still some 60 c/s hum fed to the logarithmic section, which reduces the sensitivity to approximately 5 microvolts.

The measured deviation from the true logarithmic curve over the 90 db range is of the order of ±1.5 db, and is satisfactory for the present purpose. This deviation

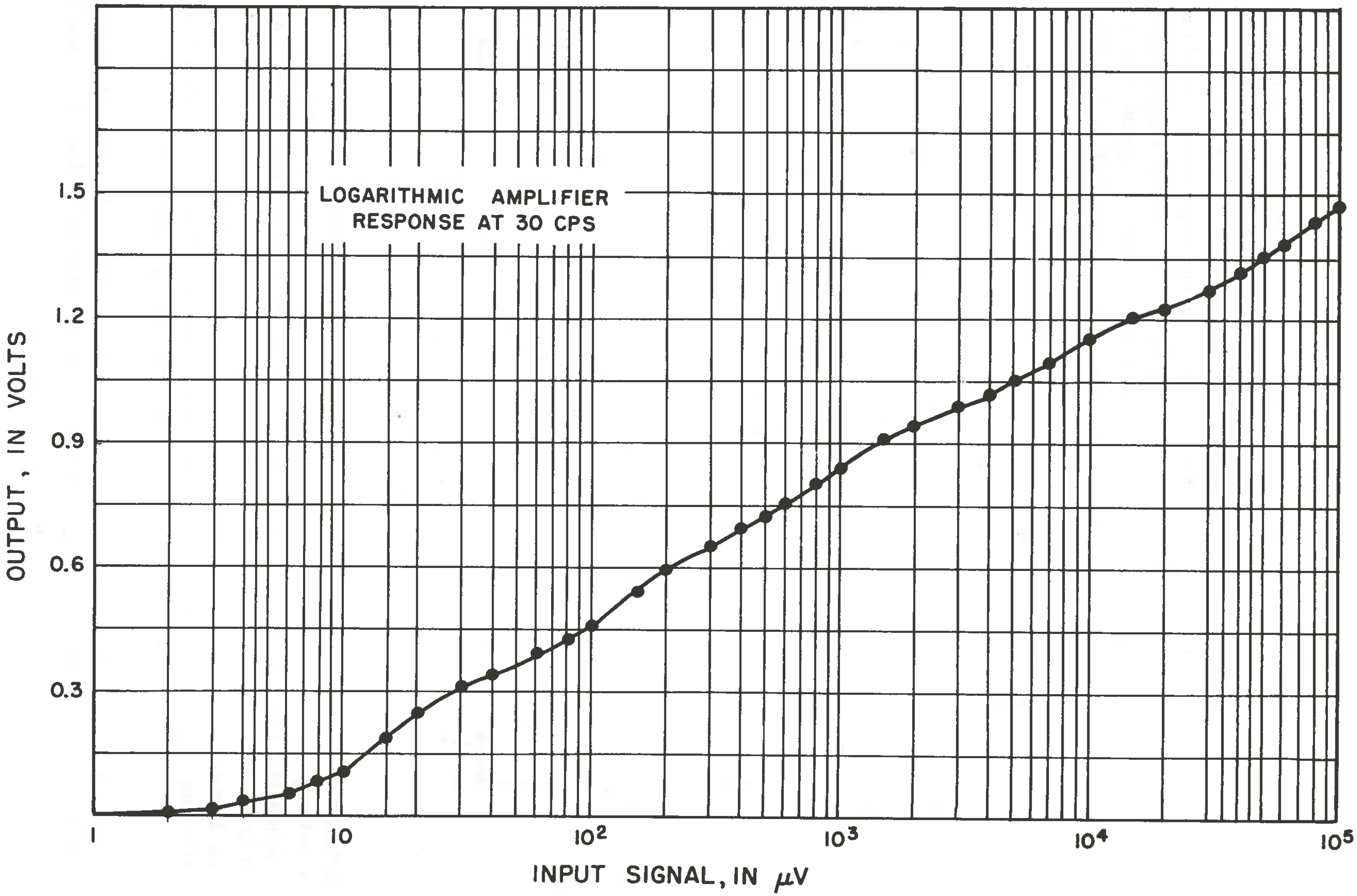


FIG. 3 RESPONSE CURVE OF LOGARITHMIC AMPLIFIER

could be reduced to approximately 1 percent of the input dynamic range expressed in decibels [2]. The over-all calibration curve of the radiometer is obtained for the lower part of the range with an argon plasma noise source, and for the higher part, with an S-band signal generator. The drift of gain due to temperature variation is less than 1 percent for a change from 28°C to 42°C. It was also observed that a 5-volt change in line voltage would cause a 0.8 db deviation in amplifier calibration. For this reason the filament supply is operated from a line which carries regulated power.

