A Solid State Logarithmic Video Amplifier for Pulse Applications

R. L. SLICE

High Resolution Branch
Radar Division

August 11, 1964

U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

ABSTRACT

A logarithmic amplifier has been designed for a data-sampling system used in connection with a radar system. The amplifier was designed primarily for pulse inputs of positive polarity with a pulse width of 1 to 2 microseconds and a pulse repetition frequency of 5.46 kc.

One outstanding feature of the amplifier is its simplicity. The design incorporates no complicated feedback arrangements to achieve the desired logarithmic characteristics.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R02-34
Projects RF 001-02-41-4008 and
RUDC-4B-000/6521/F001-99-231-2

Manuscript submitted July 13, 1964.

A SOLID STATE LOGARITHMIC VIDEO AMPLIFIER
FOR PULSE APPLICATIONS

INTRODUCTION

The logarithmic amplifier was designed as part of a data-sampling system. The data-sampling system samples rf energy returned to a radar and separates the samples into channels which are stored on magnetic tape. One sample is taken following each transmitter pulse, and this sample can be varied in time anywhere within the bounds set by two consecutive transmitter pulses. This corresponds to taking samples at various ranges. The samples follow each other in a time-sequential order, with the samples for a given range always appearing on a given channel of the data-sampler output. The operation of the data-sampling system will be covered.in greater detail in another report.

The tape system used to record the data is a frequency-modulated system with a center frequency of 6.75 kc. A maximum input voltage of 1.4 volts peak corresponds to a 40-percent deviation from the center frequency. The signal-to-noise ratio is approximately 40 db, and this is approximately equal to the expected output dynamic range of the radar receiver. It was deemed necessary to reduce the dynamic range to the input of the tape to insure that no information would be obscured by the noise of the tape system.

At the beginning of this study, several reports on existing logarithmic amplifiers were studied to determine whether they were feasible for the present application.[*][†] After studying the reports, it was believed that a simpler amplifier could be designed. The amplifier discussed in this report is the result of further investigation and experimentation. It eliminated, to a large extent, the feedback circuits and compensation circuits found in similar amplifiers.

CIRCUIT SPECIFICATIONS

Figure 1 is a block diagram of the data sampling and recording systems showing their relation to the radar system. A portion of the rf energy is coupled from the receiver and fed to a gated traveling-wave tube at a power level of approximately -12 to -59 dbm. An attenuator located between the traveling-wave tube and the radar receiver is used to set the power level so that the strongest expected signal from the receiver will just saturate the traveling-wave tube. The traveling-wave tube is gated on once each transmitter period, resulting in short bursts of rf energy which are fed to a crystal detector.

The output pulse from the crystal detector has a width (at 3-db points) of the order of 0.03 microsecond and drives an integrating preamplifier. The preamplifier adjusts the gain and width of the sample so that the sample can be accommodated by the logarithmic amplifier. The output of the preamplifier is a pulse of approximately 2 microseconds with a fast rise and a slow fall time. This pulse is the input to the logarithmic amplifier.

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[*]David Ophir and Uzia Galil, "Zener Diode Creates Logarithmic Pulse Amplifier," Electronics, July 14, 1961, p. 68.
[†]G.S. Bahrs and W.D. Hindson, "A Solid State Logarithmic Video Amplifier," Stanford Electronics Lab. Technical Report 755-2, Apr. 22, 1960.
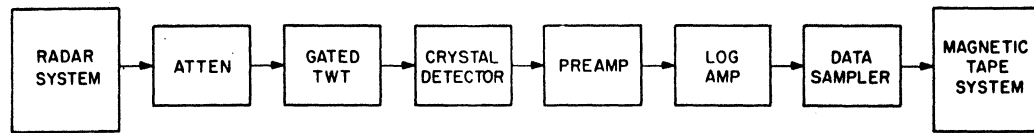
Fig. 1 - Relation of the data sampling and recording
systems to the radar system

The logarithmic amplifier has a twofold purpose. The magnetic tape recording system used to store the data has a limited dynamic range. In order that no information be lost the logarithmic amplifier is used to reduce the dynamic range of the signal. The second purpose of the logarithmic amplifier is to give a linear relationship between the rf power measured in db at the output of the traveling-wave tube and the voltage recorded on the magnetic tape.

