SEISMIC RECORDING OF PROJECTILE IMPACTS

VIA FM TELEMETRY LINK

William G. McDonald
Lamont-Doherty Geological Observatory of Columbia University
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Technical Report No. 2
CU-2-69
National Aeronautics and Space Administration
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INTRODUCTION

Impacts of meteoroids and spent Apollo components on the surface of the Moon are expected to provide important signal sources for ALSEP seismometers to be installed by Apollo astronauts. In anticipation of these impact events, a study of projectile impact phenomena has been undertaken by Lamont personnel at the White Sands Missile Test Range. An array of three geophones was established around the anticipated impact points for a series of missile impact tests. Geophone outputs were suitably processed and transmitted to an observation site where they were recorded on magnetic tape for later evaluation. A block diagram of the system is shown in Figure 1. This report describes the system employed in making the recordings and comments on problems and results.

Equipment

Equipment used in these experiments consists of:

1. Transducer Section: geophone/amplifier/voltage controlled oscillator systems which provide Frequency Modulated signals in response to ground motion (velocity).

2. Transmission Section: transmitter/antenna-antenna/receiver system which transmit and reconstruct the VCO output signal at the recording site.

3. Record Section: FM recorder/discriminator analog recorder systems which record the FM signals, convert FM signals to analog form,

and record the analog signals, and microphone/preamplifier system which provides an audio signal compatible with the FM recorder.

Details of system components are as follows:

1. Transducer Section

a) Geophones. 4.5 Hz geophones (Geospace Corporation HS-1 model K) with damping adjusted to 0.6 critical are used. Geophone response is shown in Figure 2.

b) Amplifiers. Seismic Amplifiers (Lamont P/N 12375/76) provide overall system gain of 72 db maximum and alternate gain settings 10 and 20 db below 72 db. Amplifier range is limited to $\pm$ 4.8 mv at the input (at 72 db gain).

c) Voltage Controlled Oscillator (VCO). Amplifier outputs drive voltage controlled oscillators with center frequencies (zero input) of 1500 Hz. VCO response (output frequency vs input voltage) is shown in Figure 3. The linear range of the VCO is 28 volts (+15 V to -13V). VCO sensitivity is 98.07 Hz per volt.

2. Transmitter Section

a) Transmitters. Transmitters are Motorola Type H 13 NBC 1100 (carrier frequencies 139.26 MKz, 142.32 MKz, and 143.22 MKz).

b) Transmitting Antennas. Each transmitter is provided with a conventional whip antenna. After considerable experimentation it became clear that the antenna required a ground plane in order for the signal to be received over any substantial distance (greater than 1/4

mile). This was not true during field tests of the equipment at non-desert locations. The substantially poorer transmission in the desert is probably due to the dryness of the environment and the corresponding absence of an effective natural ground plane. Elevation of both transmitter and receiver proved to be of only minimal effectiveness. Line-of-sight transmission was inadequate at 1.5 miles. Only a slight improvement was provided by elevation of the receiving antenna (25 ft). Establishment of a simple ground plane resulted in substantially improved signal reception.

c) Receiving Antennas. A 2-meter 43" beam receiving antenna is used for each channel (Hy-Gain Model 23-340).

d) Recivers. Motorola receivers (P/N H 03 ANC 1100C) are used.

3. Recording Section

a) Tape Recorder. Receiver outputs (FM) are recorded directly on an Ampex SP 700 four channel tape recorder.

b) Audio Signal. Audio signals generated at impact are monitored by a Sony Model F-98 microphone and recorded on the spare tape recorder channel after amplification by the Sony model 100 tape recorder amplifier.

c) Discriminators. Analog signals are recovered by playing the FM signals (either directly from the receiver outputs or from tape playback) into discriminators (Lamont P/N 12811) and recording the discriminator outputs on any suitable chart recorder. Discriminator

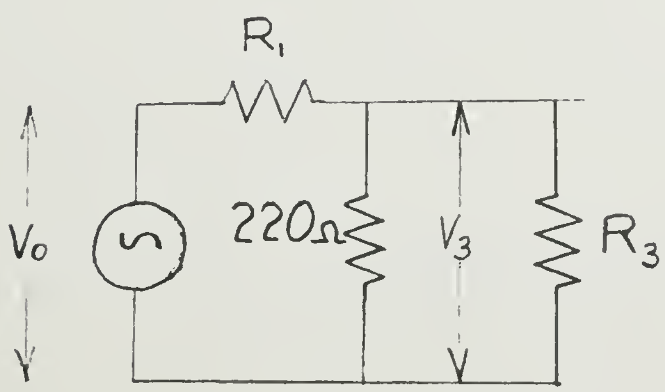
response (voltage out vs frequency in) is shown in Figure 4. Sensitivity is .0048 $\frac{\text{volts}}{\text{Hz}}$.