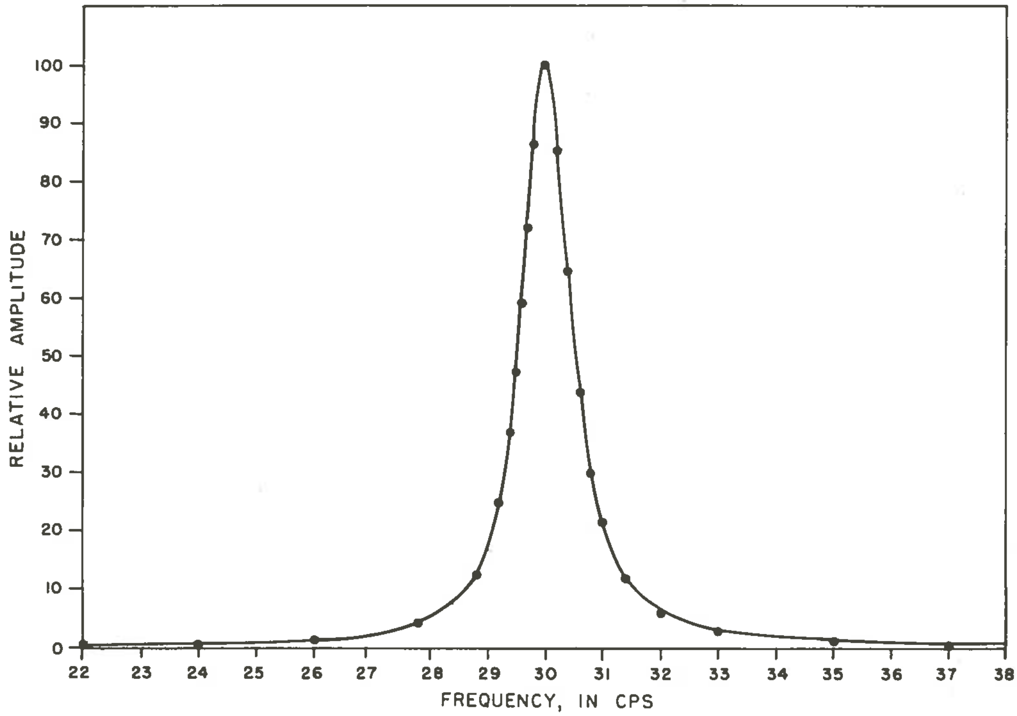


FIG. 4 FREQUENCY CHARACTERISTIC OF LOGARITHMIC AMPLIFIER

The frequency characteristic of the amplifier is shown in Fig. 4. It is centered at 30 c/s, and the bandwidth is approximately 0.6 c/s. The amount of rejection at the power line frequency is of the order of 60 db. Time response and overshoot measurements were made by applying a rectangular pulse with an amplitude of 0.1 volts, and monitoring the output on a recorder. The measured values were 1.25 seconds for rise time, with approximately 2 percent overshoot, and 2.0 seconds for decay time with no appreciable back swing.

As an initial test, the amplifier was operated in a radiometer for a period of 700 hours, and calibration was maintained to within ±0.8 db during this period.

