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AN INSTANTANEOUSLY-RESPONDING EXPANSION AMPLIFIER: A METHOD AND DEVICE FOR SIGNAL ENHANCEMENT IN NOISY COMMUNICATION SYSTEMS

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13. ABSTRACT

Electronic communication systems become unusable when relative levels of desired signal and system noise fall below critical values, typically 6 dB or less. A variable-gain amplifier having instantaneous response-time has been designed, constructed and tested, to enable recovery of a usable audiofrequency signal from noisy analog and digital systems. For 1-dB increments in signal-level at or above -40 dBm, this device will provide increments on the order of 5 dB, over the frequency-range 50 to 10,000 cps. The rise and decay envelope is apparently symmetrical, with slopes approximating one millisecond. This report discusses design features, including a modification for analog speech signals, and gives detailed results of laboratory and field tests. Upon application through Hq AFSC, the U. S. Patent Office has assigned patent application number 372433 to the device, as of 3 June 1964.

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A Method and Device for Signal Enhancement in Noisy Communication Systems

ABSTRACT

Electronic communication systems become unusable when relative levels of desired signal and system noise fall below critical values, typically 6 dB or less. A variable-gain amplifier having instantaneous response-time has been designed, constructed and tested, to enable recovery of a usable audiofrequency signal from noisy analog and digital systems. For 1-dB increments in signal-level at or above -40 dBm, this device will provide increments on the order of 5 dB, over the frequency-range 50 to 10,000 cps. The rise and decay envelope is apparently symmetrical, with slopes approximating one millisecond. This report discusses design features, including a modification for analog speech signals, and gives detailed results of laboratory and field tests. Upon application through Hq AFSC, the U. S. Patent Office has assigned patent application number 372433 to the device, as of 3 June 1964.

REVIEW AND APPROVAL

This technical documentary report has been reviewed and is approved.

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KEY WORD LIST

1. COMMUNICATION SYSTEMS
2. AMPLIFIER EXPANSION
3. NOISE (AUDIO)
4. MODELS
5. EXPERIMENTAL DATA
6. SIGNAL ENHANCEMENT

INTRODUCTION

In electrical communication systems, the problem of recovering a usable signal from background noise may be attacked in two ways. In the first instance, when signal and noise differ considerably in frequency-spectrum and but slightly in amplitude, signal-enhancement by frequency differentiation may be employed - for example, by selective filtering. In the second instance, where the spectra of signal and noise resemble each other but signal levels run a little (but not usefully) higher than those of noise, discrimination may be achieved in the amplitude dimension only, by use of nonlinear (i.e., variable gain) amplification.

The device to be discussed in this report falls in the second classification - separation of signal from noise by increasing the signal/noise amplitude difference, without reference to the frequency spectrum occupied by either. Generally speaking, the device functions as a "volume-expanding" amplifier; that is, a non-linear amplifier whose gain, or amplification factor, depends on the amplitude-level of the signal impressed across its input terminals. Thus a voltage of low initial amplitude receives less effective amplification than does a voltage of higher initial amplitude. In a noisy communication system, when signal-levels are consistently above noise-levels, but inadequate for reliable communication, the signal-to-noise relationship would be increased by action of this amplifier, and a usable signal recovered.

The ensuing sections of this report present the operating principles, a description of the circuit employed, and results of performance-measurements taken in the laboratory on a developmental model.

PRINCIPLES OF OPERATION

The variable-gain feature of this amplifier depends on the derivation of a d.c. bias voltage from the signal (or signal-plus-noise) impressed across its input terminals. This bias varies with instantaneous signal amplitude, and works to increase the overall gain of the amplifier by varying the location of the Class A operating point along the amplifier's transfer-function curve. Essentially instantaneous response of overall gain to change of input signal level is achieved by avoidance of filter or storage circuits in the signal-rectifier and control-bias sections. The signal-derived bias voltage is delivered to the control-grid of the variable-gain amplifier at a polarity negative with respect to ground, producing a reduction in conductance through the controlled amplifier which has the effect of reducing voltage-drop across its unbypassed cathode-bias resistor, and consequent descent of the tube's operating point. This effect is further enhanced by maintenance of optimum d.c. relationships among cathode, screen-grid and plate of the controlled (i.e., variable-gain) amplifier. The output circuit is so designed as to maintain a light and unvarying load on the plate of the controlled amplifier.