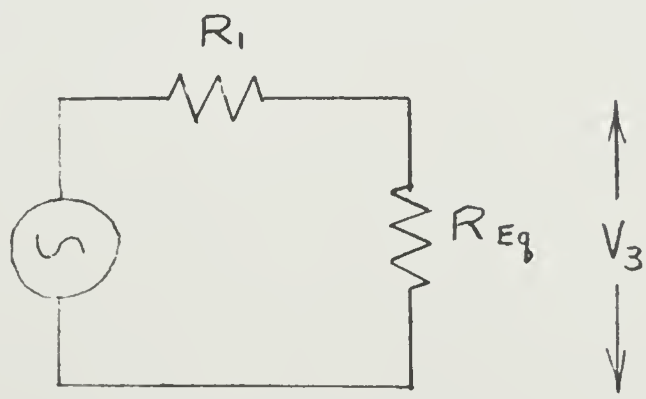
Inoperative transmitters required operation with less than a full complement of three remote recordings. For shots 1 and 2 a Sony 100 recorder was operated at geophone site 3a. For shots 3 and 4 geophone number three was installed at the observation/recording site (site 3b).

System Calibration - Frequency Response

System calibration was performed by driving the seismic amplifier with sinusoidal signals from a Wavetec function generator at frequencies between 0.5 and 100 Hz. Output was recorded on a Century Geophysical visible galvanometer recorder. Suitable correction of the resultant data for seismometer response, voltage divisions made during calibration, and frequency response of the visible recorder yield the response curve shown in Figure 5. The calibration system is shown in Figure 6.

The radio link is not included in the calibration system. Separate tests have demonstrated that system response is identical with and without the radio link. Frequency response of the amplifier/VCO/discriminator with a hard line replacing the telemetry link is shown in Figure 7.





$$V_o = I(R_1 + R_{eq})$$

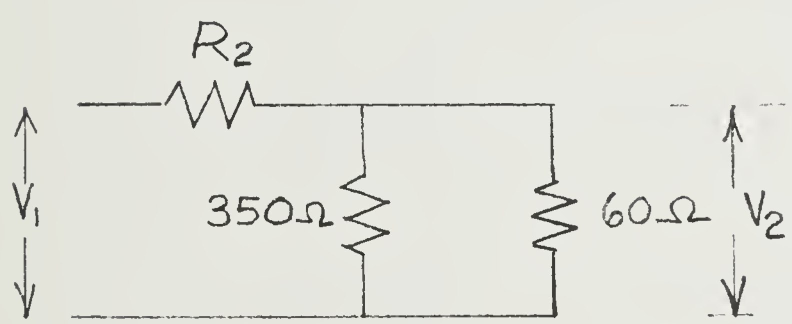
$$R_{eq} = \frac{220R_3}{220+R_3} \qquad R_3 = 511$$

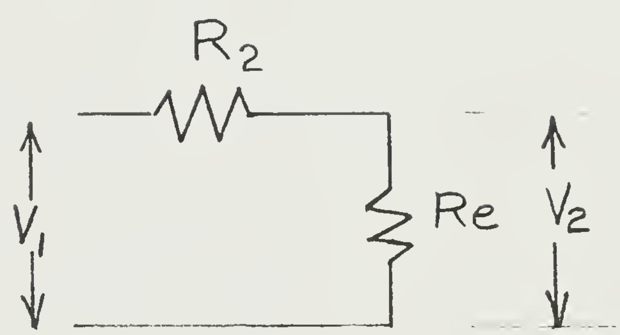
$$R_{eq} = 154$$

$$\frac{V_o}{V_3} = \frac{I(R_1 + R_{eq})}{I\,R_{eq}} = \frac{R_1 + R_{eq}}{R_{eq}} = \frac{154 + R_1}{154}$$

In all cases $R_1 = 300,000$

$$\therefore \frac{V_o}{V_3} = \frac{R_1}{154} \quad \text{or} \quad V_3 = V_o \frac{154}{R_1}$$





$$R_e = 51.2$$

$$V_1 = I_1 (R_2 + 51.2)$$

$$V_2 = I_1 (51.2)$$

$$R_2 = 40 \times 10^3$$

$$\therefore \frac{V_1}{V_2} = \frac{R_2}{51.2}$$

Next, find $\frac{V_1}{V_2} = \frac{\text{Discriminator Output}}{\text{Amplifier Input}}$

V_2 is obtained from calibration data.

$$V_2 = \frac{A}{Sg} = \frac{A}{11.3\ \frac{mm}{mv}} = \frac{A}{11.3} \times 10^{-3} \text{ Volts}$$

where

A = Trace amplitude on galvanometer recorder in millimeters

and

$$Sg = 11.3\ \frac{mm}{mv} \quad \text{(Galvanometer recorder sensitivity)}$$

$$V_1 = \left(\frac{V_1}{V_2}\right)\left(V_2\right) = \left(\frac{R_2}{51.2}\right)\left(\frac{A}{11.3}\right) 10^{-3}$$

$$V_1 = \frac{R_2 A \times 10^{-3}}{(51.2)\ (11.3)} \qquad V_3 = V_o \frac{154}{R_1}$$

$$V_3 = 3.68\ \frac{154}{R_1} \qquad V_o = 3.68V$$

$$\frac{V_1}{V_3} = \frac{R_1 R_2 A\, 10^{-3}}{(51.2)\ (11.3)\ (3.68)\ (154)} = \frac{R_1 R_2 A 10^{-8}}{3.29}$$