Changes in the dc level must be eliminated or kept to a minimum, since the major concern is signal amplitude. The logarithmic amplifier is required to have good dc stability so no false indications of radar return will appear as information on the magnetic tape.

THEORY

A linear relationship is desired between the rf power in db at the output of the traveling-wave tube and the voltage to be stored on the magnetic tape. It is to be shown that the combination of the crystal detector characteristic and the logarithmic amplifier characteristic will produce this result.

The crystal detector used to detect the rf energy has a characteristic which approximates square law detection for small signals. The square law detection characteristic may be represented by

$$P_1 = (C'V_1)^a \tag{1}$$

where $a = 1$, P_1 is the power at the input of the detector in watts, V_1 is the voltage across the detector load in volts, and C' is a proportionality constant. Figure 2 locates the various voltage and power levels.
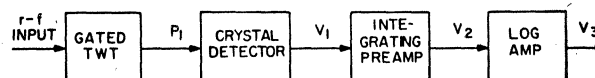

Fig. 2 - Location of the various
voltages and power levels

As the detector input signal increases, a will vary and approach 2 for very large signals. The detection is then linear. The integrating preamplifier has a unity voltage gain; therefore $V_1 = V_2$.

The logarithmic amplifier's characteristic can be represented by the equation

$$V_3 = K \log_{10} V_2 + D \tag{2a}$$

where K and D are constants. Since $V_1 = V_2$,

$$V_3 = K \log_{10} V_1 + D \ . \tag{2b}$$

The logarithm base 10 was chosen for simplicity. A change in the logarithm base would only affect the constants.

Taking the logarithm of Eq. (1) and multiplying by 10 gives

$$10 \log P_1 = 10 \ a \log V_1 + 10 \ a \log C' \tag{3}$$

or

$$10 \log P_1 = 10 \ a \log V_1 + C \ . \tag{4}$$

Rearranging Eq. (2b) and substituting it into Eq. (4) for $\log V_1$ yields

$$10 \log P_1 = 10 \ a \left(\frac{V_3 - D}{K} \right) + C \ . \tag{5}$$

Since the numerical value of P_1 (which is in watts) is the same as the number expressing the ratio of P_1 to 1 watt, Eq. (5) results in an expression for the power at the input of the detector in db relative to 1 watt:

$$P_{1_{dbw}} = \frac{10 \ a \ V_3}{K} - \frac{10 \ a \ D}{K} + C \ . \tag{6}$$

Simplifying Eq. (6) gives the desired result which shows a linear relationship between the rf power in db at the output of the traveling-wave tube and the voltage to be stored on the magnetic tape:

$$P_{1_{dbw}} = A V_3 + B \ . \tag{7}$$

It can be seen from Eq. (6) that if a changes there will be a change in slope as well as in the intercept. Equation (6) also shows that the detection need not be square law in order for the relation to be linear. It is only required that a remain constant over the operating range.

CIRCUIT DESIGN

The method adopted utilized the volt-ampere relationship of a solid state diode with a gradually bending volt-ampere curve which approximated a logarithmic characteristic. The diode is driven by a current source and the voltage developed across the diode is used to drive the following stages.

DC volt-ampere curves were plotted for various solid state diodes and some were found to have the desired characteristic curve $V \approx \log I$. However, all were not suitable when tested with a pulsed input instead of a dc input.