DESCRIPTION OF CIRCUIT

Present developmental models of the variable-gain amplifier employ vacuum-tube circuitry. Figure 1 identifies the principal components in block-schematic form: an input amplifier-rectifier, the controlled amplifier, and an output cathode-follower. Audio-frequency signal voltage from a source is impressed, through a line-to-grid transformer, upon the

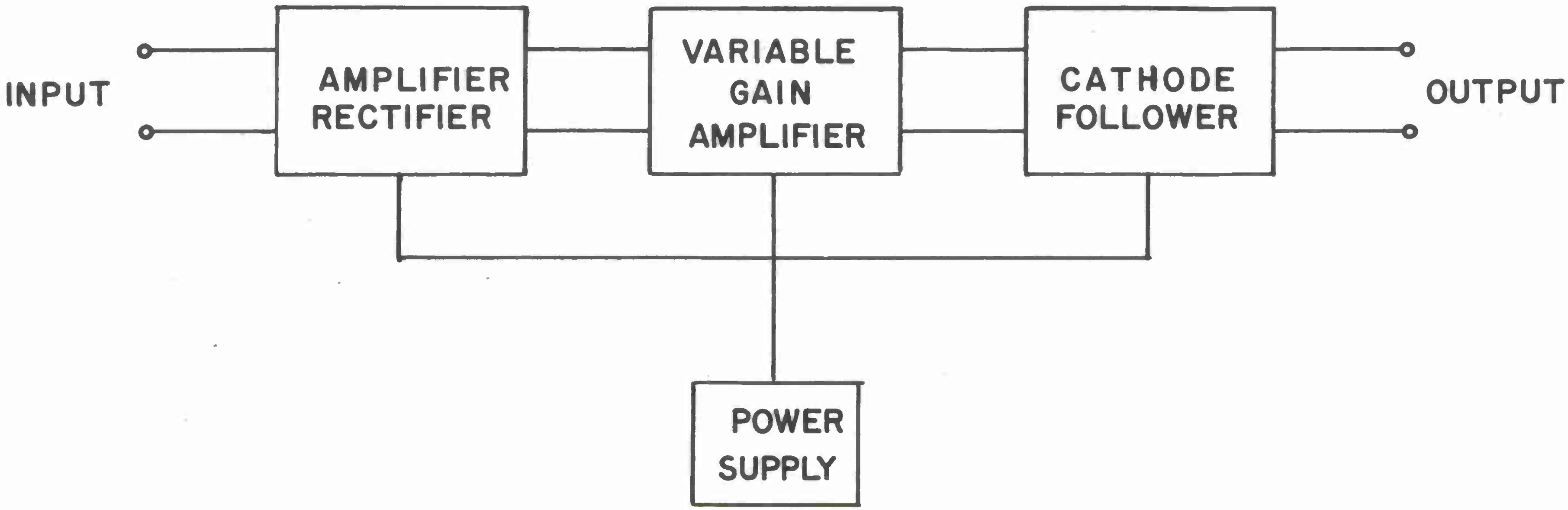


FIG. I BLOCK-SCHEMATIC DIAGRAM OF SIGNAL-OPERATED VARIABLE-GAIN AMPLIFIER control grids of both the amplifier portion of the amplifier-rectifier unit, and the controlled amplifier. The former is a medium-mu triode, the latter a sharp-cutoff pentode. Signal output voltage appearing at the plate of the triode is rectified in a half-wave diode circuit; the rectified unfiltered d.c. signal voltage is applied to the control grid of the pentode, such that an increase in the level of signal across the input terminals produces a shift in the operating-point of the controlled amplifier. Signal voltage developed across the output of the controlled stage is applied to a cathode-follower, thence to an output transformer whose secondary impedance matches that of subsequent circuits. In the controlled stage, d.c. reference voltage-differences between control-grid and cathode, cathode and screen-grid, and screen-grid and plate are maintained at appropriate levels by use of a voltage-divider between ground and B+ potential. The level of rectified signal-voltage applied to the control-grid of the controlled stage is established by means of a potentiometer across the rectifier output. Plate-voltage for all three stages is supplied by a conventional rectifier-filter circuit.

LABORATORY TESTS AND RESULTS

Two experimental models of the basic design have been subjected to the following tests:

1. Overall audio frequency response;
2. Output transfer characteristic for a single-frequency signal presented to the input at discretely-varied signal;
3. Dynamic response to a noise-free amplitude-modulated single-frequency signal.

The following paragraphs describe these tests, and discuss the results.

1. OVERALL AUDIO FREQUENCY RESPONSE

Figure 2 shows the frequency-response characteristics of the expander-amplifier, taken at a constant level of input signal below expansion threshold. From these curves it may be seen that both units are essentially flat within 1 dB over the range 50 to 10,000 cycles per second.

2. OUTPUT TRANSFER CHARACTERISTIC

Figure 3 shows, in solid line, the input-output transfer characteristic of the expander-amplifier in dB above the levels of linear signal amplification, for a steady-state tone of 1000 cps. The broken line shows linear amplification referred to the same signal levels; the magnitude of dispersion between the solid and broken lines is indicative of signal expansion effects due to operation of the circuit. A maximum expansion of about 55 dB is available for an input signal 30 dB above the onset of nonlinearity. The point of origin (0 dB) represents a power level of -65 dBm of input signal, and -45 dBm of output signal.