Therefore, the overall system response, P, is

$$P = \frac{V_1}{V_3} G$$

where G is the frequency dependent damped geophone sensitivity in $\frac{\text{Volts}}{\text{inch/sec}}$ as shown in Figure 2.

$$M = \frac{V_1}{V_3} \qquad G = \frac{R_1 R_2 A\, 10^{-8} G}{3.29}$$

$$M = \frac{R_1 R_2 A\, G_2\, 10^{-8}}{4.67} \qquad \frac{\text{Volts}}{\text{in/sec}}$$

$$M\omega = \frac{R_1 R_2 A\, G_2\, 10^{-8}}{4.67} \quad 2\pi f \qquad \frac{\text{Volts}}{\text{inch}}$$

where f = driving frequency, cycles/second

$$M\omega = \frac{R_1 R_2 A\, G_2 (2\ \ )\, 10^{-8}}{4.67} \quad \frac{10^{-4}}{2.54} \quad f \qquad \frac{\text{Volts}}{\text{micron}}$$

This expression for $\frac{\text{volts}}{\text{micron}}$ of ground motion is plotted against frequency in Figure 5.

Test Results

Ground motions from four separate missile impacts have been recorded. The following results were obtained:

Shot #1 - April 1969. Recorded FM output from geophone #3 directly on Sony tape recorder - excellent recording. Radio links inoperative. Therefore, no data recorded from geophones #1 and #2. Audio recording of air blast on Ampex channel #3. Geophone located 0.423 km from impact point.

Shot #2 - April 1969. Same recording as Shot #1. Geophone #3 located 0.402 km from impact point.

Shot #3 - April 1969. Recorded data from all three geophones. Data from geophone #3 recorded on Ampex channel #4 only - noisy but reasonably good signal. Data from geophones #1 and #2 are intermittent. Signal is recorded but frequent noise bursts make discrimination of signal difficult. Data from phone #2 usable. Data from #3 not usable.

Shot #4 - April 1969. Again recorded all channels. Excellent recording of geophone #3 on both Sony and Ampex. Geophones #1 and #2 apparently dropped out prior to shot time - receivers had been operating intermittently during setup period. Audio signal was not recorded.

System and Procedure Improvements Suggested for Future Operations

Maintaining continuous operation of the radio links has been a difficult problem throughout this program. Transmitter and receiver failures have occurred frequently - several times with serious impact on the program. A different transmitter/receiver set with higher reliability and higher transmitted power level would correct the most serious equipment problem. Spare transmitters and receivers for each operational frequency would enhance the reliability of the system.

The primary operational problem encountered in this test program involves authorization for an operator to remain at the observation/recording site during the flight/impact period and the delays in projectile impact times imposed by holds in missile launch cycles. If, in future operations,

we are not authorized to remain at the recording site during impact, then a command system should be developed for turning the recording systems on and off from whatever observation site is authorized. Alternately, telemetry range could be extended to permit recording at an allowable observation site.

Greater attention must be paid to protecting all of the equipment from penetration of the dust-like sand that covers the entire range. Tape recorders are particularly vulnerable to penetration of this material.

Discussion

It is expected that Apollo/Saturn IVB stages as well as other spent Apollo components will be directed to impact on the lunar surface after installation of ALSEP seismographs. Results of the present study will be used to select impact points in order that the impact events be of maximum value in supplementing natural lunar seismic events in the evaluation of lunar internal structure.

Applicability of results derived from these missile impact tests to interpretation of meteoroid impact data from the surface of the moon is clearly limited by the difference between the two impact mechanisms. At meteorite velocities impact is explosive and both the meteorite and part of the target are vaporized. At missile impact velocities, impact is characterized by fragmentation rather than vaporization.

Extrapolation of elastic wave generation phenomena between these two impact velocity regimes is inexact at best.