## ACKNOWLEDGMENT

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PLATE I — FRONT VIEW OF LOGARITHMIC AMPLIFIER

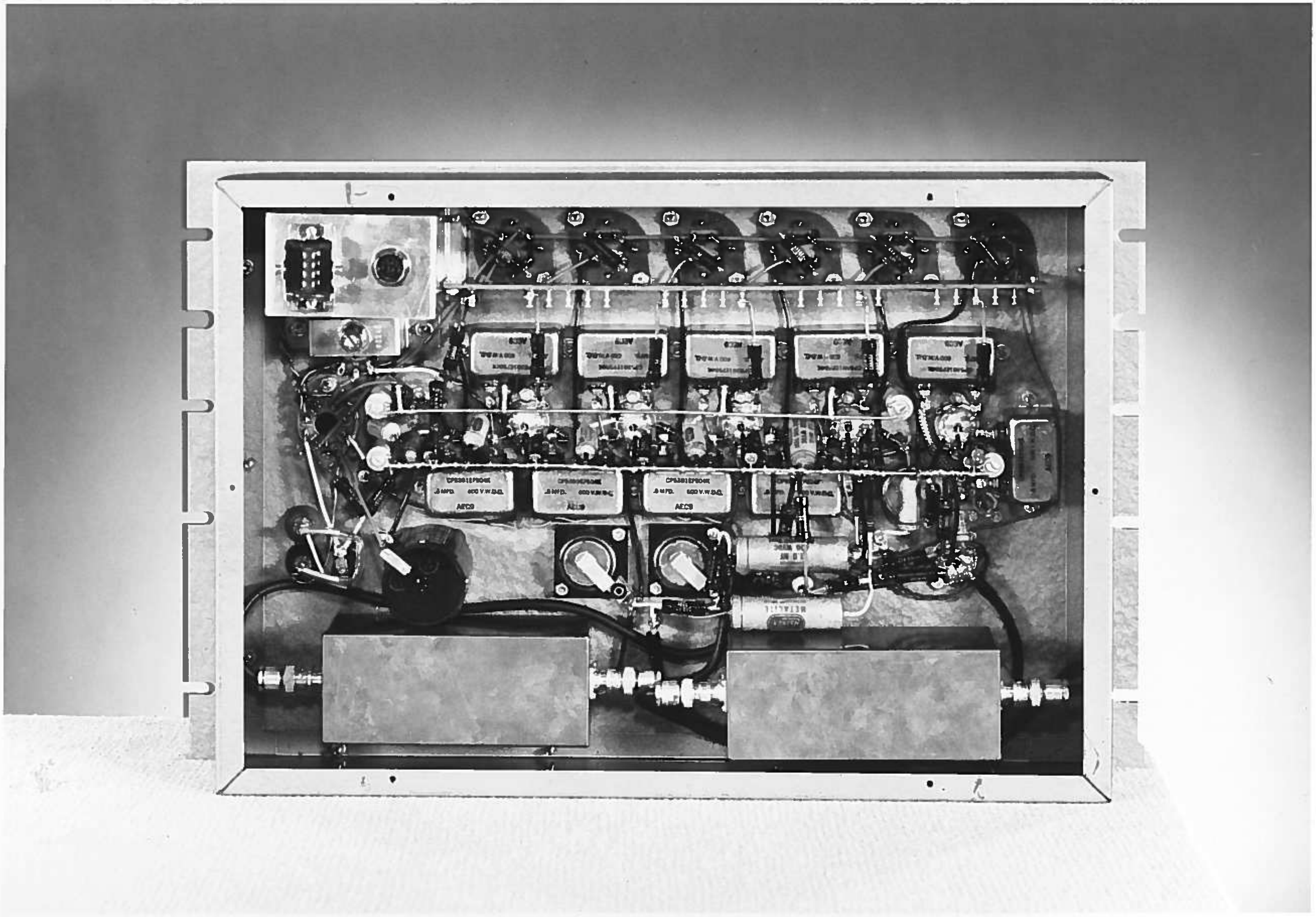

PLATE II — INTERNAL VIEW OF LOGARITHMIC AMPLIFIER