3. DYNAMIC RESPONSE TO A NOISE-FREE AMPLITUDE-MODULATED SIGNAL

To assess the expander-amplifer's response to sudden changes of level in the input signal, as well as to reveal the shape of rise and decay envelopes associated with such changes, the test set-up of Figure 4 was utilized. A steady-state audio frequency signal from the A.F. signal generator was chopped by an electronic switch into on-off bursts of about 100 milliseconds duration, at a rate of ten per second, with a duty cycle of approximately 50%. This was passed through the device at an input level of -50 dBm, displayed on an oscilloscope and photographed. Resulting photo-oscillograms are shown in

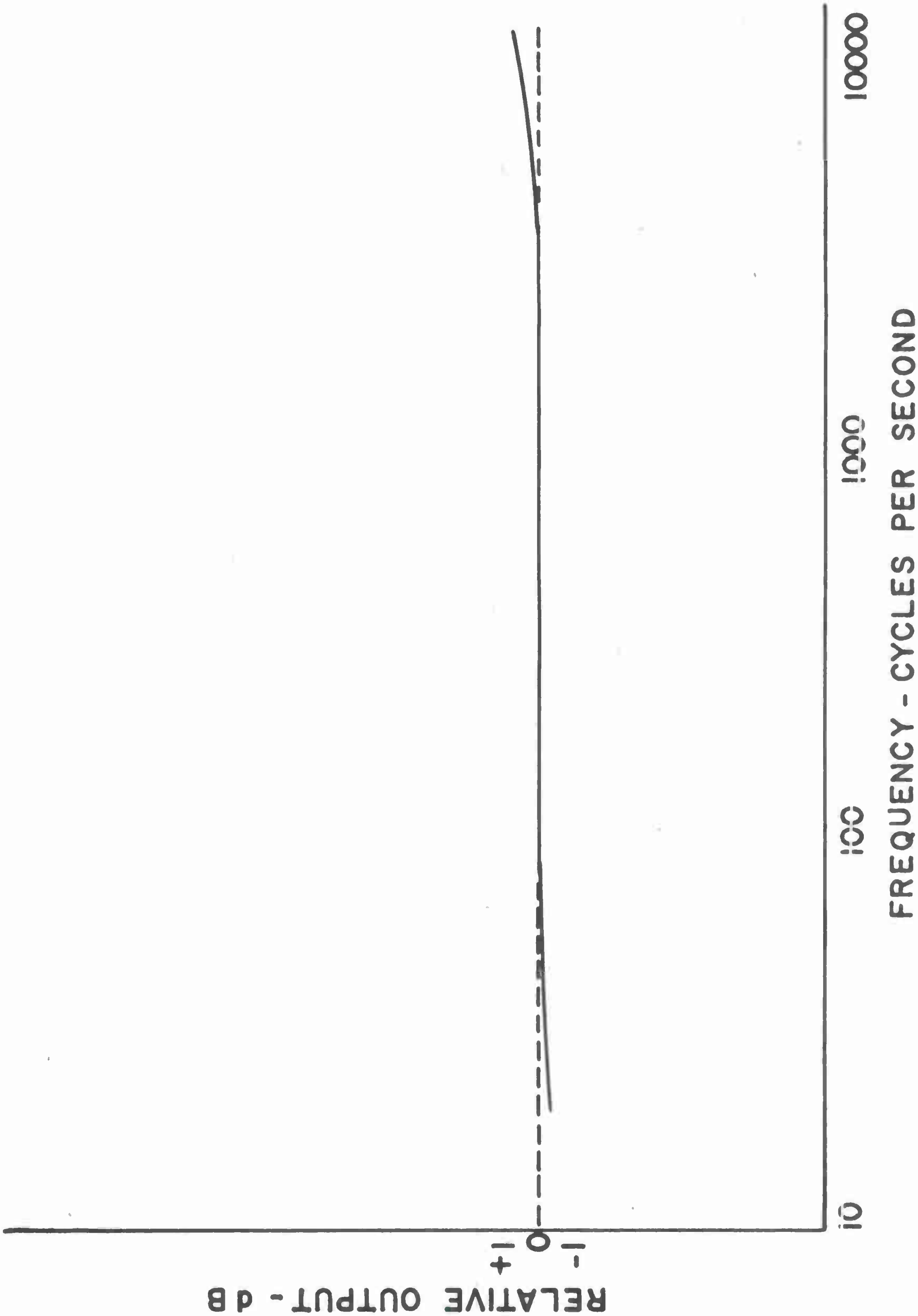


FIG. 2 FREQUENCY RESPONSE

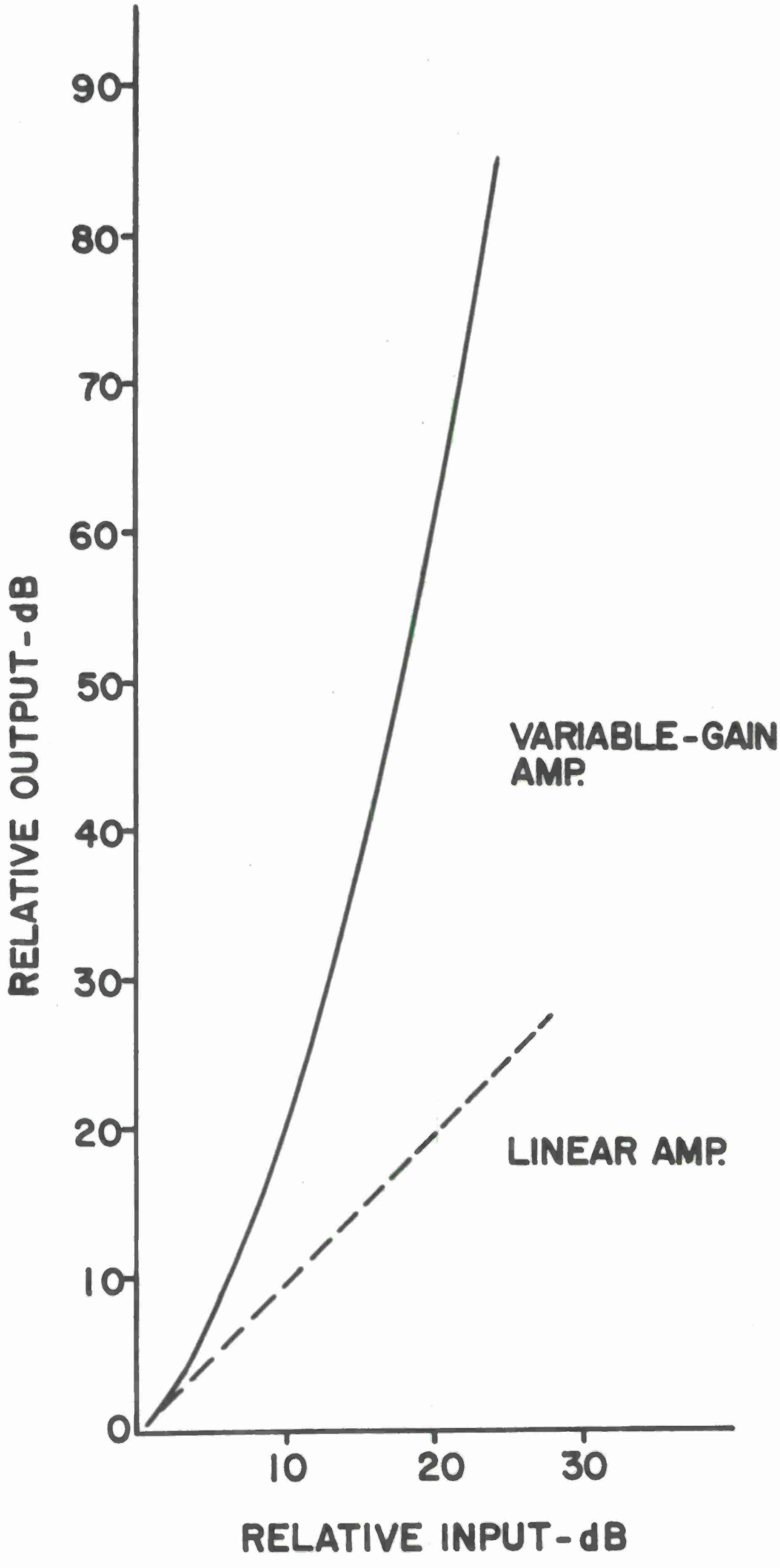
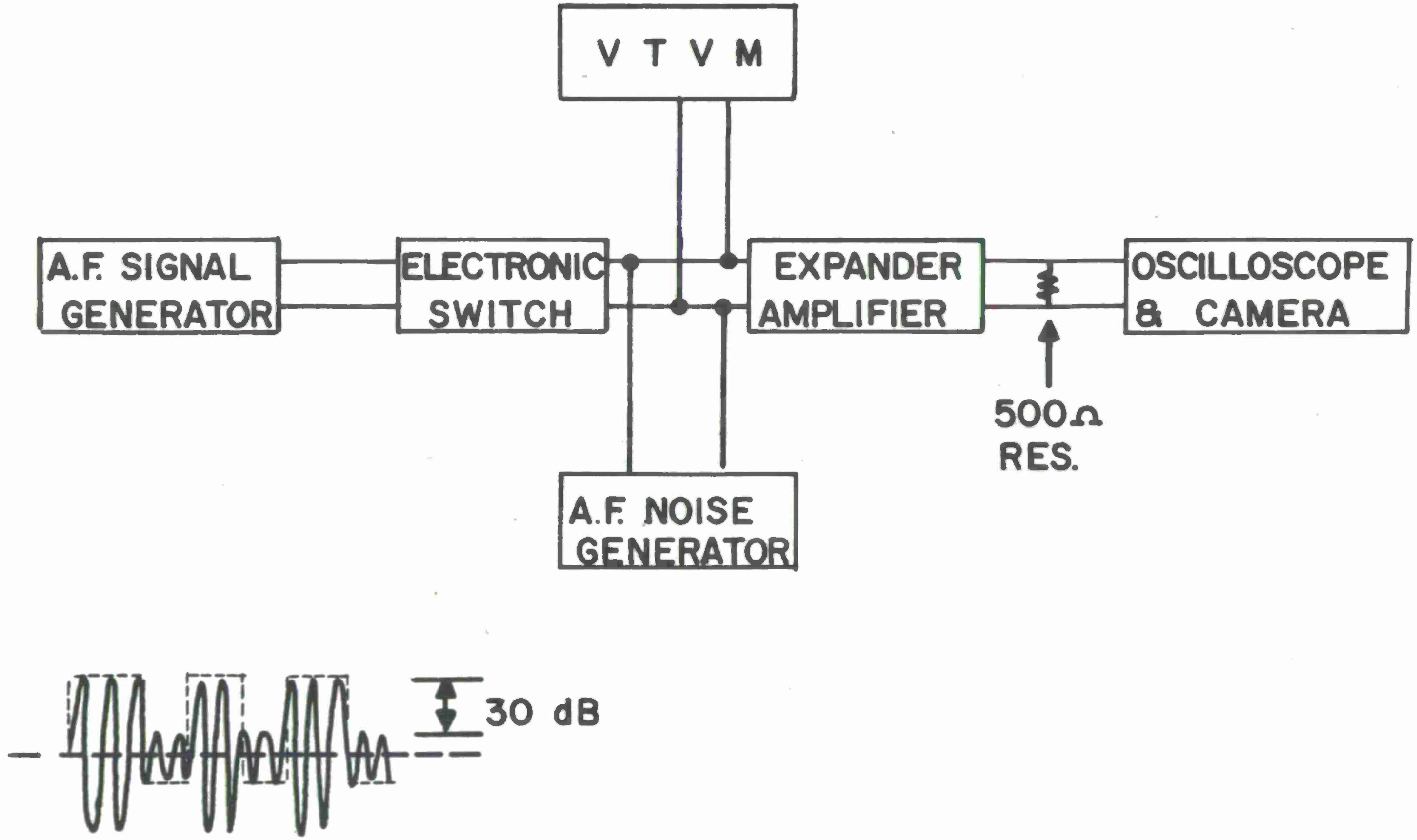