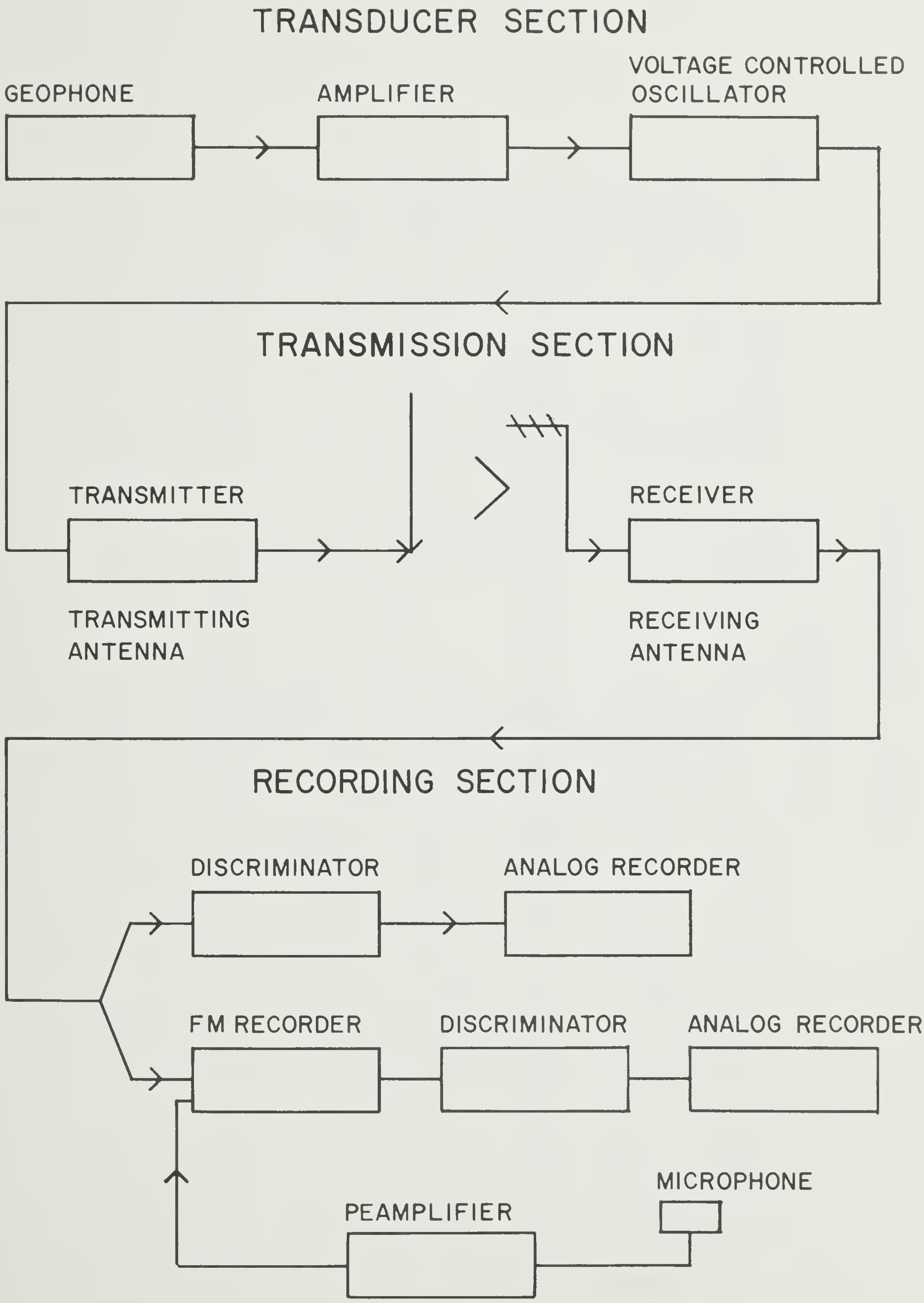


Figure 1. Projectile impact recording system block diagram - only one of three channels shown.