Figure 3 shows the dc characteristics of several diodes which were considered for the circuit. The 1N270 was chosen on the basis of its dc characteristic, its availability, and experimental results. It was determined from experimental data that the diode operated most satisfactorily with zero bias.
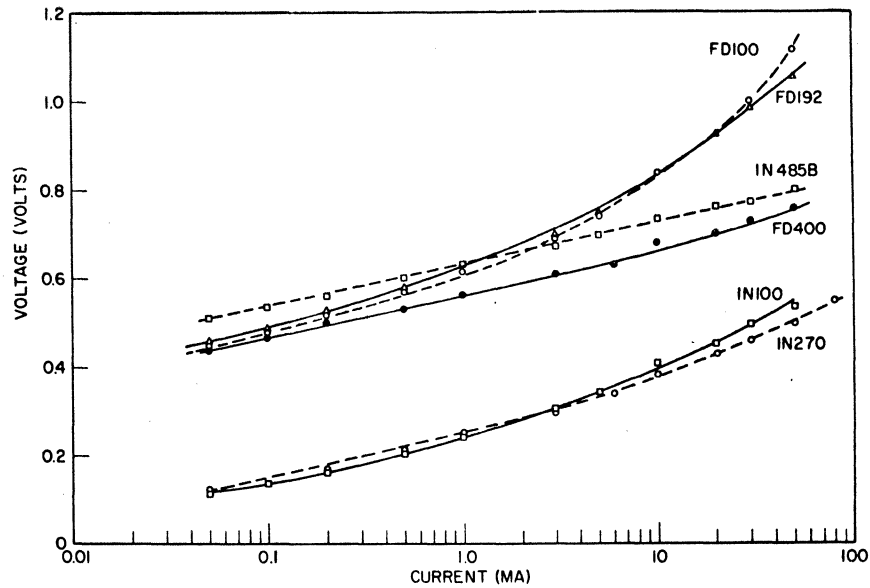
Fig. 3 - The dc characteristics of several diodes

DESCRIPTION OF CIRCUIT

Figure 4 is the schematic diagram for the logarithmic amplifier. The amplifier is composed of three transistor stages and a passive network. The input stage, T_1, is a linear amplifier utilizing both current feedback to increase stability and voltage feedback to bias the base in order to obtain a high input impedance. A high-voltage transistor was used in this stage so that a large output would be available to produce the current drive for D_1, the logarithmic element.
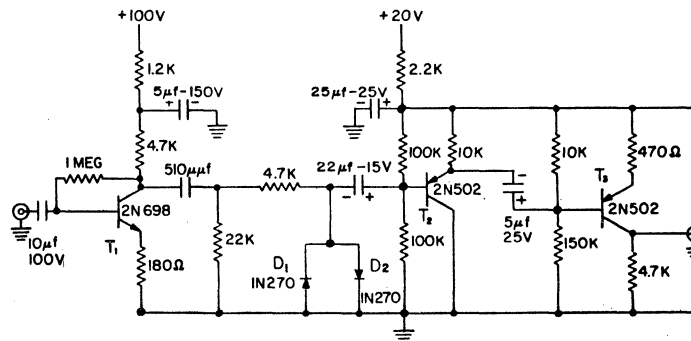

Fig. 4 - The logarithmic amplifier

The input stage is coupled to the diode D_1 through an RC network with the time constant determined so that the circuit will recover to the base line between successive pulses. This time constant is 1.17 microseconds, a compromise between amplitude attenuation and base line recovery.

The 1N270 diode network is a current driven device. The voltage developed across this diode due to the current drive is coupled through an emitter follower, T_2, to a linear amplifier, T_3, which amplifies the diode output by 10:1. The emitter-follower has a high input impedance and will not draw appreciable current to load the diode. The diode D_2 in parallel with the logarithmic element serves to limit overshoot in the reverse direction and aid the dc stability.