FIG. 3 INPUT-OUTPUT CHARACTERISTIC



Pattern of modulated tone

FIG.4 APPARATUS FOR RECORDING RESPONSE TO SQUARE-WAVE MODULATED TONE

Figure 5, 5-A being the pattern for a signal frequency of 1000 cps, 5-B for 5000 cps. From Figure 5-B it is concluded that rise and decay times are approximately equal, and appear to be less than one millisecond. Variations appearing in the zero-line and on the edges of the envelope pattern are due to residual hum voltage in the electronic switch.

4. DYNAMIC RESPONSE TO A NOISY AMPLITUDE-MODULATED SIGNAL

To test the unit's effectiveness in recovering a signal from background noise, the instrumental set-up of Figure 6 was devised. A 1000-cycle tone from the Signal Generator was chopped into 60-millisecond on-off segments by the Electronic Switch, then mixed with continuous white noise from the Noise Generator, the composite signal-plus-noise being put into the expander-amplifier at -45 dBm, with S/N = 3dB. The output from the expander was displayed on the Oscilloscope and photographed. Figure 7-A shows input signal-plus-noise for this condition, and Figure 7-B the resulting output. It will be seen that enhancement of signal-plus-noise to noise has been achieved.

CONCLUSIONS

Results of the foregoing tests lead to the following conclusions:

1. The expander-amplifier exhibits an input-output transfer characteristic whose slope depends on input signal level; that is, its gain-factor varies as a function of the amplitude of signals impressed upon its input terminals. It appears that an increase of 1 dB in input signal can produce a maximum increase of approximately 5 dB in output signal.

2. The signal-expansion achieved is independent of frequency.

3. Rise and decay times are equal, and about one millisecond long.

4. Where signal is somewhat above background noise-level, the expander appears to increase the effective signal-to-noise condition.