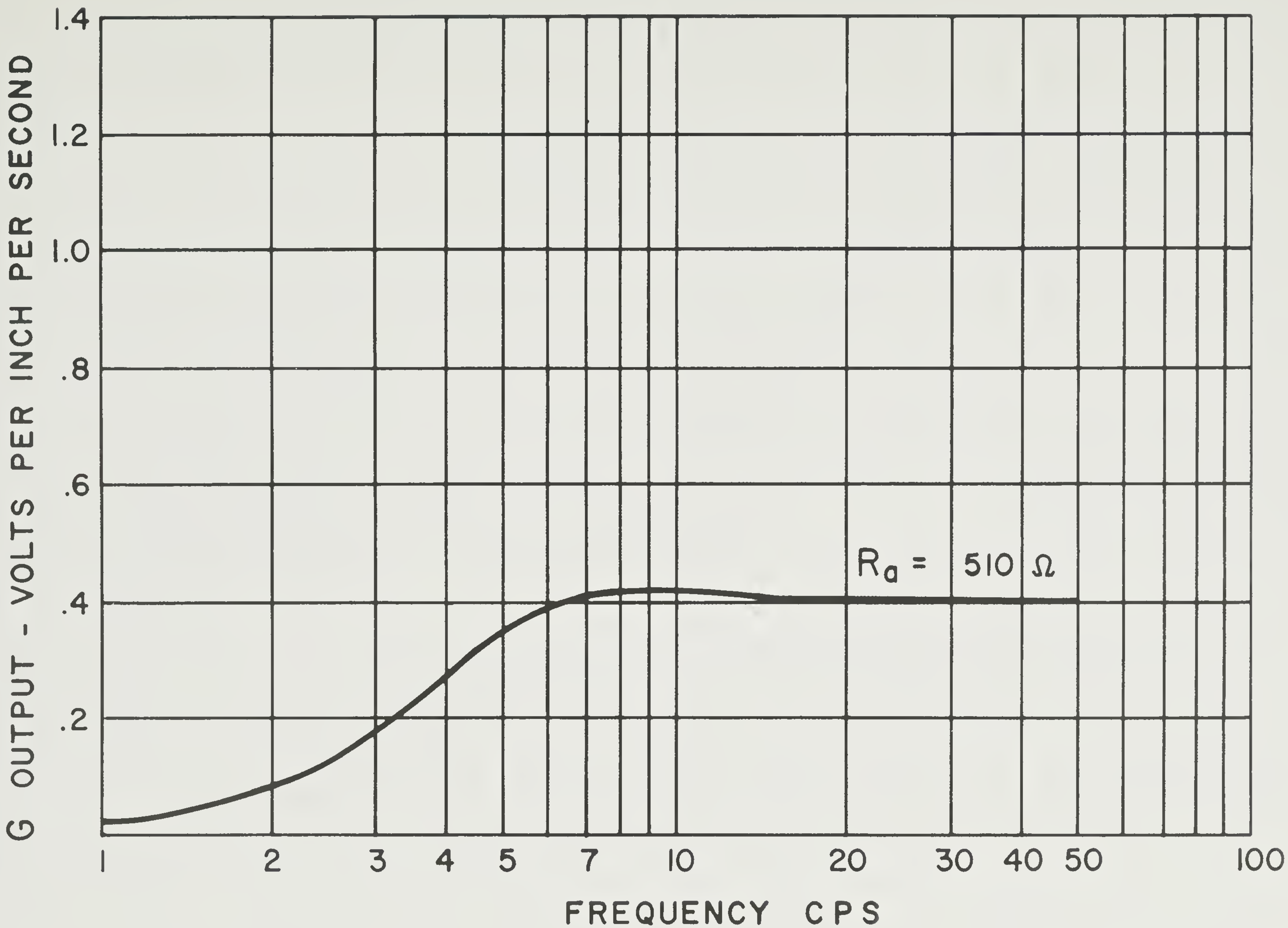


Figure 2. Geophone Response

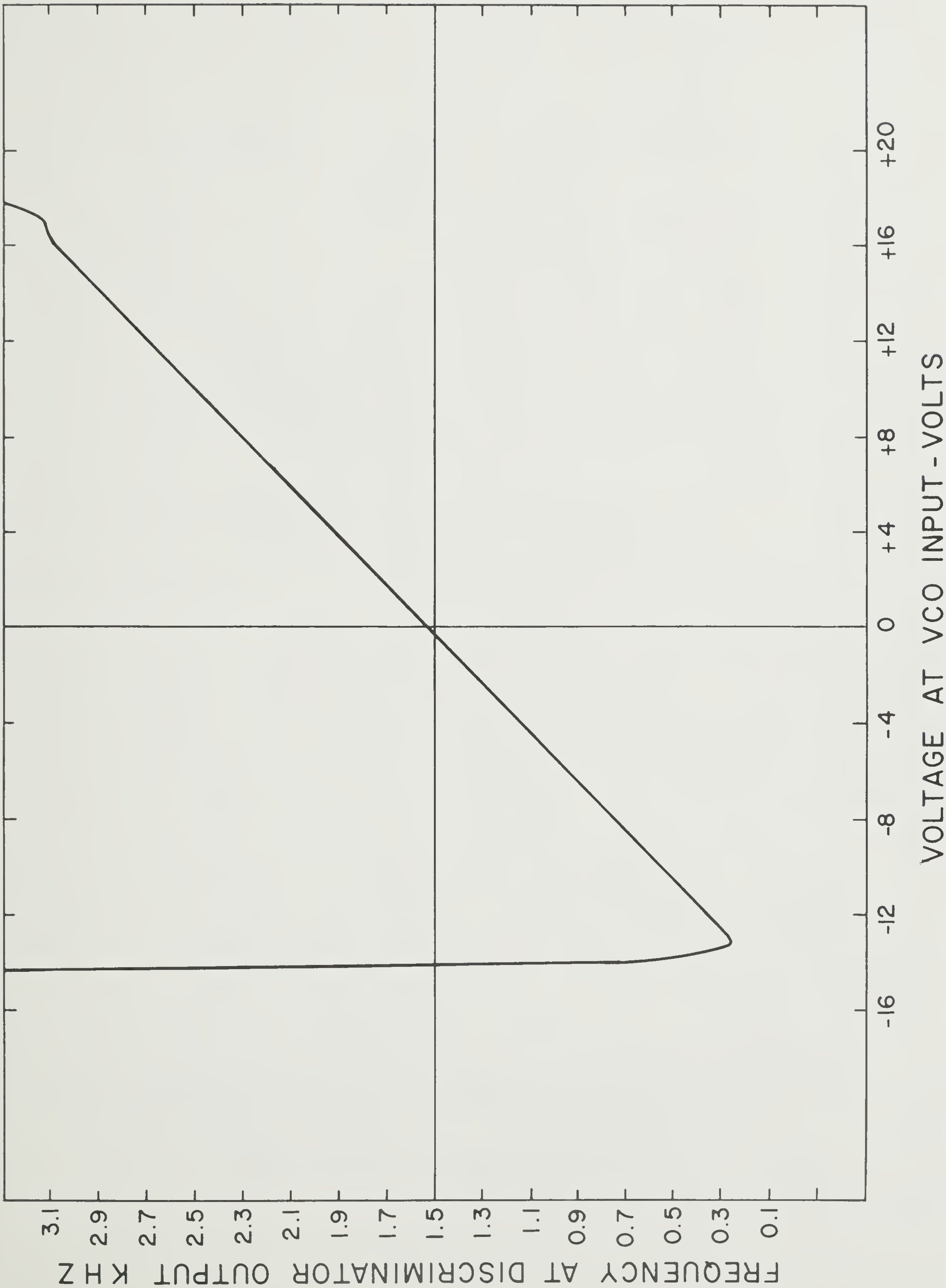