PERFORMANCE

Figures 5 and 6 show plots of the logarithmic amplifier's performance. Figure 5 is a plot of output versus input voltage of the logarithmic amplifier, using as input the integrated pulse from related equipment. The input to the gated traveling-wave tube was a cw rf signal varied from -12 dbm to -59 dbm.
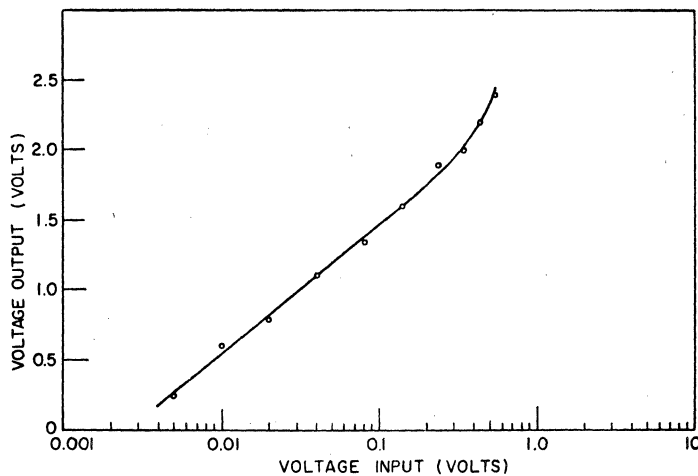

Fig. 5 - Logarithmic amplifier characteristic, using a cw rf signal gated through the traveling-wave tube as the input signal

Figure 6 shows a plot of output voltage versus input voltage using a 1-microsecond rectangular pulse at a prf of 5 kc as the input signal. The graph.shows a slight curvature at the high voltage end, but for the present application this is out of the operating range.

The above curves illustrate that the amplifier has accomplished its twofold purpose, since it can be seen that the dynamic range is reduced and the relation between input power in db and the output voltage is linear (the input power in db is proportional to the input voltage in db, Fig. 6).

The dc level of the base line is maintained by the diode D_2 and the coupling circuit between T_1 and D_1. At maximum output of 2.7 volts the dc level shift is 0.15 volt or 5.5 percent, at 1 volt output the shift is 0.025 volt or 2.5 percent, and at minimum output there is no detectable shift in the base line. It is apparent that the dc level shift is related to the output voltage, and at small signals where it would be a major concern it is not detectable.
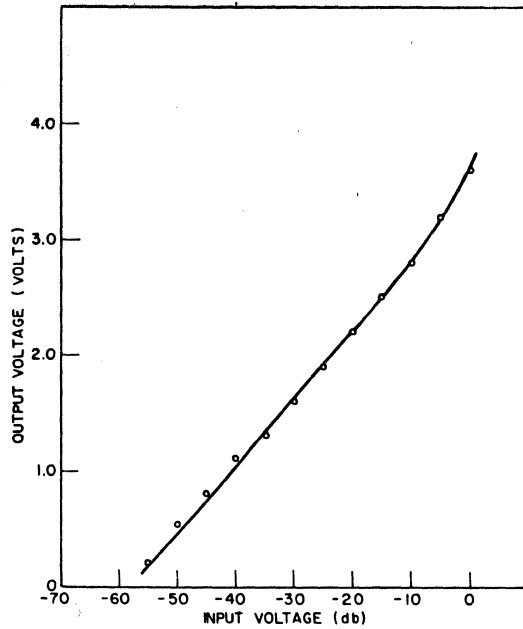
Fig. 6 - Logarithmic amplifier character-
istic, using a 1-microsecond rectangular
pulse at a prf of 5 kc as the input signal
(0 db = 5 volts)

CONCLUSIONS

The logarithmic amplifier discussed herein has been in operation for the past year
and has proven satisfactory in its present application. It is believed to be a versatile
piece of equipment, and with slight modifications could be used in many applications
where a logarithmic characteristic is desired.

If operation is desired with signals of other than positive polarity, alterations would
be necessary in the quiescent points of the transistors. Operating with signals of nega-
tive polarity would require that the polarity of the transistors be changed.

One outstanding feature of the equipment is its simplicity. The design incorporates
no complicated feedback arrangements to achieve the desired logarithmic characteristic.
Simplicity was considered as part of the design criteria to increase reliability and reduce
maintenance.