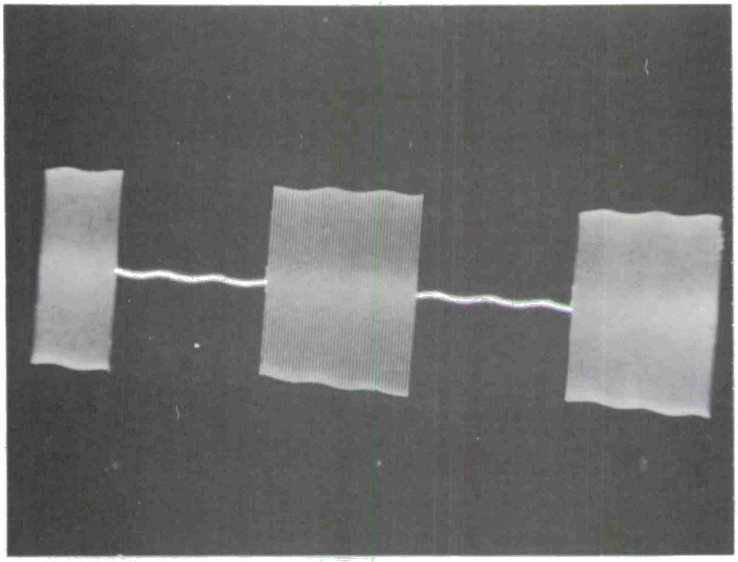


Fig. 5-A Pattern for Signal Frequency of 1000 cps.

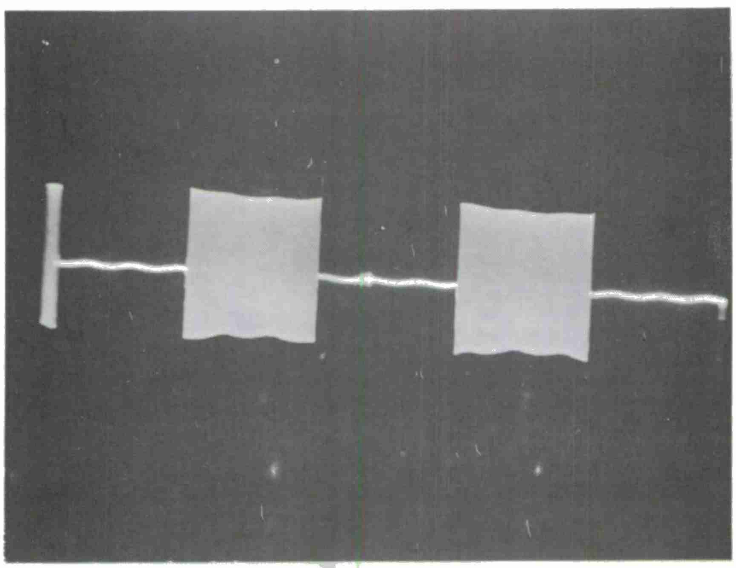


Fig. 5-B Pattern for Signal Frequency of 5000 cps.