Figure 3. VCO frequency response

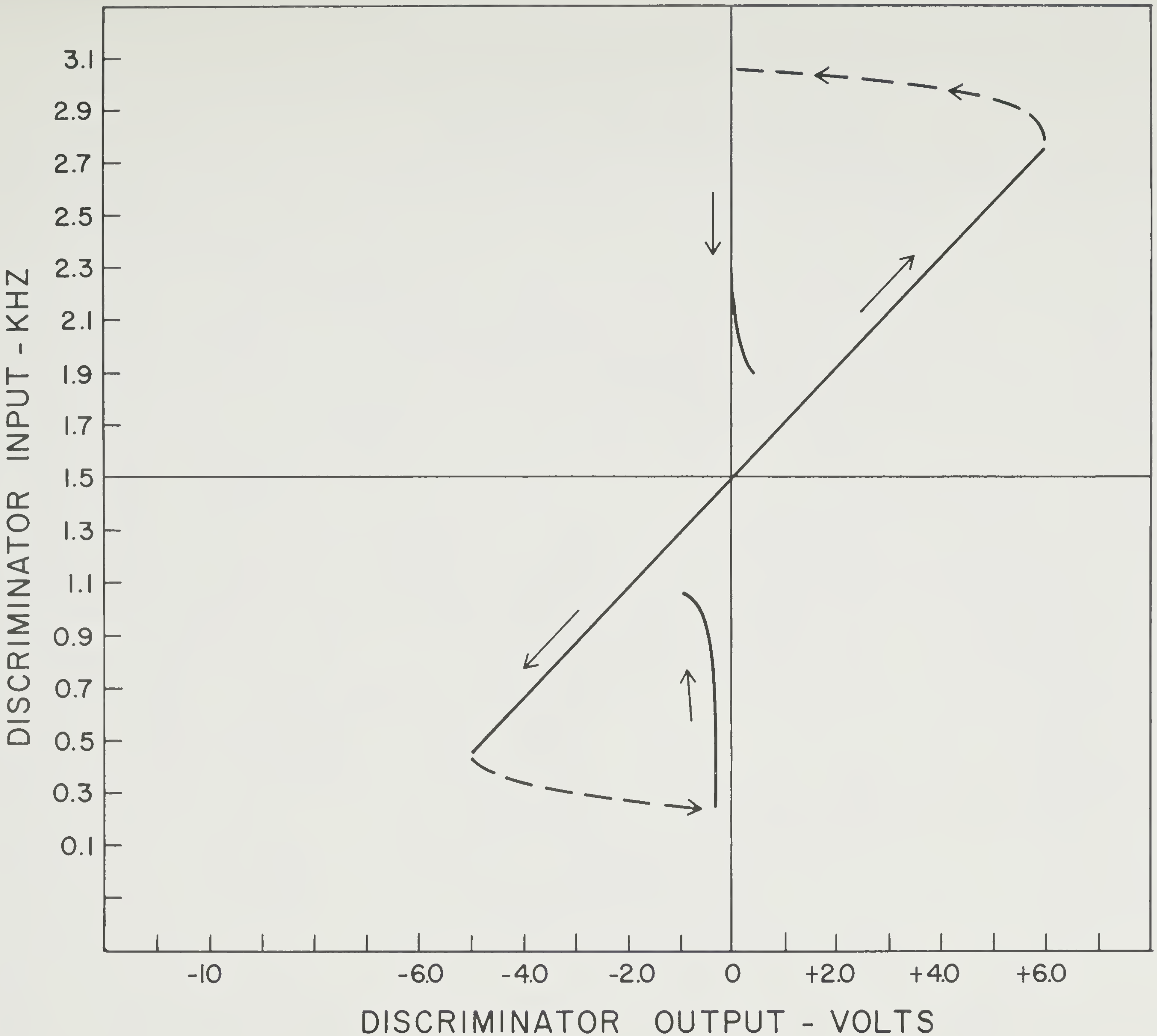


Figure 4. Discriminator response