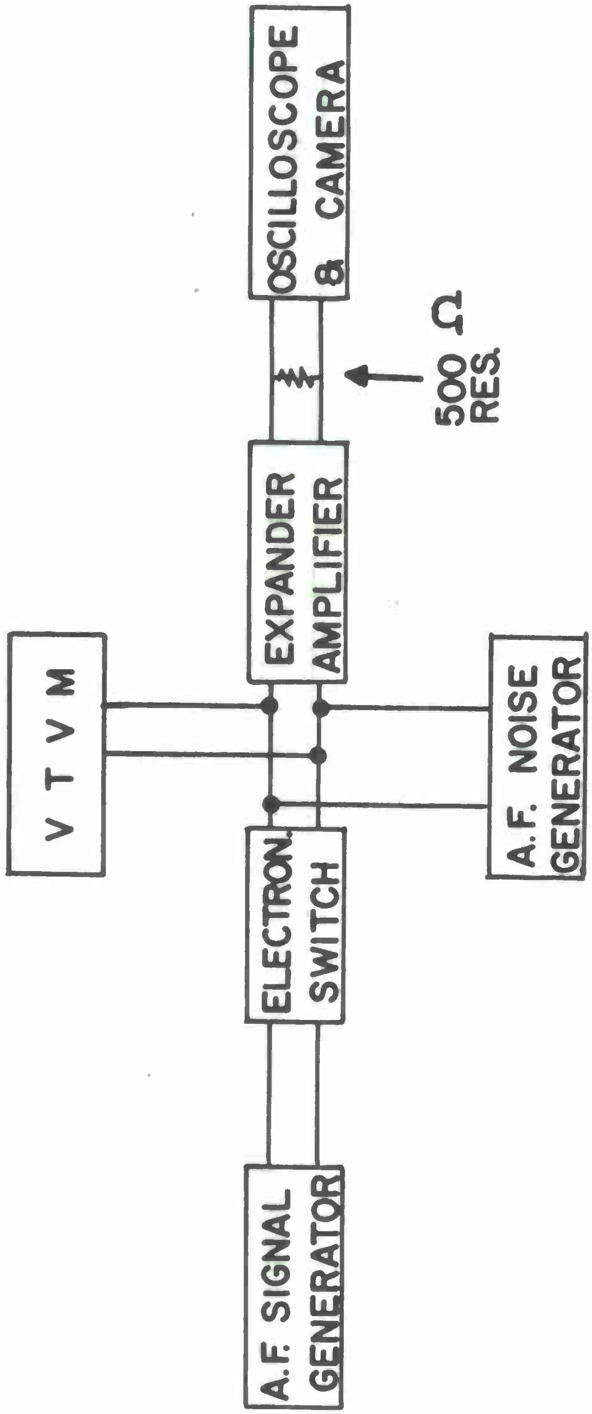


FIG.6 APPARATUS FOR DETERMINING EFFECT OF EXPANDER-AMPLIFIER ON SQUARE-WAVE MODULATED SIGNAL IN NOISE.

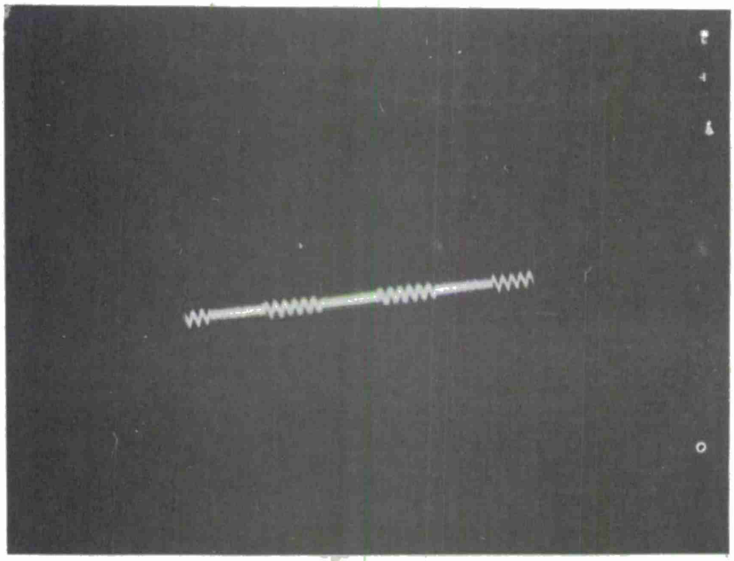


Fig. 7-A Input Signal

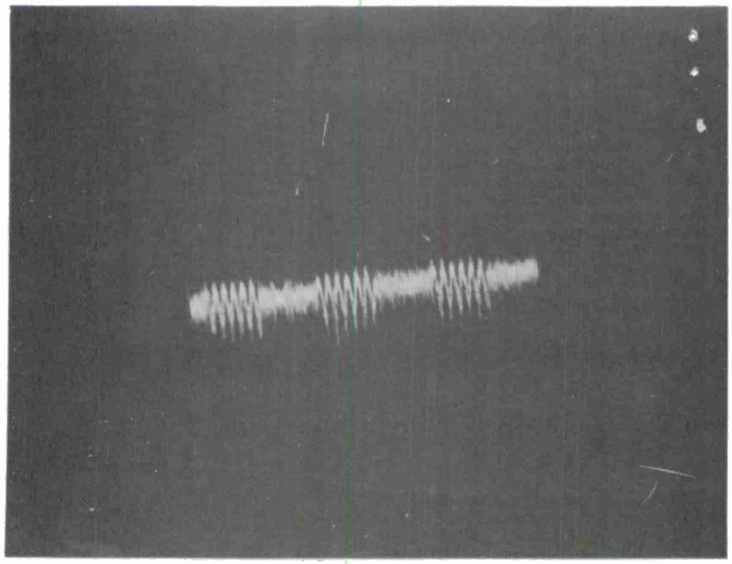


Fig. 7-B Output Signal

APPENDIX I

PRELIMINARY TRIAL ON NOISY RADIOTELETYPE SYSTEM

Using facilities provided by the Military Affiliate Radio System (MARS) station at L. G. Hanscom Field, operating tests were conducted in the following manner.

A local radioteletype loop was established consisting of a transmitting reperforator, frequency-shift r.f. exciter, radio receiver, audiofrequency noise generator, the experimental expander-amplifier, teletype converter (AN/URA-8A), and teleprinter. Test messages were transmitted via closed radio link from the frequency-shift exciter to the receiver, whose output was connected through the expander to the converter and then to the teleprinter. The noise generator was bridged across the line between the receiver output and the expander input, to permit control over signal-to-noise conditions. By measurement of steady-state (unmodulated "mark" signal) teletype output of receiver, with noise generator off, and then measurement of noise from generator with teletype signal off, a signal-to-noise ratio of less than 3 dB was established at the expander input terminals. During transmission of test messages, the expander was alternately switched into and out of the circuit. The following excerpts from test messages are annotated to show the effect of expander action under these conditions.

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6VQKYLQYUQQXKQXXVFXGVCZXWVKCZBQKQKKXKF(XGWYXV'XBFXGXNOW IS THE TIME FOR A

 GOW IS THE TIME FOR ALL GOOD MEN TO COME TO THE AID OF THEIR COUNTRY.
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KO886&/;0;21!9 .3, 59 .5 59.55 -8.91 538 :07,546.
THIS IS A MAINT TEST RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYR
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THIS IS A MAINO TEST RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRYR
NOW IS THE TIME FOR ALL GTTEEEEEEEEE OIS THE TIME FOR ALL GOOD MEN TO COM
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APPENDIX II

MODIFICATION FOR ANALOG SPEECH SIGNALS

While the device described in this report was designed primarily for use in audio-frequency teletype and data systems, the possibility of using it in voice-communication circuits has been considered. A circuit modification was installed, selectable by a two-position switch, for the purpose of reducing signal-expansion by about one-half, in order to accommodate the dynamic range of speech signals. The effect of both the original and the reduced expansion characteristics were tested in the laboratory, utilizing the Air Force Modified Rhyme Test of word intelligibility. Word lists were transmitted both in quiet and against white-noise background, simulating the performance of a degraded system. The following results were obtained:

EXPANSION	SYSTEM CONDITION	WORD INTELLIGIBILITY %
None	Quiet	98.5
Modified	Quiet	99.0
None	Noisy	86.5
Modified	Noisy	83.5
Original	Noisy	88.5

It is concluded from these findings that the device, with modified expansion, does not degrade speech in a quiet system, although it fails to improve intelligibility in a noisy system. While the original expansion characteristic would appear to slightly enhance intelligibility, the enhancement is probably not significant in either a practical or statistical sense. The above finding regarding effectiveness of the modified expansion characteristic is to some extent moderated by results of a subsequent field test, in which Modified

Rhyme Tests were transmitted through a very long high-frequency-radio signal-sideband circuit (5300 nautical miles), which yielded 55.7% intelligibility with no expansion, and 59.5% with modified expansion. These figures represent a marginally usable communication system; the difference between them, while approaching statistical significance, is not sufficient to be of practical value.

In cases where the telephonic speech signal has been processed by compression and so amplitude limited, the expander is used to restore the speech message to a linear characteristic.

The dynamic modulation range of the experimental expander will react to all amplitude changes in a telephonic speech signal and is quite independent of decay delay time (slow release).

APPENDIX III

APPLICATION TO DIGITAL DATA TRANSMISSION SYSTEMS

The expander-amplifier was connected into a simulated noisy digital-data circuit devised by adding wide-band white noise to the output of a laboratory magnetic-tape playback specially designed for sampling digital systems. Both the input to and the output from the expander were displayed on a dual-trace oscilloscope and photographed, with results as shown in Figure 8. The lower trace shows the noisy input signal; the upper trace shows the output signal, with noise content somewhat diminished, probably due to expander action.

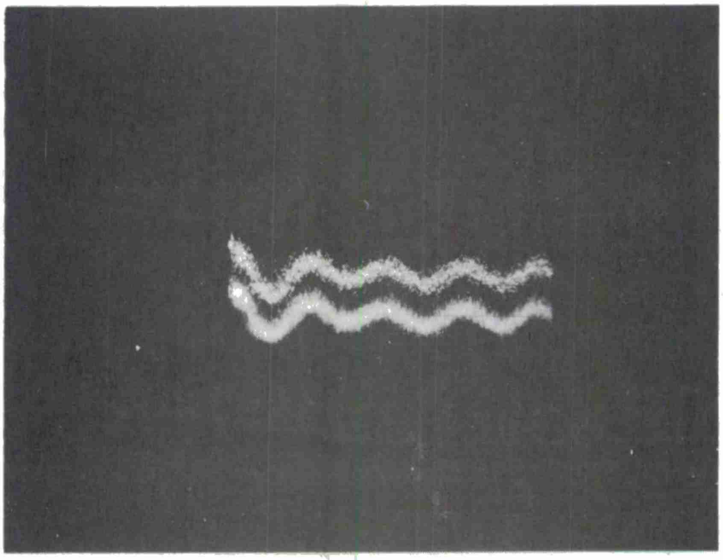

Fig. 8 Data Signal L. D. S., Tape Recorded