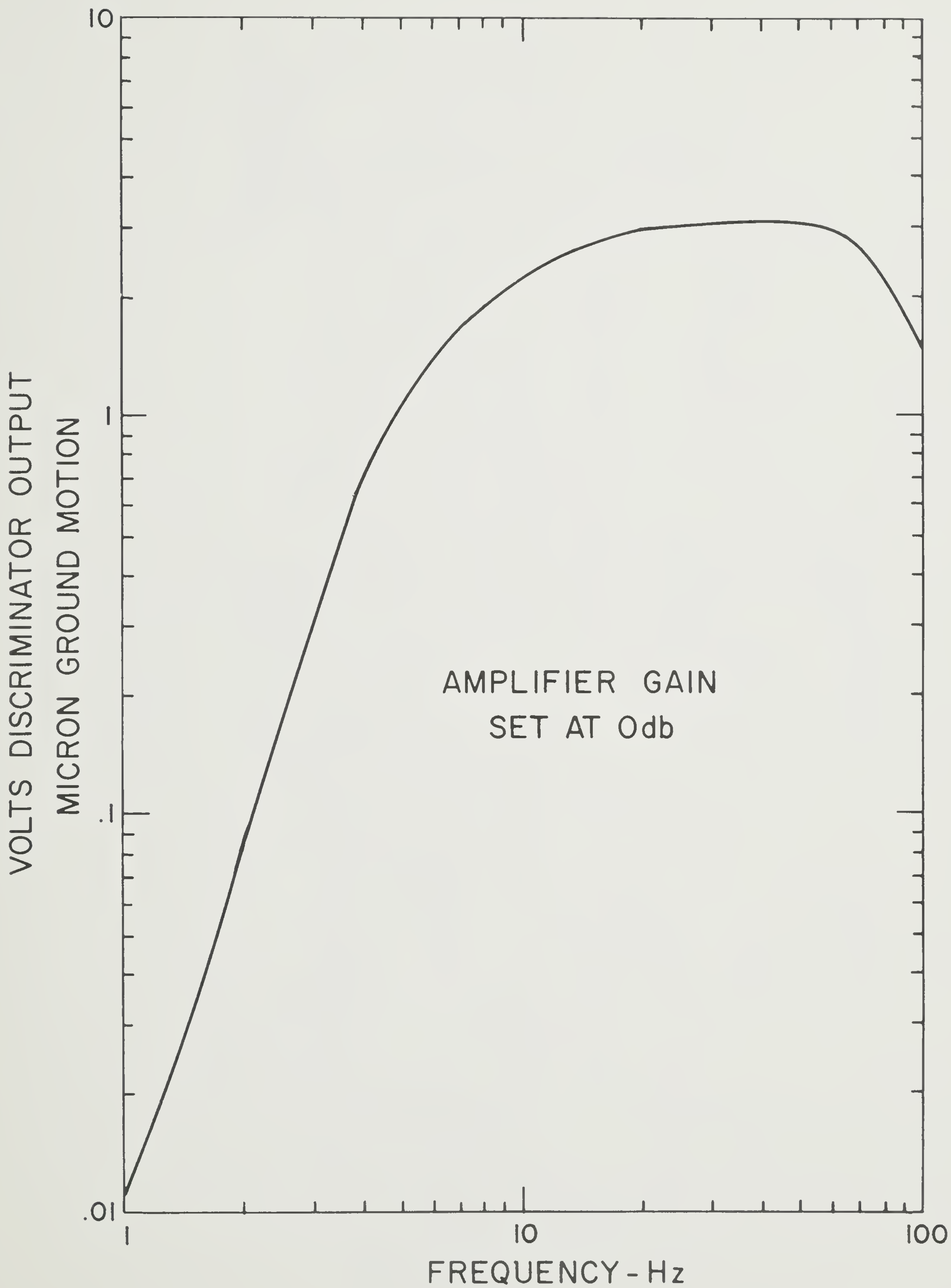


Figure 5. Overall system frequency response

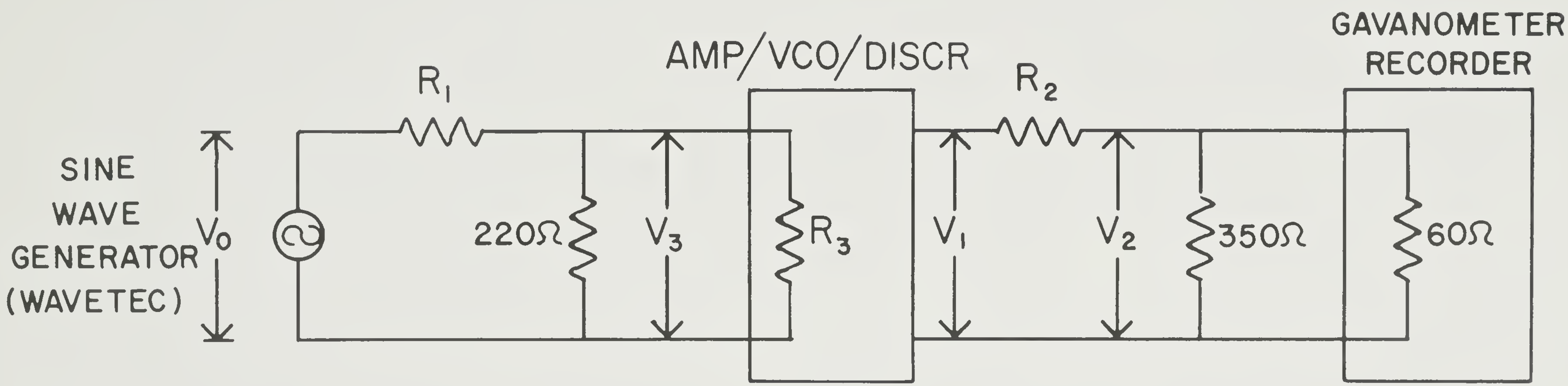


Figure 6. Calibration system

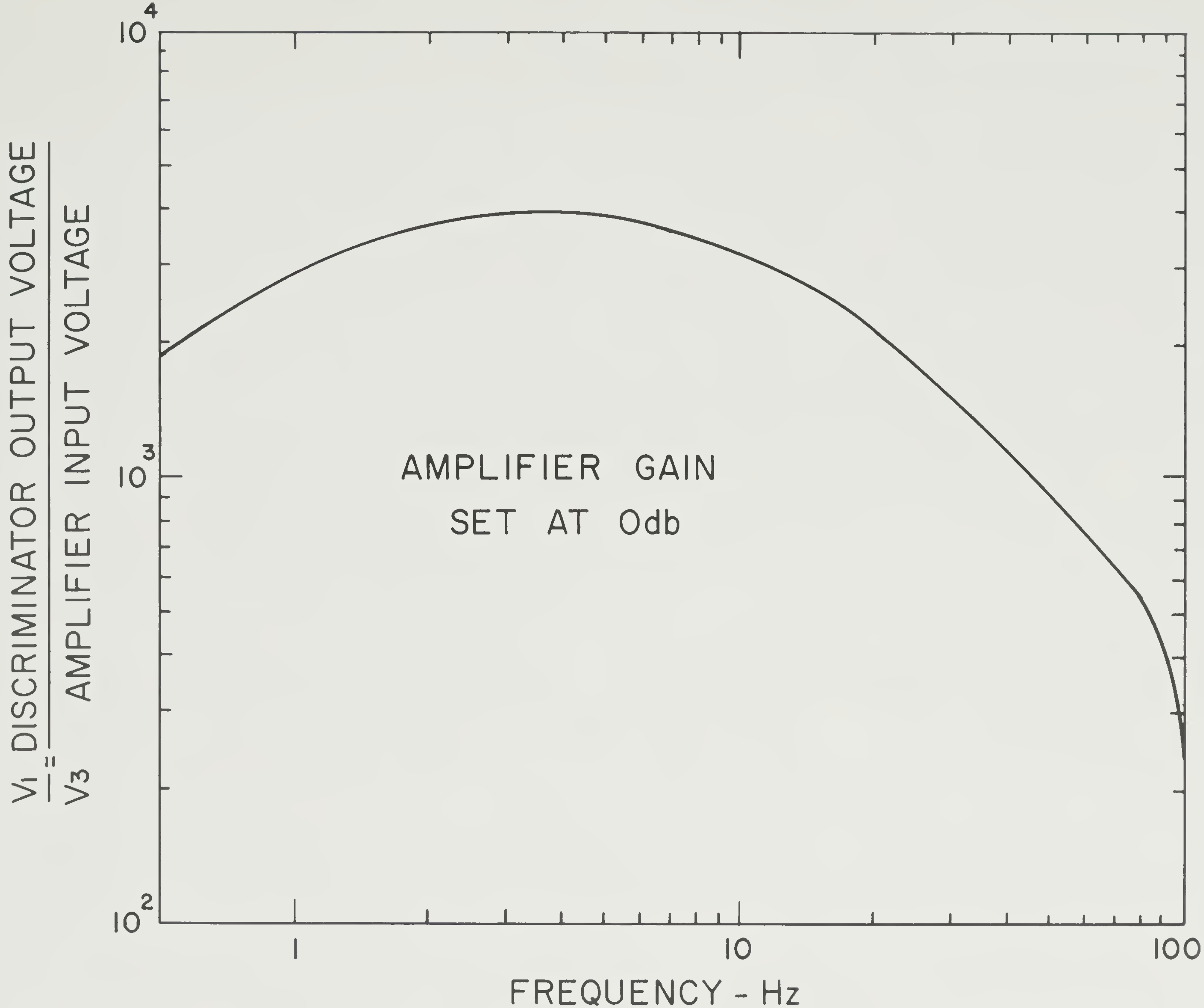


Figure 7. Amplifier/VCO/Discriminator frequency response